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Environmental Criticality of Raw Materials

An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy

German Environment Agency

Umwelt Bundesamt

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Environmental Criticality of Raw Materials

An assessment of environmental hazard potentials of raw materials from mining and recommendations for an ecological raw materials policy

by

Günter Dehoust, Andreas Manhart, Peter Dolega
Öko-Institut e.V.

Regine Vogt, Claudia Kemper, Andreas Auberger
ifeu – Institut für Energie- und Umweltforschung

Fiona Becker, Christine Scholl
adelphi

Dr. Aissa Rechlin, Dr. Michael Priester
Projekt Consult GmbH

On behalf of the German Environment Agency

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Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
info@umweltbundesamt.de
Internet: www.umweltbundesamt.de

/umweltbundesamt.de
/umweltbundesamt

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Jan Kosmol

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Abstract: Environmental Criticality of Raw Materials

The project ÖkoRess II has applied the raw material-related evaluation scheme developed within the precursor project ÖkoRess I to a wide range of mineral raw materials. In total a selection of 61 raw materials or raw material groups have been assessed. The selection is based on the raw materials examined in the criticality assessment for the European Commission in 2014 (European Commission 2014/2015). As far as possible, it was compared with the candidate lists of the new edition of this criticality assessment published in 2017 (European Commission 2017). A further research question was to identify a governance indicator which reflects best a country's mining sector governance with regard to environmental aspects. Eight indicators were tested on 23 case studies. In result, published in a separate study (ÖkoRess II 2019 b[1]), the Environmental Performance Index (EPI) was recognized as best suited.

Kurzbeschreibung: Ökologische Kritikalität von Rohstoffen

Das Projekt ÖkoRess II hat das im Vorgängerprojekt ÖkoRess I entwickelte rohstoffbezogene Bewertungsschema auf eine Vielzahl von mineralischen Rohstoffen angewendet. Insgesamt wurde eine Auswahl von 61 Rohstoffen oder Rohstoffgruppen bewertet. Die Auswahl basiert auf den Rohstoffen, die in der Kritikalitätsbewertung für die Europäische Kommission im Jahr 2014 (Europäische Kommission 2014/2015) untersucht wurden. Sie wurde, soweit möglich, mit den Kandidatenlisten der Neuauflage dieser 2017 veröffentlichten Kritikalitätsbeurteilung (Europäische Kommission 2017) verglichen. Eine weitere Forschungsfrage war die Identifizierung eines Governance-Indikators, der die Governance des Bergbausektors eines Landes in Bezug auf Umweltaspekte am besten widerspiegelt. Acht Indikatoren wurden an 23 Fallstudien getestet. Als Ergebnis, das in einer separaten Studie (ÖkoRess II 2019 b) veröffentlicht wurde, wurde der Environmental Performance Index (EPI) als am besten geeignet anerkannt.

[1] https://www.umweltbundesamt.de/publikationen/oekoress-ii

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3T	tin, tantalum and tungsten
aEHP	aggregated environmental hazard potential
AMD	acid mine drainage
AR	arctic region
ARM	Alliance for Responsible Mining
ASGM	Artisanal and small scale gold mining
ASM	Artisanal and small scale mining
ATH	Alumina Trihydrate
AZE	Alliance for Zero Extinction
AZO	aluminium doped zinc oxide
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe; [Federal Institute for Geosciences and Natural Resources]
CED	cumulative energy demand
CIGS	copper-indium-gallium-selenide
CIS	copper indium selenide
CRD	Cumulated raw material demand
CTC	Certified Trading Chains
DRC	Democratic Republic of the Congo
EHP	Environmental Hazard Potentials
EITI	Extractives Industry Transparency Initiative
EOL-RIR	End of life recycling input rate
EPI	Environmental Performance Index
FGD	flue gas desulfurization
FTO	fluorine doped tin oxide
GCC	Ground Calcium Carbonate
GEUS	Nationale Geologiske Undersøgelser for Danmark og Grønland
GSMEF	global size of material and energy flows
HREE	Heavy rare earth elements
HSLA	high-strength, low-alloy (steels)
ICGLR	International Conference on the Great Lakes Region (al Mineral Certification Framework)
iTSCi	ITRI Tin Supply Chain Initiative
JRC	Joint Research Centre
LED	Light Emitting Diode
LREE	Light rare earth elements
PA	Polyamide
PET	polyethylene terephthalate
PGM	Platinum-Group Metals
PV	Photovoltaik
RCM	ICGLR Regional Certification Mechanism
REE	rare earth elements

RJC	Responsible Jewellery Council
SEF	size of energy flows
SMF	size of material flows
SSM	small-scale mining
USGS	United States Geological Survey
WEEE (Directive)	Waste of Electrical and Electronic Equipment (Directive)
WSI	Water Stress Index

1 Introduction

Within the project ÖkoRess I (Dehoust et al. 2017) methodologies to evaluate Environmental Hazard Potentials (EHPs) of both mine sites and mined raw materials have been developed. The follow-up project ÖkoRess II focuses on the raw material-related evaluation scheme which has been applied to a wide range of mineral raw materials. In total a selection of 61 raw materials or raw material groups have been assessed. The selection is based on the raw materials examined in the criticality assessment for the European Commission in 2014 (European Commission 2014/2015). As far as possible, it was compared with the candidate lists of the new edition of this criticality assessment published in 2017 (European Commission 2017). A further research question was to identify a governance indicator which reflects best a country's mining sector governance with regard to environmental aspects. Eight indicators were tested on 23 case studies. In result, published in a separate study (ÖkoRess II 2019 b[2]), the Environmental Performance Index (EPI) was recognized as best suited.

The raw material-related approach takes into account three levels that have an impact on the Environmental Hazard Potential:

Firstly, within the area of geology, the likelihood of radioactive contamination, paragenesis with heavy metals and potential for Acid Mine Drainage (AMD) are investigated (indicators1-3). E.g. raw materials that tend to occur in sulphidic ores pose a higher Environmental Hazard Potential than raw materials occurring in oxidic sedimentary ores.

Secondly, in the technology level the mining method and the use of auxiliary substances are assessed (indicators 4-5). E.g. raw materials that are more likely to be mined in open-pit operations disturb larger surface areas than raw materials mainly mined underground. In the first two levels, 57 raw materials were described and evaluated.

Thirdly, EHPs that emanate from the natural environment are assessed (indicators 6-8). This relates to the geographic location of the mine sites and investigates hazard potentials due to floods, landslides, earthquakes and storms. E.g. if a majority of mines for a certain raw material are located in areas with frequently occurring floods, the Environmental Hazard Potential for the raw material is more likely to be high, since floods can be a cause of tailing dam failures. Moreover it is determined whether mines are located in areas with a high water stress or low water-availablility (deserts), and if mining sites are located in protected areas. With regard to indicators 6 to 8, 47 raw materials could be evaluated after intensive research. 42 of them were evaluated directly, five further raw materials, aluminium, iron, tellurium, selenium and gallium, could be assigned to their ores or main metals after the actual evaluation step.

In addition, the environmental governance (EGov) is assessed based on the weighted EPI according to the production share of the producing countries. If raw materials are mined to a large extent in countries with weak environmental governance, it is more likely that the Environmental Hazard Potentials are not properly managed and the likelihood for the occurrence of environmental impacts is higher. The EGov indicator could be calculated for 55 raw materials.

Artisanal and small-scale mining (ASM) bears a special governance risk. The most relevant reasons leading to this risk are:

- The large number and isolated situation of operations,

[2] https://www.umweltbundesamt.de/publikationen/oekoress-ii

- the close linkage between the ASM sector and poverty,
- the informality of many ASM operations,
- the migratory nature of many artisanal miners and their operations (especially with regard to alluvial deposits, i.e. for gold, coloured gemstones, diamonds, tin, tungsten and tantalum (3T), as well as gravel and sand),
- the traditional and indiscriminate use of toxic substances, i.e. mercury for the amalgamation of gold ores,
- shortcomings with respect to skilled staff on, both, the miners as well as the state institutions' side together with a lack of means for systematic mine inspections,
- the involvement of local elites in the informal exploitation and consequently a limited political will to apply sanctions.

Some of these aspects lead to weak application of the pertinent legal and regulatory framework. Particularly environmental laws are often weakly implemented as they are considered as additional costs to the miners. As the identified Governance Indicator, the EPI, looks at the general environmental performance of a country, but is neither mining specific nor ASM specific, the raw material profiles specify ASM-related governance challenges for ASM relevant resources.

Nevertheless governance challenges differ according to the exploited commodity. Especially non-metallic minerals are generally less problematic than for instance gold or the 3T.

Globally agreed numbers of ASM mining communities are non-existent. One reason is the fact that the definition of ASM and small-scale mining (SSM) differ from country to country (Small-scale operations in Peru or Chile according to the mining codes for instance would be considered large scale in Bolivia). In addition the authors of studies on ASM and SSM apply different definitions. The most cited sources for data on production shares for different resources are GEUS (2007), Dorner et al. (2012) and BGR (2007).

Lastly, the method includes two indicators addressing the size of global material and energy flows from mining to refining in order to assess the absolute physical dimension of probable impacts. For this inventory data for the indicators Cumulative Energy Demand (CED) and Cumulative Raw Material Demand (CRD) are used. The specific values per ton of refined material are multiplied by the world production (2014/15) and depict the size of material flows (SMF) and the size of energy flows (SEF) on a global level. The indicators SMF and SEF could be determined for 52 raw materials.

The indicator results of the 47 fully evaluated raw materials are then aggregated[3] and three final results are provided for each raw material (cf Chapter 2.1):

- the aggregated environmental hazard potential (aEHP), which combines the indicators 6 to 8 on a 5-level scale: low – low to medium – medium – medium to high – high EHP,
- the environmental governance indicator represented by the weighted EPI, which can be used in the sense of a risk enhancing or risk reducing factor,

[3] The description of the concrete procedure for combining the individual results of the indicators examined is shown in the general report on ÖkoRess II (https://www.umweltbundesamt.de/publikationen/oekoress-ii).

- the global size of material and energy flows (GSMEF), which combines the SMF and SEF and provides information about the global dimension of raw material mining and production.

Results are discussed in Chapter 2.2.

Chapter 3 then lists recommended measures for action which show how the results of the evaluations can be used to reduce the environmental impact of mining and material use.

Chapter 4 shows the material profiles of all 57 evaluated raw materials, 10 of which only partially evaluated as described above.

Table 1 shows an overview of the evaluation method according to ÖkoRess I, which already takes into account the changes made in the course of processing ÖkoRess II[4].

[4] The changes made are explained in the general report on ÖkoRess II (https://www.umweltbundesamt.de/publikationen/oekoress-ii).

Table 1 Scheme for the evaluation of raw material-related environmental hazard potentials (EHP)

		Indicator	Evaluation		
			Low	Medium	High
Geology	EHP	1. Pre-conditions for AMD	Geochemical preconditions for AMD do not exist	Geochemical preconditions for AMD exist in part	Geochemical preconditions for AMD exist
		2. Paragenesis with heavy metals	The deposits usually have no elevated heavy metal concentrations	The deposits usually have slightly elevated heavy metal concentrations	The deposits usually have strongly elevated heavy metal concentrations
		3. Paragenesis with radioactive substances	The deposits usually have low uranium and/or thorium concentrations	The deposits usually have slightly elevated uranium and/or thorium concentrations	The deposits usually have elevated uranium and/or thorium concentrations
Technology		4. Mine type	Commonly extracted in underground mines	Commonly extracted from solid rock open pit mines	Commonly extracted from alluvial or unconsolidated sediments and/or dredging in rivers
		5. Use of auxiliary substances	Standard extraction & processing methods without auxiliary chemicals	Standard extraction & processing methods using auxiliary chemicals	Standard extraction & processing methods using toxic reagents and auxiliary chemicals
Natural environment		6. Accident hazards due to floods, earthquakes, storms, landslides	≤ 25 % quantile of the combined assessment result of the 42 raw materials with sufficient data availability	> 25 % quantile and ≤ 75 % quantile of the combined assessment result of the 42 raw materials with sufficient data availability	> 75 % quantile of the combined assessment result of the 42 raw materials with sufficient data availability
		7. Water Stress Index (WSI) and desert areas			
		8. Designated protected areas and AZE sites			
Social environ-ment	EGov	9. Environmental governance in major production countries (EPI)	Weighted EPI of the most important producing countries of the raw material > 75 % quantile	Weighted EPI of the most important producing countries of the raw material > 25 % and ≤ 75 % quantile	Weighted EPI of the most important producing countries of the raw material ≤ 25 % quantile
Raw Mate-rial	GSM EF	10. Cumulated raw material demand of global production (CRD_{global})	≤ 25 % quantile of the 52 raw materials for which data are available	> 25 % quantile and ≤ 75 % quantile of the 52 raw materials for which data are available	> 75 % quantile of the 52 raw materials for which data are available

		Indicator	Evaluation		
		11. Cumulated energy demand of global production (CED_{global})	≤ 25 % quantile of the 52 raw materials for which data are available	> 25 % quantile and ≤ 75 % quantile of the 52 raw materials for which data are available	> 75 % quantile of the 52 raw materials for which data are available

2 Results at a glance

2.1 Overview of results

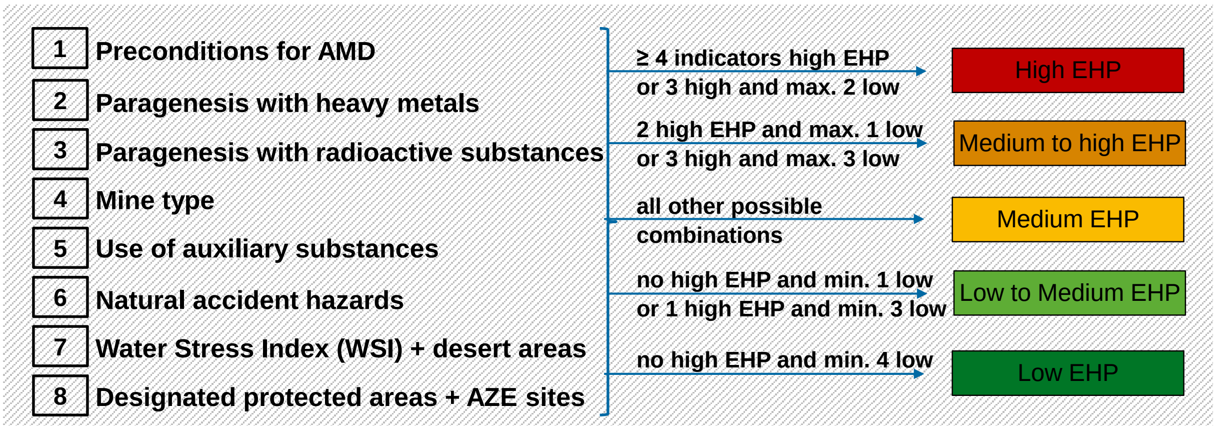
Table 3 provides an overview of the results for all fully assessed raw materials. For each material, it shows disaggregated results for all indicators as well as aggregated results. The left section of the table shows the eight indicators depicting EHPs in the areas of geology, technology and environment as well as the size of material flows (SMF) and the size of energy flows (SEF), which represent the CRD and CED multiplied by the global production. All these indicators are each rated on a three level ordinal scale from low (green) to high (red). The aggregated results (aggregated environmental hazard potential (aEHP) and global size of material and energy flows (GSMEF) as well as the environmental governance (EGov) are presented in the right section of the table.

The aEHP for each raw material is rated on an ordinal five level scale: low, low to medium, medium, medium to high or high. Hereby, the evaluations of the indicators one to eight are taken into account and evaluated for an overall result. The rules for the assessment of the aggregated environmental hazard potential (aEHP) are shown in Table 2 and illustrated in Figure 1.

Table 2 Rules for the assessment of the aggregated environmental hazard potential (aEHP)

aEHP	Rules
low	The aggregated environmental hazard potential is low if no indicator is rated with high and at least four indicators are rated with a low EHP.
low to medium	The aggregated environmental hazard potential is low to medium if no indicator is rated with high EHP and at least one indicator with low EHP, or one inidicator is rated as high and at least three indicators with low EHP.
medium	For all other possible combinations in between, the aggregated environmental hazard potential has a medium rating.
medium to high	The aggregated environmental hazard potential is medium to high if two indicators have a high EHP and max. one indicator has a low EHP, or three indicators have a high EHP and max. three indicators have a low EHP.
high	The aggregated environmental hazard potential is high if at least four indicators are rated with a high EHP, or three indicators are rated with a high EHP and max. two indicators have a low EHP.

Figure 1 Illustration of the combination of the eight individual indicators into the aEHP



The assessment of the environmental governance (EGov) was calculated for all raw materials based on the Environmental Performance Index (EPI)[5] of the mining countries and their share of the global mine production. For example, 31 % of the globally produced copper is produced in Chile. Accordingly, 31 % of the EPI for Chile was included in the EGov[6] for the raw material copper. The E-Gov corresponds to the weighted average EPI of the countries where the respective raw material is mined.

The EGov scores for the 55[7] assessed raw materials range from 70.26 to 41.68. The EGov – Scores are classified into three groups and evaluated accordingly:

≤ 25 % Quantile corresponds to a high EGov,

> 25 % up to ≤ 75 % Quantile corresponds to a medium EGov,

> 75 % Quantile corresponds to a low EGov.

The EPI and therefore the EGov inidicator is expressing environmental performance based on officially reported data and does thus not cover informal activities. Especially in resource rich developing countries the mostly informal artisanal and small-scale mining sector is a major producer of mineral ressources. This does not apply to all resources, but to a number of metals and minerals that show great value concentration, such as tantalum or gold, and to those, which generally occur in small vein-type deposits, such as antimony or chromite and to those, who require low technology and serve a local market, such as a number of construction materials and non-metallic minerals. In order to reflect the special governance challenges of the ASM sector, materials with considerable ASM share of the world production are additionaly marked (see supplementary information in the right section of Table 3 and 4 and summary figures in the material profiles in Chapter 3). The main production countries with strong ASM sector are mentioned in each material profile (chapter ASM relevance).

For the results of the raw materials for SMF and SEF, the shares of the total of all 52 evaluated raw materials were determined in each case. The resulting percentages for SMF and SEF were then added to the GSMEF. As with the indicators for the natural environment and the EPI, the raw material-related final results for GSMEF were then classified into the following groups and evaluated accordingly:

≤ 25 % Quantile corresponds to a low GSMEF,

> 25 % up to ≤ 75 % Quantile corresponds to a medium GSMEF,

> 75 % Quantile corresponds to a high GSMEF.

Besides information on ASM relevance, the section on supplementary information also contains information whether the raw material is produced as main, secondary or by-product, and the share of mining sites in the arctic region.

[5] The EPI ratings ranged from 87.42 for the country with the best rating to 30.41 for the country with the worst rating for the 180 countries included.

[7] 55 of 57 raw materials due to lack of data availability for EGov scores for 2 raw materials

Table 3 Overview of assessment results

EHP Indicators								GSMEF		Raw materials	(Aggregated)Results			Supplementary information		
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**SMF**	**SEF**		**aEHP**	**EGov**	**GSMEF**	**M/B/C**	**ASM**	**AR**
l	m	m	h	h	m	m	m	h	h	Aluminium	m-h	m	h	M		< 1 %
h	h	h	l	h	m	l	l	l	m	Antimony	h	h	m	M+**B**+C	**ASM**	< 1 %
l	m	m	h	m	m	m	m	h	m	Bauxite	m	m	h	M		< 1 %
l	l	h	m	h	l	h	m	l	l	Beryllium	m-h	l	l	**M**+B	**ASM**	< 5 %
h	h	m	m	h	m	m	l	l	l	Bismuth	h	m	l	B		< 1 %
l	l	l	m	h	h	m	h	m	h	Borates	m-h	m	m	M		0 %
l	h	m	l	m	m	h	m	h	h	Chromium	m	h	h	M	**ASM**	0 %
h	h	h	m	h	l	l	m	m	m	Cobalt	h	h	m	M+**B**	**ASM**	< 5 %
l	l	l	m	m	m	m	l	h	h	Coking coal	l	m	h	M		0 %
h	h	m	m	h	h	h	m	h	h	Copper	h	m	h	M		< 5 %
l	l	l	l	m	l	h	m	m	m	Fluorspar	l	m	m	M	**ASM**	0 %
l	m	m	h	h	m	m	m	l	l	Gallium	m-h	m	l	B		< 1 %
h	h	m	h	m	h	l	h	l	l	Germanium	h	l	l	B		< 10 %
h	m	h	m	h	m	m	h	h	h	Gold	h	m	h	M+B	**ASM**	< 5 %
l	l	l	l	m	m	m	m	l	l	Graphite	l	h	l	M	**ASM**	< 5 %
l	l	l	m	m	h	h	m	m	m	Gypsum	m	m	m	M	**ASM**	0 %
l	m	h	m	h	h	l	l	m	m	HREE	m-h	h	m	M+C		< 1 %
h	h	m	m	h	m	m	m	m	l	Indium	h	m	m	B		< 1 %
m	m	m	m	m	m	m	h	h	h	Iron	m	l	h	M		< 1 %
m	m	m	m	m	m	m	h	h	m	Iron ore	m	l		M		< 1 %
l	l	l	m	l	l	m	l	m	m	Kaolin clay	l	l	m	M		0 %
h	h	m	m	h	m	m	m	m	m	Lead	h	m	m	M+C		< 1 %
l	l	m	h		h	m	l	l	l	Lithium	m	l	l	M		0 %
l	m	h	m	h	h	m	l	m	m	LREE	h	m	m	M+C		< 5 %
l	l	l	m	l	h		m	m	h	Magnesite	m	m	m	M		0 %
l	l	l	m	h	h		l	m	m	Magnesium	m	h	m	M		0 %
l	m		m	l	l	m	h	m	h	Manganese	m	h	m	M	**ASM**	0 %
h	h	m	m	h	m	h	m	h	m	Molybdenum	h	m	m	M+B		< 1 %
h	h	m	m	m	m	l	h	h	h	Nickel	h	l	m	M		< 15 %
	m		m	h	l	l	h	l	m	Niobium	m-h	l	m	M		< 1 %
h	h	m	m	h	l	m	m	m	m	Palladium	h	m	m	C+B		< 30 %

EHP Indicators								GSMEF		Raw materials	(Aggregated)Results			Supplementary information		
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**SMF**	**SEF**		**aEHP**	**EGov**	**GSMEF**	**M/B/C**	**ASM**	**AR**
l	m	h	h	h	m	m	m	h	h	Phosphate rock	h	m	h	M		< 5 %
h	h	m	m		l	h	m	m	m	Platinum	h	h	m	M+B+C		< 10 %
l	l	l	l	m	l	m	m	h	h	Potash	l	l	h	M		0 %
m	h	m	m	h	h	h	l	l	l	Rhenium	h	l	l	B		< 5 %
h	h	m	m	h	l		m	m	m	Rhodium	h	h	l	C+B		< 20 %
l	m	h	m	h	h		l	l	l	Scandium	m-h	m	l	B		< 10 %
h	h	m	h	h	h	h	m	l	l	Selenium	h	m	l	B		< 5 %
l	l	l	h	h	m	m	h	m	m	Silica sand	m-h	l	m	M		0 %
h	h	m	m	h	m	m	h	m	m	Silver	h	m	m	M+C+B	**ASM**	< 5 %
l	m	h	m	l	l	l	m	m	m	Tantalum	l-m	h	m	C	**ASM**	0 %
h	h	m	m	h	h	h	m	l	l	Tellurium	h	m	l	B		< 5 %
m	m	m	h	l		l	m	h	mm	Tin	m	h	h	M	**ASM**	< 1 %
l	m	h	h	l	l	l	h	h	h	Titanium	m	l	h	M		< 1 %
m	m	m	l	m	m	l	l	m	m	Tungsten	l-m	m	m	M	**ASM**	< 5 %
m	h	h	m	h	m	m	m	m	m	Vanadium	h	h	m	M+**<u>B</u>**		< 5 %
h	h	m	l	h	m	m	m	m	h	Zinc	h	m	h	M		< 1 %

1. Pre-conditions for acid mine drainage (AMD)
2. Paragenesis with heavy metals
3. Paragenesis with radioactive substances
4. Mine type
5. Use of auxiliary substances
6. Accident hazards due to floods, earthquakes, storms, landslides
7. Water Stress Index (WSI) and desert areas
8. Designated protected areas and Alliance for Zero Extinction (AZE) sites

SMF Size of material flow
SEF Size of energy flow
EHP Environmental hazard potential
aEHP Aggregated environmental hazard potential
EGov Environmental governance
GSMEF Global size of material and energy flows
M/B/C Main (M), co- (C) or by (B)-product. **Fat** and <u>underlined</u> represents the largest share (e.g. **<u>B</u>**). '+' indicates that the raw material is mined as M, B, and/or C

ASM Artisanal and small-scale mining
AR Share of mining sites in the arctic region
HREE Heavy rare earth elements
LREE Light rare earth elements

h	High EHP
m-h	Medium to high EHP
m	Medium EHP
l-m	Low to medium EHP
l	Low EHP

2.2 Discussion of Results

The ÖkoRess method evaluates environmental hazard potentials (EHPs) and not the actual pollution situation. The indicator for Environmental Governance (EGov) aims to depict the probability that measures are taken that prevent the realization of the EHPs in form of actual environmental damage. The indicators on the size of material and energy flows (SMF/SEF/GSMEF) provide information on the global dimension of possible damages. The results therefore provide information on environmental aspects of mining for each raw material that deserves special attention and further analysis.

This is a qualitative assessment for 47 raw materials whose aggregated result can be used as an environmental dimension within the matrix type criticality framework. In the following, the aggregated EHPs are compared with the results of the EU Criticality Study of 2017 which assesses criticality by assessing supply risks and importance for the EU economy (EC 2017). The economic importance axis of the EU study can be used to assess environmental criticality which we defined as such. From the perspective of other countries or regions whose industries are dependent on other raw materials, different criticality assessments may result (Kosmol et al 2017).

If the Economic Importance threshold 2.8 for "critical" is exceeded for a raw material and the raw material is assigned a high or medium to high aEHP, the raw material is classified as environmentally critical[8].

The comparison with the raw materials classified as critical according to EC 2017 is not intended to express our support for the binary approach of classifying raw materials as critical or non-critical by arbitrarily defining thresholds for supply risk and economic importance. Rather, in our opinion, criticality is a relative concept which means that criticality analyses allow to state that some raw materials are more (or less) critical than others. To be more precise, only a higher or lower economic importance or a higher or lower supply risk, respectively in our case, a higher or lower aEHP, can be identified. Following the concept of classical risk assessment, relative criticality scores can then be derived by multiplicatively linking economic importance and supply risk respectively aEHP (Glöser et al 2015).

Here we follow the debatable, binary criticality approach of EC 2017 in order to show that assessing the environmental criticality of raw materials (as defined above) leads to partially different results than conventional criticality analyses. It highlights raw materials which deserve special attention from an environmental economics and environmental policy perspective.

In total, 21 raw materials are classified with a high aEHP (cf. Table 4).

Comparing these raw materials to the EC criticality assessment (EC 2017), it becomes obvious that only 2 out of these 21 commodities are located below the specified threshold with regard to Economic Importance. These are gold and rhenium, which are therefore neither classified as Critical Raw Materials (CRMs) in the classic criticality assessment nor as ecologically critical in the defined sense. The remaining 19 raw materials, which were classified with a high aEHP, are therefore classified as environmentally critical according to our definition.

The following 11 commodities or groups: Antimony, cobalt, platinum, vanadium, rhodium, phosphate rock, palladium (as PGM), indium, LREE, bismuth and germanium are classified as environmentally critical and are also classified as CRMs by European Commission (EC 2017).

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Table 4 Assessment results grouped by aEHP, EGov und GSMEF

EHP Indicators								GSMEF		Raw materials	Aggregated results			Supplementary information		
1.	2.	3.	4.	5.	6.	7.	8.	SMF	SEF		aEHP	EGov	GSMEF	M/B/C	ASM	AR
h	h	h	l	h	m	l	l	l	m	Antimony	h	h	m	M+**<u>B</u>**+C	ASM	< 1 %
h	h	h	m	h	l	l	m	m	m	Cobalt	h	h	m	M+**<u>B</u>**	ASM	< 5 %
h	h	m	m	h	l	h	m	m	m	Platinum	h	h	m	M+B+C		< 10 %
m	h	h	m	h	m	m	m	m	m	Vanadium	h	h	m	M+**<u>B</u>**		< 5 %
h	h	m	m	h	l	h	m	m	m	Rhodium	h	h	l	C+B		< 20 %
h	h	m	m	h	h	h	m	h	h	Copper	h	m	h	M		< 5 %
h	m	h	m	h	m	m	h	h	h	Gold	h	m	h	M+B	ASM	< 5 %
l	m	h	h	h	m	m	m	h	h	Phosphate rock	h	m	h	M		< 5 %
h	h	m	l	h	m	m	m	m	h	Zinc	h	m	h	M		< 1 %
h	h	m	m	h	l	m	m	m	m	Palladium	h	m	m	C+B		< 30 %
h	h	m	m	h	m	m	m	m	l	Indium	h	m	m	B		< 1 %
h	h	m	m	h	m	m	m	m	m	Lead	h	m	m	M+C		< 1 %
l	m	h	m	h	h	m	l		m	LREE	h	m	m	M+C		< 5 %
h	h	m	m	h	m	h	m	h	m	Molybdenum	h	m	m	M+B		< 1 %
h	h	m	m	h	m	m	h	m	m	Silver	h	m	m	M+C+B	ASM	< 5 %
h	h	m	m	h	m	m	l	l	l	Bismuth	h	m	l	B		< 1 %
h	h	m	h	h	h	h	m	l	l	Selenium	h	m	l	B		< 5 %
h	h	m		h	h	h	m	l	l	Tellurium	h	m	l	B		< 5 %
h	h	m	m	m	m	l	h	h	h	Nickel	h	l	m	M		< 15 %
h	h	m	h		h	l	h	l	l	Germanium	h	l	l	B		< 10 %
m	h	m	m	h	h	h	l	l	l	Rhenium	h	l	l	B		< 5 %
l	m	h	m	h	h	l	l	m	m	HREE	h-m	h	m	M+C		< 1 %
l	m	m	h	h	m	m	m	h	h	Aluminium	h-m	m	h	M		< 1 %
l	l	l	m	h	h	m	h	m	h	Borates	h-m	m	m	M		0 %
l	m	m	h	h	m	m	m	l	l	Gallium	h-m	m	l	B		< 1 %
l	m	h	m	h	h	l	l	l	l	Scandium	h-m	m	l	B		< 10 %
l	l	h	m	h	l	h	m	l	l	Beryllium	h-m	l	l	**<u>M</u>**+B	ASM	< 5 %
l	m	hh	m	h	l	l	h	l	m	Niobium	h-m	l	m	M		< 1 %
l	l	l	h	h	m	m	h	m	m	Silica sand	h-m	l	m	M		0 %
l	h	m		m	m	h	m	h	h	Chromium	m	h	h	M	ASM	0 %

EHP Indicators								GSMEF		Raw materials	Aggregated results			Supplementary information		
1.	2.	3.	4.	5.	6.	7.	8.	SMF	SEF		aEHP	EGov	GSMEF	M/B/C	ASM	AR
m	m	m	h	l	m	l	m	h	m	Tin	m	h	h	M	ASM	< 1 %
l	l	l	m	h	h	h	l	m	m	Magnesium	m	h	m	M		0 %
l	m	h	m	l	l	m	h	m	h	Manganese	m	h	m	M	ASM	0 %
l	m		h	m	m	m	m	h	m	Bauxite	m	m	h	M		< 1 %
m	m	m	m	m	m	m	h	h	h	Iron	m	l	h	M		< 1 %
m	m	m	m	m	m	m	h	h	m	Iron ore	m	l	h	M		< 1 %
l		h	h	l	l	l	h	h	h	Titanium	m	l	h	M		< 1 %
l	l	l	m	m	h	h	m	m		Gypsum	m	m	m	M	ASM	0 %
l	l	l	m		h	h	m	m	h	Magnesite	m	m	m	M		0 %
l	l	m	h	m	h	m	l	l	l	Lithium	m	l	l	M		0 %
	m	h	m	l	l	l	m	m	m	Tantalum	l-m	h	m	C	ASM	0 %
l	l	l	l	m	l	h	m	m	m	Fluorspar	l-m	m	m	M	ASM	0 %
m	m	m	l	m	m	l	l	m	m	Tungsten	l-m	m	m	M	ASM	< 5 %
l	l	l	l	m	m	m	m	l	l	Graphite	l	h	l	M	ASM	< 5 %
l	l	l	m	m	m	m		h	h	Coking coal	l	m	h	M		0 %
l	l	l	l	m	l	m	m	h	h	Potash	l	l	h	M		0 %
l	l	l	m	l	l	m	l	m	m	Kaolin clay	l	l	m	M		0 %

Legend: see Table 3.

In addition there are the 8 raw materials with a medium to high aEHP. The HREE, which were also poorly rated with regard to EGov, and aluminium, which also has a high GSMEF stand out here. With the exception of aluminium and quartz sand, all of these raw materials and groups are also classified as CRMs. Alumium is above the threshold value of the EU in terms of economic importance and can therefore be classified as environmentally critical (cf. Table 5).

Table 5 Raw materials with high (bold) or medium to high (normal) aEHP, grouped according to the results of the classical criticality assessment by EC 2017

Classified as CRM and evaluated as being environmentally critical	Not classified as CRM but evaluated as environmental critical	Not classified as CRM and not evaluated as environmental critical
Antimony, Beryllium, **Bismuth,** Borates, **Cobalt,** Gallium, **Germanium,** HREE, **Indium, LREE,** Niobium, **Palladium (als PGM), Phosphate rock, Platinum, Rhodium,** Scandium, **Vanadium**	Aluminium, **Copper, Lead, Molybdenum, Nickel, Silver, Selenium, Tellurium, Zinc**	**Gold, Rhenium,** Silica sand

On the one hand, the ecological hazard potential stands on its own and represents an important argument for putting raw materials into the focus of politics, business, science and society in order to effectively reduce the ecological impacts associated with the extraction of these raw materials. In this sense, the results of the ÖkoRess assessment also highlight the environmental relevance of Aluminium, Copper, Gold, Lead, Molybdenum, Nickel, Rhenium, Silica sand, Silver, Selenium, Tellurium and Zinc, which are not classified as critical raw materials by EC (cf. Table 5).

In addition, a high potential for environmental hazards can also significantly increase general supply risks. Not only factors such as a high concentration of production in some countries and political instability in these countries can lead to supply bottlenecks for these raw materials. Negative ecological impacts can also cause acceptance by the population and politicians to dwindle.

On the other hand, low requirements for compliance with environmental standards can - at least in the short term - lead to higher profits for mining companies because less effort is required to protect the environment. Where the potential damage to the environment and local residents is examined less intensively, approval procedures may also be simpler and faster.

In the long term, however, it can be assumed with a high degree of certainty that the general supply risk will increase as a result of poor environmental governance and pollution and damage caused by mining:

Experience has shown that environmental impacts can lead to the temporary or permanent closure of sites, on the one hand, and to difficulties in exploring or approving new sites, on the other. The assessment that a raw material shows a high environmental relevance with regard to its mine production is influenced not only by the environmental hazard potential but also by other factors. We assume that the worse the environmental governance (EGov) in the main production countries of a raw material is, the lower the probability that sufficient measures are taken by the government or mining companies, to effectively control potential hazards and avoid or reduce environmental damage. From this point of view, the raw materials antimony, cobalt, platinum, vanadium, rhodium and the HREE group come into focus, as here a poor EGov meets a high or medium to high aEHP. The most important producing countries leading to the poor EGov classification of these raw materials are China, DR Congo and South Africa.

A further indication of the physical dimension of possible environmental damage is the additional inclusion of global production and the extent of the associated material flows and primary energy consumption. These two aspects were combined to form the Global size of material and energy flows (GSMEF).

Raw materials with a high aEHP, poor EGov and high GSMEF were not identified. A high aEHP in combination with a high GSMEF shows copper, gold, phosphates rock and zinc, additionally aluminium shows a medium to high aEHP in combination with a high GSMEF (see also Table 4).

The figures (Figure 2 - Figure 4) show the CED-global of the individual raw materials and groups investigated, plotted over the CRD-global. The colours of the dots which stand for the individual raw materials, show the respective result of the evaluation for the EHP (see also legend table 3). Since all raw materials cannot be displayed clearly in one graph, three representations were chosen, depending on the GSMEF classification.

Figure 2 CED-global plotted over CRD-global - for the raw materials with high GSMEF

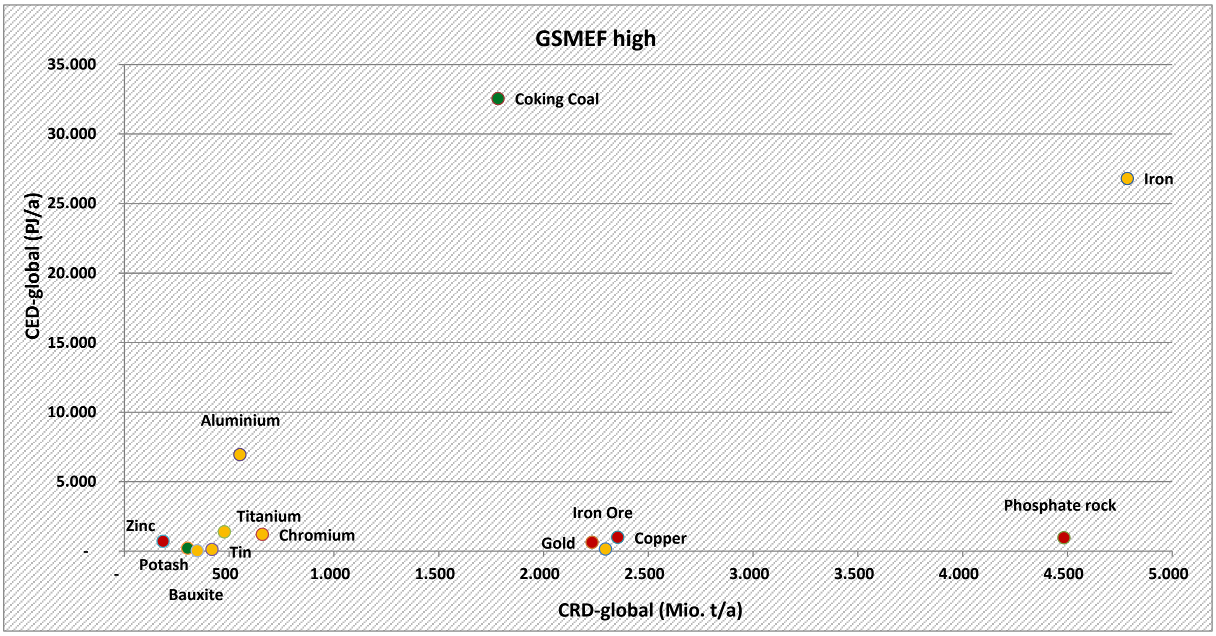
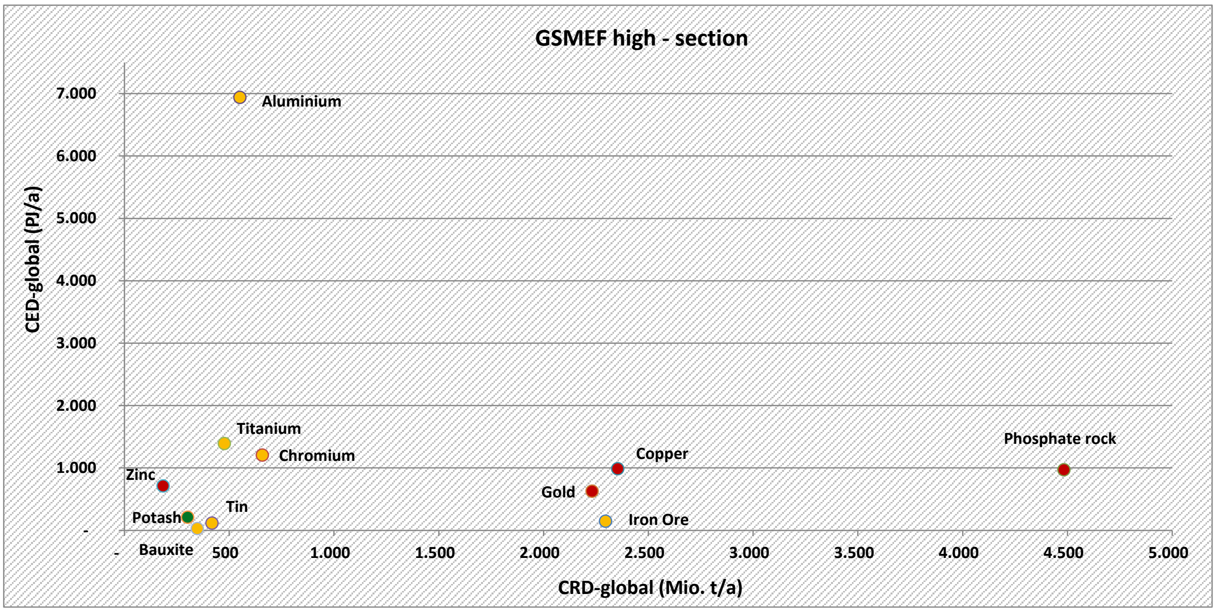


Figure 2 - Figure 4 include information on the global material and the global energy required to process the raw materials. The production quantities affect both the global CRD and the global CED. Low ore contents (and correspondingly high mining waste amounts) increase the global CRD, complex processing methods in particular the global CED, but also the global CRD of a raw material due to the primary energy sources required.

Figure 2 shows, for example, that the processing of iron ore into iron significantly increases both the global CRD and the global CED. In the case of bauxite, which is further processed into aluminium, the increase is not quite as high.

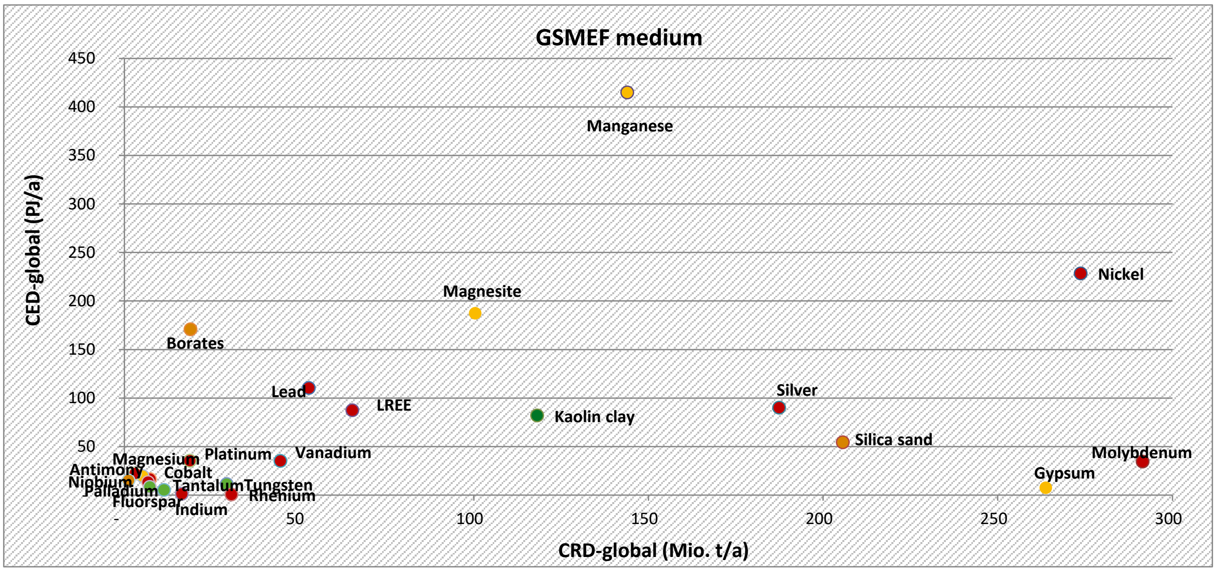
Coking coal, the raw material with the highest global CED, has a low aEHP rating. In the group of raw materials with a high GSMEF, high aEHP is found in gold, copper and phosphate rock (see Figure 2).

Figure 3 **CED-global plotted over CRD-global - for the raw materials with high GSMEF, Section without Coking Coal and Iron**



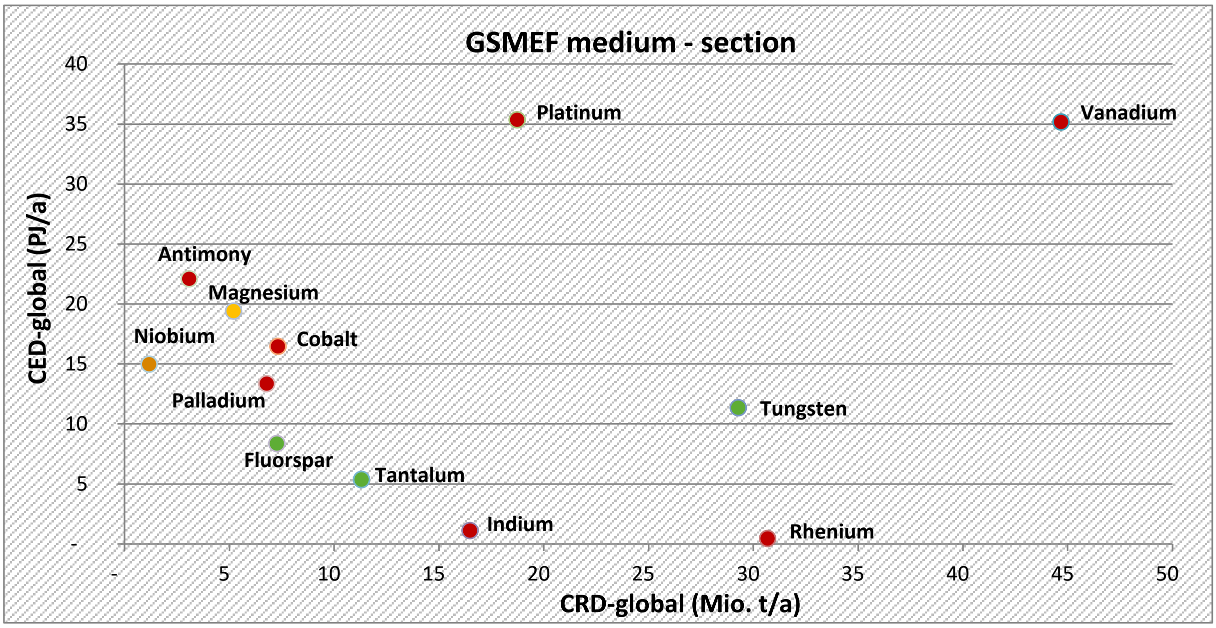
In order to better recognize the placement of the raw materials with high GSMEF but only medium to low CED-global, Figure 3 shows a section from Figure 2 without the two raw materials coking coal and iron.

Figure 4 **CED-global plotted over CRD-global - for the raw materials with medium GSMEF**



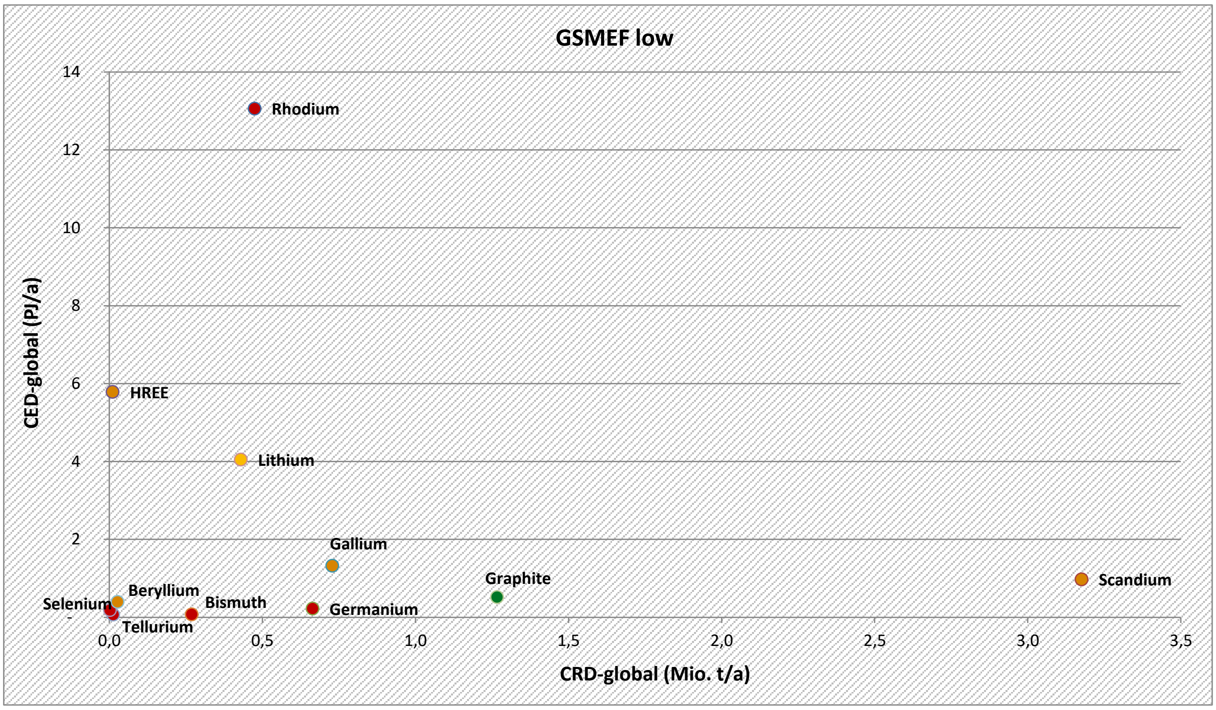
In the group of commodities with a medium GSMEF, manganese has the highest global CED, while molybdenum, nickel and gypsum have the highest global CRD values. Manganese and gypsum were rated average aEHP, nickel and molybdenum high aEHP. Lead, LREE and silver were also rated at around 100 million PJ/a by global CED in conjunction with a high aEHP (see Figure 4). Since a large number of raw materials are located in the low CRD-global and CED-global range, the presentation here is confusing. For this reason we have enlarged this section in Figure 5.

Figure 5 CED-global plotted via CRD-global - for raw materials with middle GSMEF, section CED-global up to 40 PJ/a and CRD-global up to 50 million t/a



Rhodium has the highest global CED and scandium the highest global CRD in the group of raw materials with low GSMEF. With the exception of graphite and lithium, all raw materials with a low GSMEF have a high or medium to high aEHP.

Figure 6 CED-global plotted over CRD-global - for the raw materials with low GSMEF



Concerning the question which raw materials should be the most urgently targeted for optimisation measures with regard to environmentally sound and safe mining and efforts to improve resource efficiency and recycling, it is of decisive importance whether the raw materials are primarily extracted as main or by-products. For raw materials with high aEHP, which are only or predominantly obtained as byproducts or coproducts, the respective main products of the extraction process must also be taken into account.

Table 6 shows that of the raw materials which do not have a high or medium to high aEHP themselves, only iron in relation to vanadium and tungsten in relation to bismuth are additionally in the focus of attention as main products that are relevant for the production of by-products and coproducts which are valued with a high aEHP. On the other hand, the list in Table 6 shows that especially for the raw materials that are exclusively or predominantly obtained as the main product, steps must be taken to reduce the environmental hazard potentials and to increase recycling (where possible), namely for aluminium, beryllium, borates, copper, nickel, niobium, phosphate rock, silica sand and zinc.

This does not mean that raw materials with high or medium to high aEHP, which are only obtained as by-products, should not be considered. With these, however, the situation of the main products must always be taken into account. This applies, for example, to selenium and tellurium whose environmental hazard potential cannot be improved without taking into account the situation with copper. See Table 6 for further examples.

Table 6 Raw materials having a high or medium to high aEHP and their simplified grouping according to main product, co-product and byproduct and the corresponding classifications

	Products	Corresponding Co- and By-product	Corresponding Main Product
Solely Main Product	Copper	Gold, Cobalt etc.	
	Phosphate rock		
	Zinc	Lead, Indium	
	Nickel	Cobalt, PGM	
	Aluminium	Gallium	
	Borates		
	Niobium	Tantalum	
	Silica sand		
Predominantly Main Product	Beryllium	Feldspar	
Main-, By- and/ or Coproduct, of equal rank	Platinum	PGM	Nickel
	Gold	Silver	Copper, Zinc
	Lead	Zinc	
	LREE	Iron	
	Molybdenum		Copper
	Silver		Zinc/Lead, Copper, Gold
	HREE	Iron	
Predominantly By- or Coprodukt	Antimony	Lead, Silver, Tungsten, Tin, Gold	
	Cobalt		Nickel, Copper
	Vanadium		Iron, Alumnium
Exclusively By- or Coprodukt	Rhodium	PGM	Nickel
	Palladium	PGM	Nickel
	Indium		Zinc
	Bismuth		Lead, Tungsten, Copper, Tin
	Selenium		Copper
	Tellurium		Copper
	Germanium		Zinc
	Rhenium	PGM	Nickel
	Gallium		Aluminium
	Scandium		

3 Recommendations for action

3.1 Introduction

Both the 10 country case studies and the research and investigations of the raw material-specific environmental hazard potentials have again shown that the extraction and processing of abiotic raw materials is often associated with a variety of environmental problems. After applying the ÖkoRess method to more than 50 abiotic raw materials, it can be concluded - despite isolated data gaps - that the EHP of primary extraction of some raw materials is higher than for others e.g. copper has a significant impact on the environment from a global perspective. This circumstance results above all from the fact that copper deposits are very often associated with sulphidic ores and is a heavy metal. Moreover significant parts of the production are extracted in countries with high water stress. In addition, the consistently large global production quantities also play a role, which - in connection with the circumstances outlined above - indicates a particularly high relevance from a global point of view. Other raw materials have a lower EHP, particularly non-metallic materials like potash are often not associated with heavy metals or sulphidic minerals.

In the parallel UBA project: "International Governance for Environmentally compatible raw material supply", political options for action and recommendations for the implementation of improvements in the environmental conditions of raw material supply were also drawn up (see Bodle et al. 2019).

3.2 Recommendations for action in the field of extraction and supply of raw materials extracted from mines

3.2.1 Linking the environmental and raw materials policy debate

The results show that mining of a number of raw materials, e.g. platinum, copper, lead or rhodium is considered to be more problematic than of other raw materials, like kaolin clay, potash or graphite from a global environmental point of view and that there is a different need for action in each case. The need for action does not only arise from environmental reasons - as already described in the predecessor project ÖkoRess I, there is a link between the environmental impacts of mining and the global availability of raw materials that should not be underestimated. After all, the environmental impacts of mining are being discussed openly in more and more regions of the world and are increasingly leading to a general questioning and regulatory restriction of mining activities (Dehoust et al. 2017). The assessment of the environmental hazard potential of mining provides important information on criticality assessment, in which environmental aspects have so far played a rather subordinate role in most studies, but the high demand for the development of adequate methods is increasingly formulated by the criticality research community (Schrijvers et al. 2019).

Recommendations 1:

In this sense, it is recommended to strengthen the link between the environmental and raw materials policy debate. The aim must be to see the improvement of environmental conditions in global mining as a central element in ensuring the availability of raw materials and to steer raw materials policy more closely to ecological criteria. Ideally, environmental raw materials policy should not only be promoted in the federal policy debate, but also at the level of the European Union and other international bodies such as the OECD.

3.2.2 Prioritising raw materials

In order to operationalize the corresponding environmental and raw materials policy debate, it is essential to focus on selected raw materials. General programs to conserve resources and an overarching goal for all raw materials are not sufficient to set in motion the urgently needed raw material shift (Buchert et al. 2016, Degreif/Buchert 2017). In view of an almost unmanageable number of abiotic raw materials, political and economic initiatives must be concentrated on particularly relevant flows. Such prioritisation does not rule out the possibility that other raw materials and value chains will be addressed by corresponding initiatives at a later date.

Recommendation 2:

With this in mind, it is recommended that in further processes of environmental raw materials policy, raw materials should be specifically addressed that have been assessed in the present study as having a high overall environmental hazard potential in mining. For Germany, which is heavily or even completely dependent on imports for the vast majority of abiotic raw materials, it should also be borne in mind that a positive influence is possible above all via the market power of the demand side. Accordingly, German raw materials policy should focus primarily on those raw materials for which, on the one hand, mining has a high overall environmental hazard potential and, on the other hand, for which the German economy accounts for a relevant share of global nickel demand (BGR 2017b)[9] or is at least represented among the most important customer countries, such as aluminium, copper and lead (BGR 2017a)[10]. This should be measured not only by the directly imported quantities of unprocessed raw materials and low-processed raw materials, but also by the materials processed in semi-finished and finished products, the so-called indirect raw material imports[11]. Only by taking into account the entire supply chain - including upstream raw material expenditures abroad - the raw material extraction induced by the German economy and the associated environmental risks will be fully included.

With the exception of lead, which is obtained as both, main and by-product, the given examples all encompass raw materials exclusively obtained as main products (see Table 6) and whose production is therefore largely responsible for the respective environmental hazard potential.

A further criterion for prioritising raw materials may be their relevance for future technologies and a potentially unsatisfactory end-of-life recycling rate. Under this aspect, additional raw materials come into focus, which are, however, partly or exclusively obtained as by-products or coproducts of other raw materials, such as (the corresponding main products are listed in brackets): antimony (lead, silver, tungsten, tin, gold), vanadium (iron, aluminium) LREE (iron), HREE (iron) and beryllium (feldspar) and others (see also Table 6 and chapter 2.2). In the case of these raw materials, it is important to first analyze the relationships and interdependencies with the respective main products and to take them into account when prioritising individual raw materials.

3.2.3 Raw material specific targets and measures

The analyses carried out also show that the problems among the mining of raw materials are usually very different: While the geochemical composition of the ores, especially sulphidic minerals associated with heavy metals, is a major cause of soil, groundwater and surface water pollution from mining of many metals like copper, nickel, lead, etc., this aspect plays a much less

[9] share of world demand: nickel 2,7%
[10] Ranking ofe countries in terms of worldwide demand: aluminium (3.), copper (3.) and lead (5.)
[11] A rough survey showed, for example, that the share of intermediate products in EU imports is 41 % for iron, 46 % for Copper, 66 % for aluminium, 71 % for tin, 73 % for lithium and 88 % for platinum (Schüler et al. 2017).

important role for other minerals like bauxite, iron ore and most of the non-metallic minerals. Other minerals like phosphate or light rare earth elements are often associated with radioactive substances, and for both toxic auxiliary materials are used for extraction and processing. In combination with sediment mining for phosphate and a high EHP of natural accident hazards due to storms, earthquakes, landslides or floods for light rare earth elements, this also indicates an overall high environmental hazard potential. Also metals with low ore grades particularly precious metals like gold or PGMs require higher energy inputs to produce a unit of metal. Moreover, the amount of material that needs to be moved is significantly higher when compared to bulk minerals such as iron or bauxite. The applied mine type also plays a significant role when assessing the area that is disturbed by mining. While e.g. zinc, tungsten and graphite are almost exclusively mined underground, tin and gold are often mined in alluvial deposits disturbing much larger surface areas.

Furthermore, policy measures should take into account the global dimension of raw materials mining, on the one hand, and the status of environmental governance of producer countries, on the other hand. For example, copper is of high global relevance, and Nickel is currently mined in producer countries with rather good environmental governance performance.

Accordingly, it must be noted that environmental policy measures to improve the extraction of raw materials cannot follow a fixed scheme, but must address the problems and challenges of individual raw materials and value chains on a very individual basis.

Recommendations 3:

Therefore, individual raw material-specific processes should be initiated for the raw materials that have been prioritised for German raw material policy in accordance with Recommendation No. 2, in order to characterize the environmental problems more precisely and to identify options for action. In these individual processes scientific facts as well as the knowledge about mining, industrial processes, applications, recycling and substitution possibilities for the respective raw material systems should be compiled and processed. Moreover, important stakeholder groups and branches of industry should be consulted with regard to possible improvements. Overall, clear targets, combinations of measures and success indicators should be developed in these processes. As far as possible, clear responsibilities and time horizons should be defined for the implementation of the measures. This approach should also address related raw materials policy objectives such as security of supply and human rights in order to contribute to sustainable development in line with the integrated understanding of sustainability in Agenda 2030. Possible conflicts between the above-mentioned raw materials policy objectives should be clearly identified and, if possible, resolved.

It should be mentioned that in many cases higher environmental standards will also result in higher raw material prices (see also Recommendation No 9), as costs will be internalized. While this connection can be interpreted superficially as a conflict, a broader interpretation is more obvious: the internalisation of environmental costs increases the acceptance of mining worldwide in the medium term, which in turn has a positive effect on security of supply.

3.2.4 Environmental and development-oriented raw material partnerships

The following recommendations represent various options that have been repeatedly mentioned in the debate on the promotion of sustainable mining and which have already been implemented in some areas. However, as described in the text of Recommendation No. 3, the selection of the appropriate instruments and measures must be raw material-specific and supported by solid facts and impact assessments.

In general, it can be assumed that even an industrialized country such as Germany can have only a limited influence on global supply chains for many raw materials. Although such a limited influence should not be a sufficient reason for inactivity, it is recommended that raw material policy goals be pursued as far as possible in cooperation with other countries and economic players.

Recommendation 4:

For this reason, Germany is encouraged in its raw materials policy to enter into targeted partnerships with countries rich in raw materials in order to improve the environmental and social conditions of primary extraction - especially for raw materials which, on the basis of the present analysis, have a high or medium environmental hazard potential and for which the German economy at the same time accounts for a large share of world demand (see Recommendation No. 2). E.g. cobalt already plays and will play an increasingly important role in the production of batteries for e-mobility. The German government supports the establishment of domestic cell manufacturing capacities. Significant reserves and production take place in the DR Congo and the environmental governance performance for cobalt mining is poor (high EGov). A partnership could both help to lower the environmental hazard potential by introducing better standards and simultaneously secure the supply of the raw material.

While Germany already maintains raw material partnerships with some countries, some of which have a mixed track record, the expectations of both sides should be clarified and documented in advance when this instrument is relaunched or deepened. It is generally to be expected that developing countries in particular will have a keen interest in investment, economic growth and the sustainable development of peripheral regions. Since it can generally be shown that mining serves these goals while complying with environmental and social standards, it should in many cases be possible to identify common interests. Possibly can be based on the work of the BGR and GIZ.

3.2.5 Long-term supply relationships and purchase guarantees

In the context of raw material partnerships, it must also be defined what role Germany can play actively in such partnerships. Germany does not have a developed and externally oriented mining industry that could help to implement corresponding policy goals together with partner countries. In contrast, however, Germany has a mature industrial structure with a high demand for metals and industrial minerals and semi-finished and finished products made from them.

Recommendation 5:

Germany's demand potential can be used both within raw material partnerships and beyond to provide countries rich in raw materials with planning security for the development of a sustainable mining industry. In general, planning security is increased by the fact that buyers of concentrates arrange long-term purchase agreements that deliberately leave sufficient scope for the ambitious implementation of environmental and social standards with regard to pricing. Naturally, such supply relationships take place in the private sector and are only subject to flanking political influence.

3.2.6 Partnerships between mining and manufacturing industries

Long-term supply relationships as described above can be implemented primarily for raw materials purchased from German industry as concentrates. Raw materials, which are mostly imported in the form of semi-finished products, are usually subject to complex value chains, so that direct trade relations between mining and German industry exist only in a few cases. However, various, mostly industry-initiated initiatives in recent years have shown that there are opportunities for cooperation between the mining and manufacturing industries even in complex value chains.

Recommendation 6:

Industrial partnerships and standard initiatives aimed at achieving targeted improvements in the environmental and social conditions in mining should be specifically promoted and expanded. The basic prerequisite should be that the relevant initiatives a) pursue ambitious and measurable objectives, b) take into account socially relevant forms of mining (above all small-scale mining) and c) strive for a fair burden-sharing of any additional costs incurred through the implementation of ambitious standards (see also Recommendation No. 8).

3.2.7 Standards

Within industrial partnerships, but also far beyond them, standards and catalogues of criteria for mining are increasingly being defined as the basis for cooperation and certification of raw materials. Indisputably, these standards will be indispensable in many areas, especially in cooperation with countries with weak state environmental governance. Nevertheless, it has been observed in recent years that the number of such standards is rising sharply, while implementation in mining projects is progressing at a much slower pace.

Recommendation 7:

In the context of voluntary mining standards, it is therefore recommended not to support developing further standards and to strive for the consolidation and integration of existing standards and certification schemes. The medium-term goal must be to disseminate existing ambitious standards and promote their implementation.

To this end, it may be helpful to prepare a qualified selection of particularly high-quality and promising approaches and to add application- or target-group-specific recommendations. Such an overview should make clear whether a standard / certification is primarily suitable for mining companies themselves or, for example, for manufacturing industries using raw materials. An overview should also show which approaches cover minimum requirements (avoidance of the worst practices and impacts) and which specifically promote particularly responsible raw material extraction.

In general, it must be borne in mind that voluntary standards in mining are necessary since many mining countries have inadequate environmental governance. For example, the current major producing countries for the mining of antimony, cobalt, platinum, vanadium, tantalum, etc. have been identified of having poor environmental governance in the present study (high EGov). The long-term goal should therefore be to replace or supplement voluntary standard initiatives with effective state governance in the producing countries.

3.2.8 Focus on impact

The measures outlined above, such as raw material partnerships and purchase guarantees, are based on relatively complex impact hypotheses. It is generally assumed that the implementation of one or more of these measures will also lead to noticeable improvements in mining. A variety of examples are known from many areas (including abiotic raw materials) in which respective control instruments have achieved inadequate impacts or were associated with unintended impacts. For example, the Dodd Frank Act (section 1502) has led companies to switch to other production sites instead of optimising the transparency of supply chains in the Congo as intended.

In general, focusing on the planning and development of new instruments entails the danger that private and state actors may, on the one hand, refer to a large number of activities but, on the other hand, not contributing significantly to sustainable improvements in mining. There are many initiatives in which a large part of the funds is used for meetings and public relations work, while the mining regions only receive trainings for a fraction of the budget.

Recommendation 8:

In this context, existing and new approaches should always be accompanied by impact monitoring. The impact hypothesis, objectives, target groups and risks must be documented for each approach. Similarly, the degree to which objectives have been achieved must be made measurable for each approach with the help of suitable indicators. To this end, ongoing efforts in this area should be continued to ensure quality standards and develop uniform methods. One example is the International Social and Environmental Accreditation and Labeling (ISEAL) Alliance, which with its ISEAL Code of Good Practice: Assuring Compliance with Social and Environmental Standards provides best practice guidelines for monitoring and evaluating the effectiveness of standard and certification systems. In the medium term, only those approaches should be promoted / supported which achieve positive effects in mining after the application of such recognized monitoring methods.

3.2.9 Additional costs along the value chain

The implementation of ambitious standards in the extraction of raw materials is sometimes associated with considerable expenditures for the mining industry. In this context, the current practice of not reimbursing these additional costs but basing supply contracts on globally established market prices for raw materials must be viewed critically: International market prices are formed in the tension between supply and demand. With global supply being one major factor in the price formation one must take into account that the supply also includes production that has externalized cost by applying low environmental standards or none at all. Such price formation can therefore only be regarded as fair and forward-looking if the majority of market participants have committed themselves to a corresponding global minimum standard and thus effectively exclude mining with lower standards from the market. In other words, prices only provide market participants with incentives for environmentally friendly behaviour if the polluter pays principle is largely implemented in the market and external costs are largely internalised. In the case of standards that cover smaller market shares, for example because they deliberately want to promote above-average mining quality, price formation must incentivize the effort that goes beyond the respective world market price so that the additional costs can be passed on and distributed along the value chain. This requires an increased willingness to pay for raw materials extracted to higher standards along the entire global value chain.

Recommendation 9:

Ambitious mining-related standards and raw material certifications must increasingly take into account the fact that implementation is usually associated with additional costs in mining. In order to make such approaches attractive, a fair distribution of the additional costs along the value chain must be achieved. This also means that awareness must be created that the current world market price level for raw materials is often only possible by externalizing costs.

This could be achieved by increasing the demand for sustainably mined raw materials. Public procurement should increasingly aim at including sustainably produced metals and minerals in their projects. Morevoer information portals and platforms need to be created to inform relevant stakeholders and to increase the visibility of sustainability standards.

3.2.10 Consideration of global market shifts in the internalisation of environmental costs

Internalisation of environmental costs will lead to higher costs for mining companies because it will shift the relationship between the revenue side (revenues from resource content, processed ore, output and economically significant by-products) and the cost side (financing costs, extraction and processing costs, costs for social measures, infrastructure links, transport, taxes and levies, etc.) by additional costs for compliance with legally binding or voluntary environmental standards. These costs vary depending on the type of mining: in the case of open-cast mines they are generally higher than in underground mines, and in the case of low grade ore deposits they are higher than in the case of rich mineraliations.

Recommendation 10:

Within the framework of a model development, it should be examined how stronger internalisation of environmental costs affects a shift from mining activity to other types of deposits and which political recommendations can be derived from this for resource-rich producing countries to adapt their resource policy framework. The formulations should also address how international actors - e.g. mining finance - can strengthen a steering effect in favour of environmentally friendly mining activities.

3.2.11 Transparency initiatives and Due Diligence

Beyond bilateral raw material partnerships, industrial partnerships, standards and certifications, two other raw material policy control instruments have had an impact on global mining in the last decade. These are:

- various transparency initiatives with the primary objective of making it more difficult for the mining industry to undermine standards by disclosing payment flows from the mining industry to government agencies
- Extension of the principle of "due diligence" for companies to ethical responsibilities in global supply chains, including the procurement of raw materials.

Initiatives such as the Extractives Industry Transparency Initiative (EITI) as well as regulatory approaches to the publication of payment flows between mining companies and public authorities bring more transparency into the financial aspects of the mining sector and support a gradual cultural change, not least in countries where raw material governance has so far been inadequate. Whereas, appropriate due diligence / supply chain due diligence are being applied at company level. In general, due diligence systems should be seen as an important step in companies' continuous and systematic engagement with risks of human rights and environmental aspects in their commodity supply chains. The systems, which are already widespread in many large companies, form a management framework at company level around individual measures such as the support of on-site projects and/or the procurement of certified raw materials.

Recommendation 11

Transparency initiatives in the area of payment flows between private and public actors in the raw materials sector should be further supported. This includes adequate funding of existing initiatives such as the EITI, as well as implementation of the EU directives on accounting and transparency.

Appropriate due diligence approaches in the commodities sector should also be further supported and developed. It should be noted that the concept of due diligence should remain a flexible concept, due to the complexity of supplier relationships and possible risks, offering sufficient scope for companies and industries to take their specificities into account. Nevertheless, work should also be done here to ensure that environmental problems in the extraction of raw materials are taken into account more intensively and systematically in the corresponding risk analyses. The available project results offer a good approach that can be used both at industry and company level.

3.2.12 Support for partner countries in the field of environmentally oriented raw materials governance

Developing countries rich in natural resources are often faced with major challenges in the area of resource governance, which are based on limited staffing, lack of knowledge and the lack of effective administrative processes. In particular, there is a need for support in the subtasks of adapting mining law to new challenges (climate change, environmental protection, conflicts over resources, protected areas, etc.), awarding concessions, approving operating plans, inspecting companies, implementing the legal framework, distributing costs and benefits fairly (e.g. state income from mining) and mediating mining-induced conflicts. It is often the environmental hazards and consequences of mining that lead to problems with the local population or the public.

Recommendation 12

German bilateral international cooperation is recommended to use the products of the project within the framework of raw material governance projects in order to focus the environmental orientation of the raw material governance of the partner countries and to make it more effective.

The aggregated results can be used against the background of mining and geology in the partner country to prioritize the raw materials to be processed (high EHP).

The disaggregated results (EHP profiles) can be used to formulate raw material-specific specifications for environmental impact assessments, requirements for the approval of environmental management plans and for focusing inspections.

Germany should also feed such approaches into the development cooperation approaches of multilateral donor organisations.

3.2.13 Consideration of environmental aspects as a criterion for the formalisation of ASM

Artisanal and small-scale mining (ASM) is a reality for many resource-rich developing countries that has very positive effects on the local economy and the generation of sources of income in rural areas, especially for low-skilled workers. On the other hand, ASM often creates massive environmental (and social) problems that challenge public authorities due to informal working methods, lack of technical knowledge and lack of funds for investment in environmentally friendly processes. These problems are very raw material-specific and differ considerably from gold, diamonds, coloured gemstones and non-metal raw materials. In addition, the interventions and risks, e.g. of mining of alluvial deposits, are much more serious than those of underground mining.

The importance of the sector has also been recognized in developing countries. For example, the African Mining Vision highlights the social and economic benefits of the ASM and calls for increased efforts to formalize it in order to limit the negative consequences of informal activities.

Recommendation 13

The results of the present project can help to selectively align ASM formalisation programmes to those mining activities that are tolerable - and thus formalisable - from an environmental point of view, provided that the operators comply with the legal requirements. In a country where the two raw materials gold and graphite are mined by ASM (as e.g. in Zimbabwe), the environmental hazard potentials of the two raw materials suggest to concentrate first on the formalisation of graphite due to lower hurdles, to gain experience with it, and then to tackle the gold sector later.

Similarly, using the site related assessment method from the previous project, where appropriate, the results facilitate the identification of practices that are intolerable and where enforcement agencies should intervene to end this activity. The site-specific method helps, for example, in gold mining. While underground mining of rich ore veins has a greater prospect of formalisation due to lower ERP, in other locations, e.g. due to protected areas or due to massive mercury (Hg) contamination or insufficient use of deposits, it is unacceptable to legalise the operations. A good example is Peru, where large areas in the small mining region of Madre de Dios cannot be formalised due to the environmental impacts and existing laws, the underground mining operations in the northern Atacama desert in Peru can very well be formalised, which is impressively demonstrated by the now certified operations working there.

In this respect, project planners should include the application of this evaluation approach and its results as project elements, and implementers and consultants should train partner professionals in the use of the method, thus anchoring the relevant competencies in the specialist institutions of the partner countries.

Similarly, resource projects should proactively address small-scale mining and its formalisation in order to improve environmental protection.

3.3 Recommendations for action in the field of material efficiency, circular economy and raw material substitution

The focus of the developed assessment system is on environmental aspects of mining. However, these aspects are linked to the questions of how to use less material in a more productive and circular way in order to avoid the negative impacts of primary production and to ensure accessibility in the medium and long term. Key strategies in this policy field comprise material efficiency, substitution and circularity (reuse, recovery and recycling).

3.3.1 Approaches to support material efficiency in mining and processing

There are potentials to enhance material efficiency along the entire value chain. While material efficiency potentials in the manufacturing has been extensively analyzed lately, the development of approaches for the systematic assessment of possible material losses and optimisation possibilities in the field of extraction (mining and processing) is still in its infancy. This involves partial aspects such as the most complete possible extraction of the deposit (high degree of ore extraction and low cut-off / marginal content), low ore dilution (to reduce processing costs) as well as a high yield of valuable materials and the use of by-products. A first study on this topic is, for example, "Evaluation system for an efficient and responsible use of deposits" ("Bewertungssystem für eine effiziente und verantwortungsvolle Nutzung von Lagerstätten") of the BGR (Federal Institute for Geosciences and Natural Resources). The study (not yet published) aims to identify resource-optimised use at deposit level.

Recommendation 14:

Studies in this context are a valuable contribution to the conservation of resources and the precautionary avoidance of environmental impacts of mining and processing. It is therefore recommended to promote similar or further studies. In addition, the results of such studies enable mining companies to identify optimisation potentials with regard to material efficiency. They should be encouraged to apply such assessment methods systematically.

3.3.2 Prioritisation of products and product groups as a basis for contributions to a circular economy

A main aim of a circular economy is to reduce negative impacts on human health and ecosystems by minimising the landfilling and energy recovery of waste and closing material cycles. This not only involves end-of-life waste management, but also all process steps in the life cycle of products, starting with product design, the selection of raw materials and the production process through the consumption phase to the final phase of waste management. Closing the cycles is a key strategy to effectively reduce the environmental impact of primary production by substituting primary with secondary raw materials. In addition, the circular economy can be seen as a strategy for reducing supply risks for critical raw materials (IRTC 2018) and to conserve resources for future generations. According to the "EU Action Plan for the Circular Economy" (EU COM 2015), the "Circular Economy will strengthen the competitiveness of the EU by protecting companies from resource scarcity and volatile prices [...]".

For selected products and product groups (e.g. batteries, packaging), legal frameworks and technical specifications have been established to clarify responsibilities and improve waste management practice. Due to the high, unmanageable number of more or less complex products, it is not possible to issue corresponding product responsibility specifications for all product groups at the same time. The prioritization of the product groups is therefore necessary in order to set priorities in the further development of the circular economy, e.g. by extending product responsibility to other product groups in accordance with waste legislation and the requirements of the Ecodesign Directive with regard to resource efficiency.

Recommendation 15:

It is proposed to use the prioritization of raw materials recommended in Recommendation 2, in accordance with the results of this study on the environmental hazard of their extraction, to identify the most relevant products or product groups in which these raw materials are predominantly used. These include but are not limited to a) Stainless steel products (such as household appliances, construction products) to reduce the consumption of primary nickel, b) Vehicles (in addition to the Directive on end-of-life vehicles) and aluminium building products, such as window frames, shutters, house claddings to reduce the consumption of primary aluminium, c) electric motors and electrical installations to reduce the consumption of primary copper. The main current areas of application are described in the raw material profiles (cf. Chapter 4).

For those products and product groups that are identified as the most important on this basis, the various measures described below to initialize and promote a consistent circular economy should then be tackled as a matter of priority in order to address the above described aims of a circular economy in a systematic way. This information on the use of raw materials should then be deepened and supplemented at product and sector level. The necessary data are largely available, also taking into account future developments, e.g. in the field of environmental technologies against the background of global energy change and a low carbon economy (cf. Buchert et al. 2019, Marscheider-Weidemann et al. 2016, Schriefl and Brunckner 2016).

3.3.3 Extending the duration and intensity of use of selected product groups

Numerous studies have shown that many products are disposed of as waste before the technical end of life is reached, such as smartphones, televisions, tablets etc. (Prakash et al. 2016). On the other hand, there are manufacturers of cheap products who do not design their products for a long life and/or service life. Other products may have a long service life, but are rarely used during the life of the product (e.g. many electrical tools in private households).

Measures to achieve a long and intensive use phase are usually very complex and and can only be defined in very general terms without prioritizing the products and product groups (Oehme et al. 2017).

Recommendation 16:

Measures to promote durability and intensity of use should be taken progressively for product groups produced with raw materials with high EHP according to this study. These include, for example, all electrical and electronic equipment, vehicles, electric motors and batteries because they contain a large number of raw materials with a high EHP, such as copper, aluminium and nickel, but also cobalt, platinum and others.

To this end, different commercial and private sharing concepts are to be examined and supported for the selected product groups. In addition to material efficiency (cf. Recommendation 12), legal requirements for the design of products should also focus on the ability to be repaired. Repair shops and the used goods trade will be supported in particular by relieving ancillary labour costs and by tax relief, while repair shops will also be supported by rules on free and cost-effective access to spare parts. By increasing the quality requirements for new products (product standardisation, EU Ecodesign Directive), the useful life and/or service life is directly increased on the one hand, and indirectly on the other hand, because this increases the repair worthiness and reduces the competition between "cheap" new products for repairs. In order to increase the quality of new production, the guarantee periods for products should also be extended, with specific guarantee periods being chosen for different product groups (cf. also Oehme et al. 2017 and Prakash et al. 2016).

In addition, further legal instruments such as the introduction of a mandatory minimum product life, a reversal of the burden of proof in the event of defects and the introduction of a "functional warranty" should be considered.

Reusable beverage systems should be transferred to other packaging systems and encouraged.

3.3.4 Promoting design-for recycling

The recycling of many products is made more difficult or even impossible because their design focuses on other aspects, especially marketing (Ciacci et al. 2015). While recycling systems have been developed and established for many years for bulk metals such as iron, aluminium and copper the end-of-life recycling rate is quite high for these raw materials, there are still very incomplete or no functioning recycling approaches for numerous important technological raw materials such as tantalum, lithium, neodymium, selenium, beryllium and others (Schüler et al. 2017, UNEP 2011, UNEP 2013).

Examples of previous regulations to promote recycling of product groups, like the directive on packaging and packaging waste or Directive on end-of life vehicles, often show that their implementation can be better achieved the more concrete the specifications are formulated. Therefore, it is important to relate these requirements to narrowly defined product groups!

Recommendation 17:

Concrete requirements for product design to increase recyclability, in particular with regard to material composition, dismantlability, avoidance of additives containing harmful substances etc. should be increasingly included in the EU Eco-design Directive and extended to other product groups (see Recommendation 13). This is intended to increase recycling, particularly in the area of technology metals, for which there is currently no functioning recycling system.

Using neodymium as an example, a mandatory and standardized labelling of motors and generators could already help to identify components containing neodymium and to recycle them at the end of their life cycle.

Within the framework of setting legal requirements and to supplement them, research and implementation of Design for Recycling should also be promoted in stakeholder processes with producers and recyclers as well as through scientific funding programs.

3.3.5 Improve framework conditions for investments in innovative recycling technologies

Sound waste management already significantly contributes to circular economy. However, numerous recyclable waste materials are not collected and separated from other waste streams. In addition, poor processing and inappropriate treatment are still widespread from a global perspective. This is also the case (but not only limited to) material embedded in end-of-life vehicles and old electrical and electronic appliances. This inappropriate recycling is particularly pronounces in many developing countries and some emerging economies and has severe polluting effects with adverse impacts on human health and the environment. Exports of used equipment and partly also waste material from EU countries to other world regions further add to this problem (Manhart et al. 2016, Manhart et al. 2019, Manhart/Prakash 2017, Buchert et al. 2007). But also in industrialized countries, collection rates are mostly unsatisfactory effective recycling processes for many trace material missing or not installed on an industrial scale (Steger et al. 2019, UNEP 2013, European Commission 2017a and 2017b).

Recommendation 16:

For raw materials that cannot yet be economically recycled but, according to this study, have a high or medium to high environmental hazard potential in primary extraction (e.g. phosphor, an essential raw material that is extracted as the main product, as well as antimony, vanadium, LREE, HREE and beryllium, which are all also won as main product) the prerequisites for recycling are to be improved. While this assertion applies for almost all raw materials, some exemptions may exist for raw materials mined as by-products but that are not yet entirely extracted in subsequent refining process. This, for example, applies to gallium, a by-product of aluminum. While gallium recycling from end-of-life products is challenging and costly, the generation from already extracted aluminium ore (bauxite) might be much more efficient and would also not lead to additional mining activities. Therefore, recycling policies for raw materials primarily extracted as by-products, the dependence and interdependence with the respective main ores should first be analyzed in order to decide whether the recycling of these materials can also have positive effects on mining.

In particular, concrete targets for material recovery rates for individual product groups in conjunction with targets for the use of recycled materials in new production (see recommendation 17) are intended to create the economic framework conditions to make investments in high-quality sorting, processing and recycling facilities in Europe attractive. For example, the separation of different metal alloys is necessary to ensure that alloying elements are not dissipative lost in the metal recycling process and that the quality of the recycled materials is compromised.

With the support of promotional measures the recycling processes for special metals are to be further developed in such a way that the efficient use of the individual raw materials from mixtures of substances is optimized.

Countries with insufficient and polluting waste management and recycling systems shall be supported in developing effective infrastructure and systems in this segment. This should not only entail installation of treatment technologies, but socio-economically adapted waste management systems comprising (incentive driven) collection, sorting and processing chains that are supported by appropriate policies and financing mechanisms (see e.g. Buchert et al. 2015, Manhart/Schleicher 2015, Manhart et al. 2014, Manhart 2013).

3.3.6 Exclusion in relation to substitution.

Decisions on the selection of substitutes for the raw materials use must be based on Life Cycle Assessments that take into account the entire life cycle of the products, starting with the extraction of the raw materials, through the entire production and use phases, to the disposal of the products that have become waste. This is the only way to select the most environmentally appropriate raw materials, because higher environmental impacts from the extraction of raw materials could be overcompensated by advantages in production and/or in the use or end of life phase. Given the scope of this study, which deals exclusively with the extraction and processing of raw materials and whose results cannot be related quantitatively to defined quantities of raw materials, decisions on the substitution of materials cannot be made solely on the basis of the results of this work.

Therefore, a comparison of the study results for the purpose of decision-making on material substitution should not be carried out.

However, the prioritization of raw materials (cf. Recommendation 2) and product groups (cf. Recommendation 15) can be used on the basis of the results to identify raw materials for which Life Cycle Assessments should preferably be prepared as a basis for substitution decisions.

In addition, the results of ÖkoRess II can serve as an aid and orientation for the concrete evaluation of the raw material extraction phase within the framework of a comprehensive life cycle assessment.

3.4 Further need for research

The work on ÖkoRess has shown that the data available on the environmental hazard potentials of mining and processing are sometimes very incomplete. Due to its global significance, it is therefore necessary to close the existing gaps.

3.4.1 Enhancing the application of spatial data and linkage of databases on mining activities

The developed methodology for the ÖkoRess II assessment is strongly linked to the quality of input data. Ideally there would be a global georeferenced database which contains all active mining projects and information on geology and applied technologies. This database could be linked to annual production numbers and the EHPs could be assessed on the level of a single mine. This ideal database is not available which is why different data sources had to be combined and a statistical approach for the natural environment indicators was used to overcome the data gaps. The USGS MRDS database is considered to be outdated and it is recommended to develop a mining activity database at least on European level. Actually the member states of the European Union are obliged to make spatial information on mining activities public as part of the INSPIRE directive (2007/2/EC). This database could be linked to other national geological surveys with available data. Data gaps still can be filled up by the old USGS MRDS data. It has to be noted, that the generation of spatial data on mining activities is a dynamic field and a lot of datasets and databases especially on national level became available in the last years (e.g. Australian Mining Atlas[12] or MapX[13]).

Although, it is challenging to compile and update a global database which is needed for the ÖkoRess II evaluation, the aim should be to build up a valid database including mine specific production data. If feasible also other information on geological and technological conditions could be covered. This would enable the implementation of a full empirically based geospatial evaluation of mining sites and raw materials.

The indicators for geology and technology are generally based on literature and expert judgement. If a future geospatial-database is able to cover further information on geological and technological conditions, an empirical approach can be implemented for these indictors as well. The application of spatial data on natural hazards, protected areas and water sensitive regions is already well implemented. But the development in this sector is very dynamic and even in the last years huge amounts of new datasets are available for public use. It is estimated that 90 % of the data in the world has been created in the last two years and it is expected to increase by 40 % annually (UN, Big Data for Sustainable Development[14]). UNEP GRID and UNEP-WCMC activities need to be monitored and updated datasets should be implemented in the ÖkoRess assessment on a regular basis. Furthermore, new datasets such as e.g. biodiversity hotspots (Conservation International, 2016) are available and the update of indicators should be regularly revised.

The extent of the mining area is an important parameter in the analysis. The method used in this report considers an average extent of 500 m. This approach can be further improved by creating categories of mines which correspondent with a certain extent. The categorization should consider e.g. the raw material, the mining type and the topography. Remote sensing analysis is considered to be a beneficial method in this context and should be further analyzed in the future.

3.4.2 Further development of the ÖkoRess method

In order to be able to implement the proposed measures and recommendations for action in a qualified manner, particularly with regard to the internalization of external costs, extensive

[12] http://portal.geoscience.gov.au/ (accessed 18.7.2019)
[13] MapX was developed by UN Environment, the World Bank and the Global Resource Information Database (GRID-Geneva) to capitalize on the use of new digital technologies and cloud computing in the sustainable management of natural resources. https://www.mapx.org/ (accessed 18.7.2019)
[14] https://www.un.org/en/sections/issues-depth/big-data-sustainable-development/index.html (accessed 18.7.2019)

research is also required to create a widely accepted database on the costs of environmental pollution.

In particular with regard to the interface between the environmental hazard potentials assessed in ÖkoRess II and the current impacts and the implemented standards for preventing or reducing environmental impacts due to the given hazard potentials, data should be collected and made available from mining practice as well as from the handling of environmental impacts resulting from accidents or emissions during normal mine operation.

The results of this study can help to focus on certain questions:

1. In which regions are heavy precipitation events and floods to be expected and therefore particularly high demands to be made on the safe construction of tailings dams?
2. For which raw materials is it particularly important to pay attention to the geological conditions (AMD, levels of radioactive substances and/or heavy metals) and the processing techniques used?
3. Which measures can most effectively avoid that the environmental hazards potentials described result in environmental damage and which (additional) costs can arise as a result?
4. To what extent would the widespread implementation of such measures have an impact on commodity prices? How would that influence the economics of recycling?
5. In the light of these additional costs, is it possible and reasonable to specify these costs in the price-mechanism for raw materials on the world market? Can any additionally generated revenues be used to expand responsible mine types?

4 Detailed Results – Material Profiles

The aim of the study was to describe and evaluate 51 raw materials. In order to be prepared for the case that for some raw materials the data situation is not sufficient for an evaluation, the study was started with 61 raw materials and groups of raw materials. In the course of processing, 57 raw materials were selected. Missing data were determined as far as possible by intensive follow-up surveys (e.g. queries with the BGR (Bundesanstalt für Geowissenschaften und Rohstoffe)) or recalculated, e.g. for CRD-global and CED-global. Ultimately 47 could be fully evaluated.

In this chapter, the 57 raw materials or groups of raw materials that were described and evaluated are presented in Material Profiles. Ten out of these 57 raw materials could only partially be assessed due to data availability. First, the results for the 47 fully evaluated raw materials and raw material groups are displayed in an overview graphic. This is followed by an overview of the general properties of the material, its main applications, recyclability and substitutability (General Information).

ASM is not explicitly considered in the evaluation according to Öko-Ress II. For this reason, the findings on ASM are listed separately as part of the general information for the raw materials concerned. The associated separate environmental hazard potentials are also described.

Finally, the environmental hazard potentials for each indicator are shown as an ÖkoRess evaluation (Profile xy). The environmental hazard potentials per indicator range from low, medium to high and are supplemented in the same way by information on data quality.

4.1 Aggregates

4.1.1 General Information

Introduction and characteristics

Aggregates include sand, gravel and crushed rock, which are mostly mined in open pits or dredged from fluviatile deposits. Since the value to weight ratio is very low, the materials are mined where they are needed to lower the transport distances (European Commission 2017a).

Applications

Aggregates are widely used in construction in different compositions depending on the requirements (European Commission 2017a).

Recycling

The estimated input rate for end-of-life recycling of aggregates in the European Union is 8 %. Secondary aggregates are mostly by-products of other industrial processes, such as blast furnace slag, fly ashes and others. Recycled aggregates are produced from materials previously used in construction, e.g. for demolishing buildings, but are currently not common throughout Europe due to costs. (European Commission 2017a).

Substitution

Due to the heterogeneous nature of aggregates, one aggregate can be substituted by another. The most important factor in the substitution of aggregates is the value, although a large variety of materials with the required characteristics could be possibly used, they are often more expensive and not as abundant as aggregates (European Commission 2017a).

Main product, co-product or by-product

Aggregates are a main product (European Commission 2017a).

Primary production

No data are available on the total worldwide production of construction sand and gravel. Although the USGS regularly publishes data on the production of silicate sands and gravel for industrial applications (e.g. use in fracking, the semiconductor industry, metallurgy and glass production), this does not include production quantities for use as building materials. In addition, national statistics often do not quantitatively record the extraction of construction sand and gravel.

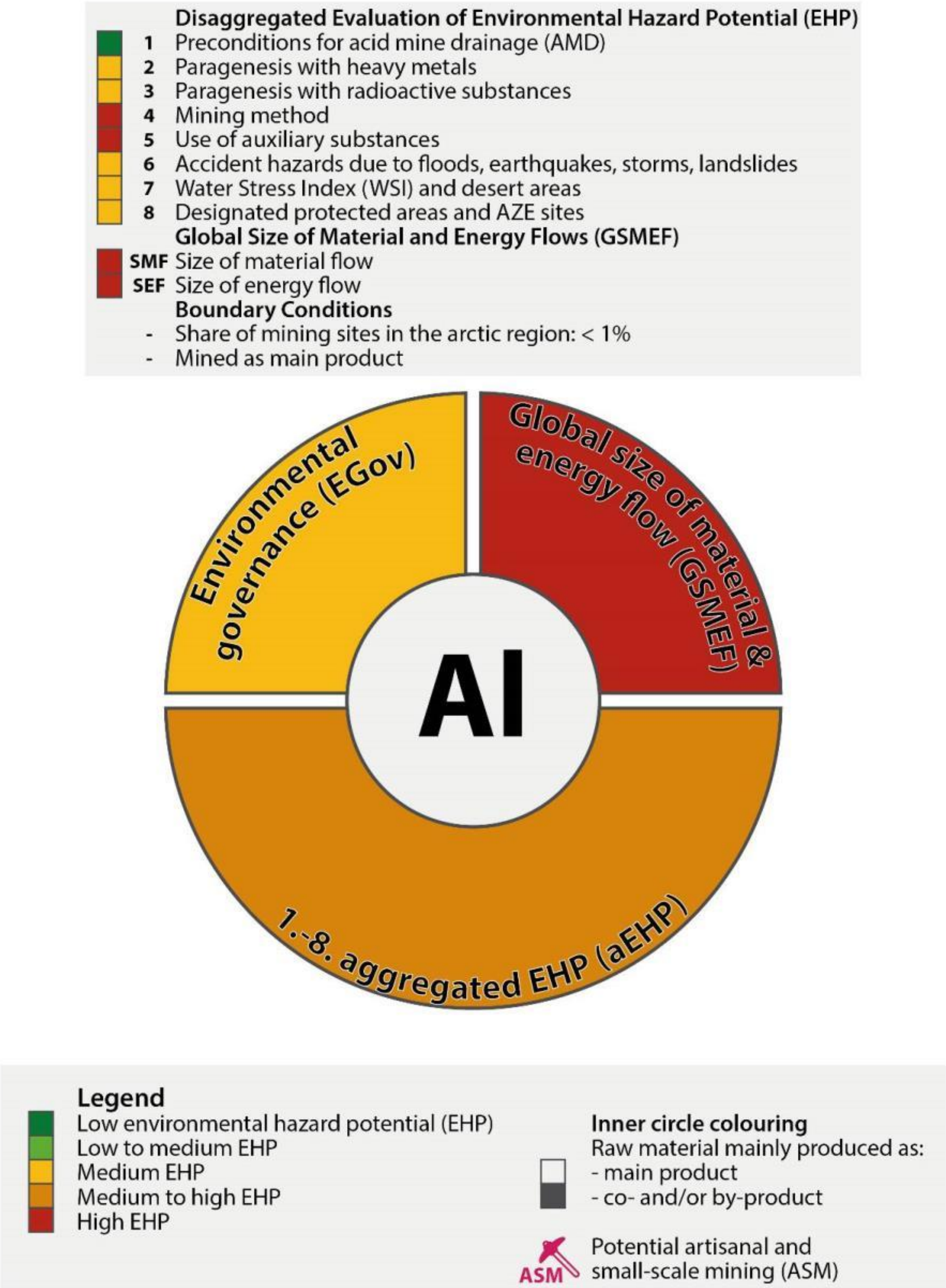
Information on Deposits

Sedimentary deposits, either fluviatile or marine, more rarely aeolian. Due to the formation processes no association with soluble companions (sulfides or heavy metal compounds).

4.1.2 Profile Aggregates

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Construction sand and gravel come from sedimentary deposits that have no potential for auto oxidation.	medium
Indicator 2: Paragenesis with heavy metals		
Low EHP	Construction sand and gravel are non-metallic raw materials made of inert material. Sand and gravel are usually extracted from local deposits, which, with regard to average heavy metal concentration, are to be classified in the range of the natural background concentrations of rocks.	high
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Construction sand and gravel are usually extracted from sedimentary deposits which predominantly contain low concentrations of radioactive substances. Gravel from granite may be an exception.	low
Indicator 4: Mine Type		
High EHP	Loose rock opencast mining, extraction from rivers and beaches	high
Indicator 5: Use of auxiliary substances		
Low EHP	No use of auxiliary substances	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
N/A	Information not available due to data restrictions	N/A
Indicator 7: Water Stress Index and desert areas		
N/A	Information not available due to data restrictions	N/A
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
N/A	Information not available due to data restrictions	N/A
Indicator 9: Environmental governance in major production countries (EPI)		
N/A	No information available, due to	N/A
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
N/A	Since no information on production is available cumulated CRD values cannot be determined	N/A
Indicator 11: Cumulated energy demand of global production CED_{global}		
N/A	Since no information on production is available cumulated CED values cannot be determined	N/A
Indicator 12: Position of mining sites in the arctic region		
N/A	Information not available due to data restrictions	N/A

4.2 Aluminium



4.2.1 General Information

Introduction and characteristics

Aluminium is a metal with the atomic number 13. It is a lightweight metal of silvery-white colour being the third most abundant element in the earth's crust (European Commission 2014).

Aluminium is produced from bauxite, the aluminium ore, which is also described and evaluated separately in the chapter 4.5. In the Bayer process, bauxite is first converted into a soluble aluminium-hydroxide using sodium hydroxide and then fired at over 1200 °C to aluminium-oxide (alumina). This is then reduced in the melt electrolysis process using the Hall-Héroult process at about 950 °C with high energy consumption. (Dehoust/Merz 2012)

Aluminium has an excellent malleability and a low melting point making it highly workable. Moreover the metal can be alloyed with other metals forming a large variety of wrought and cast alloys. Aluminium is the second most widely used metal after iron (JRC 2018).

Applications

The main end-use markets for aluminium are building and transport, each with around one third of the total market. Other important applications are electrical and mechanical engineering, office equipment, domestic appliances, lighting, chemistry, packaging and pharmaceuticals (European Commission 2014)

Recycling

As aluminium is a highly sought-after commodity that can be produced by recycling at only around five percent of the energy input required for primary production, all available aluminium scrap is remelted. This can either be done by type or the desired target alloy can be produced by blending different scrap metals and, if necessary, primary aluminium. It may be desirable to collect and process scrap of certain alloy specifications in a single grade in order to counteract the alloy cascade and thus achieve the greatest possible usability of recycled aluminium. From a technical point of view, however, this is not necessary at the moment, as all recycled aluminium can be used even if it is not sorted by type (Dehoust/Merz 2012). The End-of-Life Recycling Input Rate is 12 % and the End-of-Life Recycling Rate is 51 % in Europe (JRC 2018).

Substitution

The substitution of aluminium is possible for a variety of applications. Composites could possibly be used as a substitute in aircraft or automotive applications, combining light weight and high strength requirements. In packaging glass, paper, plastics or steel it can be used instead of aluminium; in electrical applications copper; in construction different composite materials, steel, vinyl or wood can substitute the metal. However, in practice due the abundance of aluminium and its unique properties it is only rarely substituted (European Commission 2014).

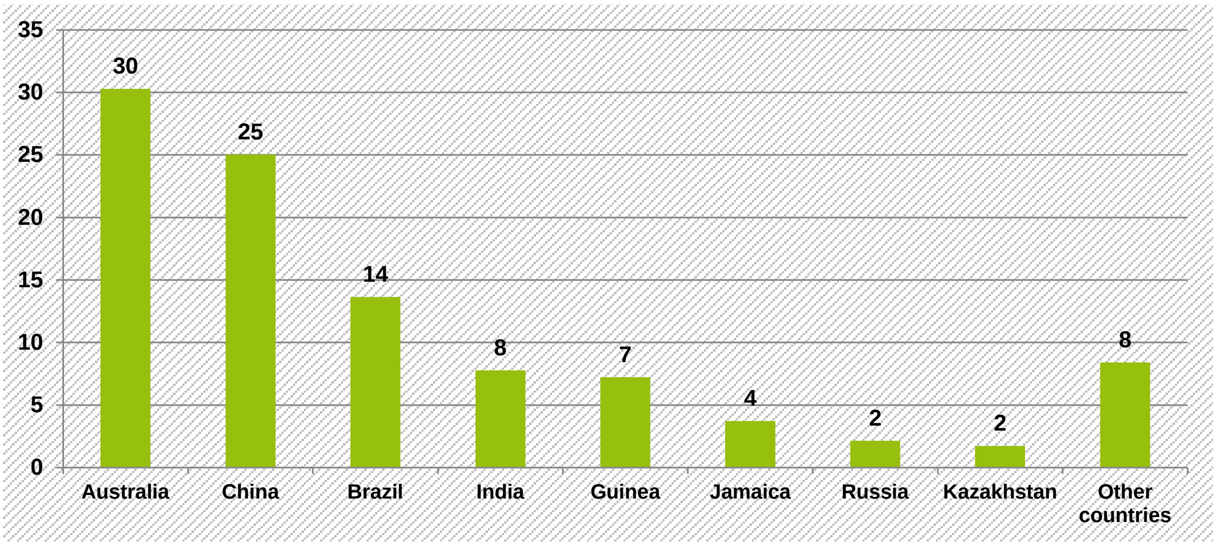
Main product, co-product or by-product

Aluminium is a main product (European Commission 2014).

Primary production

Total global production 2014: 52,958,304 t (BGS 2016).

Percentage of Bauxite (aluminium ore) mines mined in 2014 (%) (See also 4.5.1)(BGS 2016)



Information on Deposits

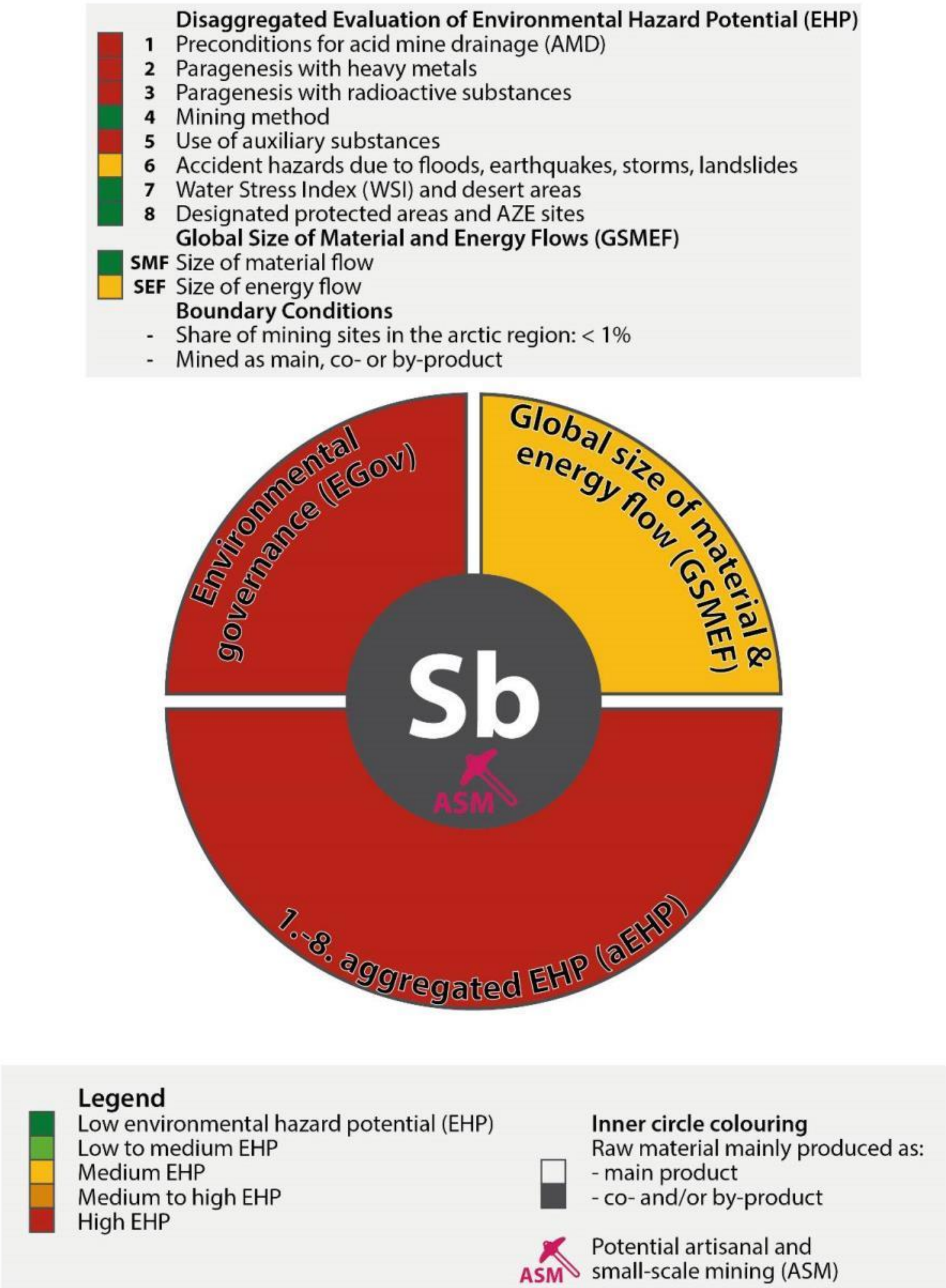
Bauxit, the lithophilic aluminium ore, is a product of (lateritic) weathering in tropical climates. Thus near-surface loose rocks are mined. No paragenetic associations with sulfides. The subsequent enrichment of poor ores by chemical weathering has often led to the formation of economically feasible concentrations in the cementation zones.

4.2.2 Profile Aluminium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	According to the Goldschmidt classification, aluminium (and thus also bauxite as Al ore) is a lithophilic element and is mostly oxidic.	high
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Aluminium is not a heavy metal. According to the recommendations of the method description regarding metals, an evaluation with average EHP is carried out.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Average data on Chinese bauxite deposits (16.3 % of world production) suggest that in many cases aluminium is associated with slightly elevated concentrations of uranium and/or thorium.	medium
Indicator 4: Mine Type		
High EHP	Bauxite is extracted from tropical weathering horizons that are stored near the surface and therefore require loose rock surface mining as a method of extraction.	high
Indicator 5: Use of auxiliary substances		
High EHP	Sodium hydroxide solution is used in the Bayer process. The treatment in the Bayer process usually takes place in the vicinity of the mining sites.	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	Aluminium is mainly made from bauxite, therefore, the assessment corresponds to the assessment for bauxite	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	Aluminium is mainly made from bauxite, therefore, the assessment corresponds to the assessment for bauxite	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		

Environmental hazard potential	Explanation	Data quality
Medium EHP	Aluminium is mainly made from bauxite, therefore, the assessment corresponds to the assessment for bauxite	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 58.36.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 551 million t/a results from the $CRD_{specific}$ of 10.4 t/t and the global annual production of 52,958,304 t/a. CRD_{global} takes into account mining, alumina production and smelting.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 6,938 PJ/a results from the $CED_{specific}$ of 131,000 MJ-eq/t and the global annual production of 52,958,304 t/a. CED_{global} takes into account mining, alumina production and smelting	high
Indicator 12: Position of mining sites in the arctic region		
Medium	Aluminium is mainly made from bauxite, therefore, the assessment corresponds to the assessment for bauxite	medium

4.3 Antimony


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 1%
- Mined as main, co- or by-product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Sb
ASM
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.3.1 General Information

Introduction and characteristics

Antimony (chemical symbol Sb) is a silver-grey metalloid with the atomic number 51. It is soft, has a relatively low melting point of 630 °C and lustrous. It can be found in over 100 different mineral species, typically in association with elements such as mercury, silver and gold. It is stable in air at room temperature, but reacts with oxygen when heated to form antimony trioxide (Sb_2O_3). Antimony is rare in the Earth's crust. The main ore mineral of antimony is stibnite (Sb_2S_3). Antimony dusts and certain antimony compounds are under suspicion to cause dermal irritation and respiratory-related problems (European Commission 2017b).

Application

The major global end uses of antimony are mainly as flame retardants (43 %), in the production of lead-acid batteries (32 %), in lead alloys (14 %), as catalyst in the production of polyethylene terephthalate (6 %) and in the manufacture of high quality clear glass as degassing agent (European Commission 2014).

Antimony in the form of antimony trioxide combined with halogenated flame retardant compounds constitutes a highly effective flame retardant. Those flame retardants find applications in plastics, coatings, furniture, car seats, fabrics and household appliances (European Commission 2017b).

Recycling

The secondary raw material antimony is mainly recovered from lead-acid batteries. Thus the availability of secondary antimony is strongly dependent on the extent of lead recycling and the market conditions for lead and lead-acid battery scrap (European Commission 2017b). Antimony used in the manufacture of plastics and flame retardants is normally not recycled because it is dispersed in these products. The global End of Life recycling rate for antimony is estimated to be between 1 – 10 % (UNEP 2013). The global end of life recycling input rate is 28 % (EC 2017).

Substitution

In its main use as flame retardant, compounds such as alumina trihydrate, magnesium hydroxide and zinc borate may substitute for antimony, but their performances are inferior to antimony-based flame retardants.

In the production of lead alloys, there are potentially several metals that may substitute for antimony however properties of a given alloy are not controlled by a single metal, but rather by several metals.

Compounds of chromium, tin, titanium, zinc and zirconium can substitute for antimony in the manufacture of pigments and glass.

Various combinations of cadmium, barium, calcium, lead, tin, zinc and germanium have the properties to substitute for antimony in the production of plastics, but the substitution is dependent on prices (European Commission 2017b).

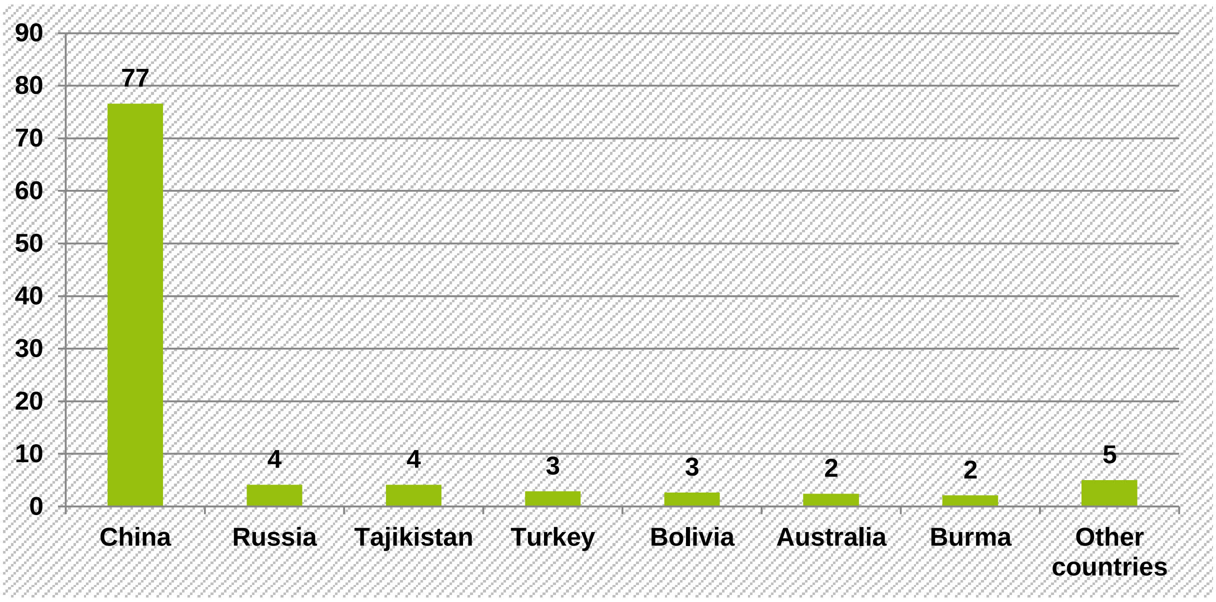
Main product, co-product or by-product

Antimony is a main product or co- or by-product of Au, Pb, Zn (European Commission 2017b).

Primary production

Total global production 2014: 156,683 tonnes (BGS 2016).

Percentage of antimony mines mined in 2014 (%) (BGS 2016)



ASM relevance

Global antimony production share of ASM is according to BGR 4 % and from SSM according to GEUS (2007) 45 %. This relatively high number for the SSM production explains itself by the geology of the deposits: Hydrothermal vein deposits are often of small dimensions and require selective underground mine types, thereby favoring small operations.

Important antimony producing countries with prominent ASM production is China and Bolivia. 83 % of antimony is produced in countries with ASM (GEUS 2007).

Information on Deposits

Chalkophilic elements are found in hydrothermal deposits. Economically degradable ore minerals are antimonite (stibnite) and tetraedrite, both sulfides that occur together with other sulfides in vein mineralisations. Antimony is often associated with arsenic minerals, gold, cinnabar (HgS), galena and zinc blende.

4.3.2 Profile Antimony

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	According to the Goldschmidt classification, antimony is a chalcophilic element and is generally sulfidic.	high
Indicator 2: Paragenesis with heavy metals		
High EHP	Approximately 40 % of the antimony extracted is a by-product of lead extraction. In addition, antimony is often associated with mercury and arsenic.	high
Indicator 3: Paragenesis with radioactive substances		
High EHP	Approximately 40 % of the antimony extracted is a by-product of lead extraction. Accordingly, the rating for lead is adopted (see rating for lead).	low
Indicator 4: Mine Type		
Low EHP	underground mining	high

Environmental hazard potential	Explanation	Data quality
Indicator 5: Use of auxiliary substances		
High EHP	Flotation, gravimetry, partly with heavy turbidity separation (in the coarse fraction), manual separation	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for antimony range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 23 % low, 51 % medium, 26 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Low EHP	The results for antimony range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 93 % low, 0 % medium, 7 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for antimony range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 52.04. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 3.1 million t/a results from the $CRD_{specific}$ of 19.7 t/t and the global annual production of 156,683 t/a.	medium
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 22 PJ/a results from the $CED_{specific}$ of 141,000 MJ-eq/t and the global annual production of 156,683 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for antimony range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99.9 % low, 0.1 % medium EHP.	medium

4.4 Baryte

4.4.1 General Information

Introduction and characteristics

Baryte (or barite) occurs in nature as the mineral barium sulphate (Ba_SO_4). It is inert, non-toxic, nearly non-soluble in water, has a high fusion point (1,580°C), brightness and a low oil adsorption. The colour differs between white, grey or black depending on the presence of other compounds and elements (European Commission 2017b).

Application

Baryte is used primarily as a weighting agent in drilling fluids by the oil and gas industry (60 %).

Baryte and barium compounds find also an application as fillers (30 %) and in chemicals (10 %). Specific examples for its use are additives in industrial products including rubber, paint, ceramics/glass, high density concrete, plaster, dielectrics and medical applications (European Commission 2017b).

Recycling

Only a small percentage of baryte of drilling projects is recycled for re-use. In most applications, baryte cannot be recycled. The end of life recycling input rate is approximately 1 % (European Commission 2017b).

Substitution

When used as weighting agent for the oil and gas industry baryte can be substituted by hematite (Fe_2O_3), ilmenite ($FeTiO_3$) and calcium carbonate ($CaCO_3$). However, they are economically less attractive thus baryte has currently over 99 % of the market. For fillers, the key substitutes are calcium carbonate and clays (kaolin, talc) which are broadly used for general purpose fillers where quality or technical aspects are less severe. Those substitutes cannot be applied when heaviness, sound proofing and radiation shielding are necessary. In the chemical sector, there are several substitutes for barium carbonate like strontium carbonate is sometimes used as a substitute in ceramic glaze. Barium carbonate in dielectrics cannot be substituted and no safe substitute is available for medical applications (European Commission 2017b).

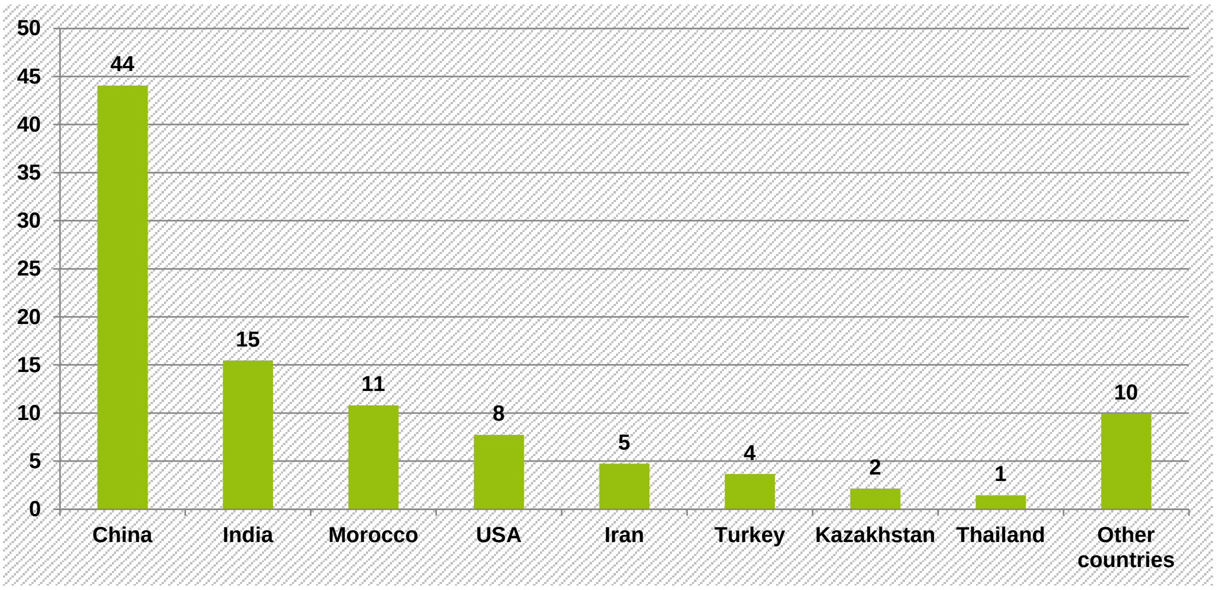
Main product, co-product or by-product

Baryte is a main product (European Commission 2017b).

Primary production

Total global production 2014: 9,305,762 t (BGS 2016).

Percentage of baryte mines mined in 2014 (%) (BGS 2016)



ASM relevance

GEUS (2007) figures the SSM share of the global production with 60 %. This is due to the limited size of baryte deposits, which therefore mostly allow mining only on a small scale.

Low environmental hazard potential due to inert chemistry, low accessories in mined deposits and absence of toxic heavy metals. Hardrock mining in quarries, mostly even in ASM in a mechanized or semi-mechanized form. Low amount of mining residues due to the high grade of baryte deposits.

Many of the small operations in developing countries, i.e. Nigeria, are informal. They have problems with the authorities and the local population and cause conflicts over resources and with regard to environmental management and efficient use of deposits. In this respect, the ASM is a particular challenge for policy-makers and authorities.

Important baryte producing countries with prominent ASM production are China, India and Morocco. 76 % of baryte is produced in countries with ASM.

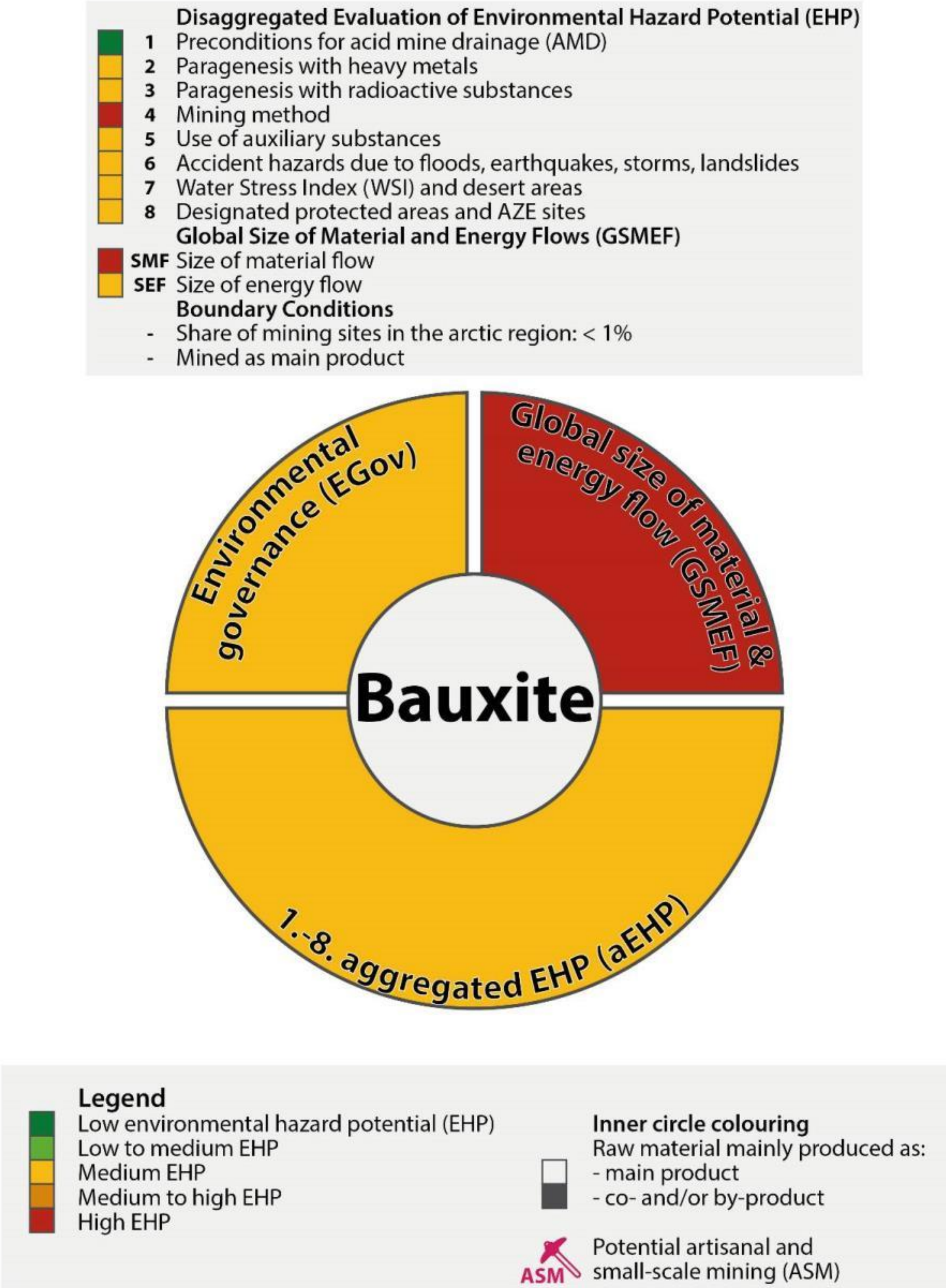
Information on Deposits

Barium is a lithophilic element which is mined in the form of barite, barite and $BaSO_4$. It occurs in hydrothermal deposits as well as in marine sedimentary deposits. For most applications the presence of sulfidic contaminants is harmful, so that mainly deposits without sulfide paragenesis are mined.

4.4.2 Profile Barytes

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	No presence of sulfidic minerals in the paragenesis of barite recoveries.	high
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Extraction predominantly from baryte galleries which are largely free of heavy metal-containing companions. Deposits of minor importance partly associated with lead and zinc.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Extraction predominantly from heavy spades which are largely free of radioactive companions.	medium
Indicator 4: Mine Type		
Medium EHP	Surface mining, underground mining	medium
Indicator 5: Use of auxiliary substances		
Medium EHP	heavy turbidity separation, gravimetry	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
N/A	Information not available due to data restrictions	N/A
Indicator 7: Water Stress Index and desert areas		
N/A	Information not available due to data restrictions	N/A
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
N/A	Information not available due to data restrictions	N/A
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 51.77. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 85 million t/a results from the $CRD_{specific}$ of 9.1 t/t and the global annual production of 9,305,762 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of140 PJ/a results from the $CED_{specific}$ of 14,996 MJ-eq/t and the global annual production of 9,305,762 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
N/A	Information not available due to data restrictions	N/A

4.5 Bauxite


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 1%
- Mined as main product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Bauxite
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.5.1 General Information

Introduction and characteristics

Bauxite is a Sedimentary Rock and the main source for aluminium production. It contains primarily Al_2O_3 (up to 40 %) and the minerals gibbsite, boehmite, diaspore, silica, iron oxide, titanite, aluminosilicate and other associated minerals. The colour varies and can be differ between brown, red-brown, yellow-brown, white, grey or mottled depending on the share of the respective substances. Deposits of bauxite are remaining accumulations caused by lateritic weathering (European Commission 2017a).

Application

Approximately 90 % of bauxite mined in the world is converted to alumina (aluminium oxide). The main uses of aluminium are in transportation (aircraft, vehicles, trains, boats, spacecraft, etc.), construction (windows, doors, cladding, curtain walls, etc.), packaging (cans, foil, food trays, boxes, etc.), high-tech engineering (electrical transmission lines, ladders, cylinder blocks, pistons, pulleys, etc.) and consumer durables (domestic appliances, cooking utensils, cutlery, paint, coins, etc.).

Bauxite is also used in refractories, cement, abrasives, chemicals and other minor uses (European Commission 2017a).

Recycling

Bauxite is used completely during all of its applications thus no recycling is necessary. The majority of bauxite uses results in materials that are subsequently transformed into a different product, e.g. alumina into aluminum metal. In contrast to bauxite, aluminium is infinitely recyclable without loss of performance. The end of life recycling input rate for bauxite is 0 % (European Commission 2017a).

Substitution

Nearly no substitutes are commercially in use. Russia is supposed to extract aluminium oxide (alumina) from nepheline raw materials but generally alumina is refined from bauxite. Substitutes for other applications than the production of alumina are of minor importance as 90 % of bauxite mined in the world is converted into alumina (European Commission 2017a).

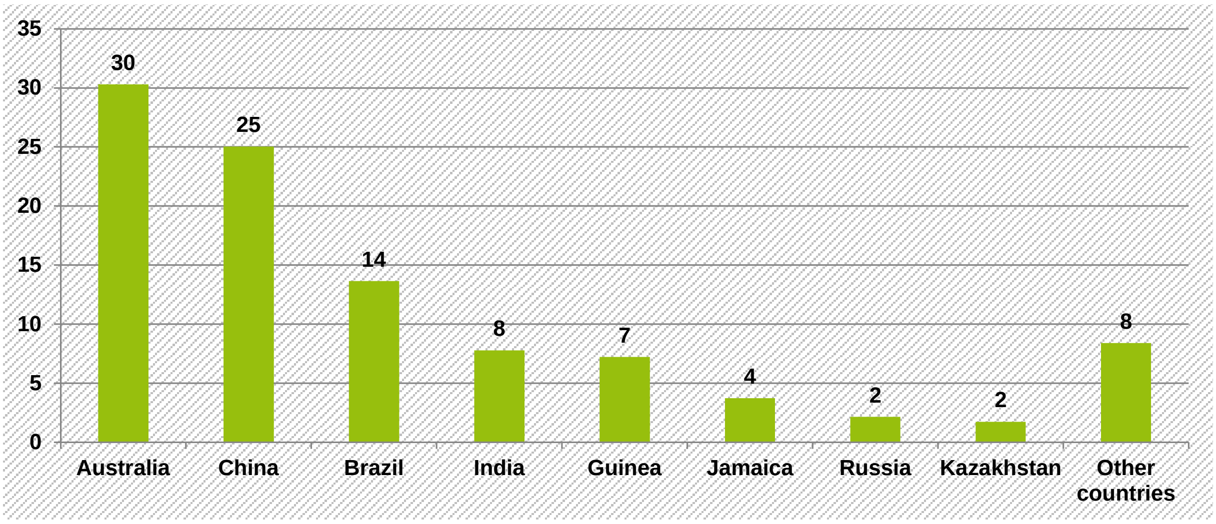
Main product, co-product or by-product

Bauxite is a main product (European Commission 2017a).

Primary production

Total global production 2014: 259,584,940 tonnes (BGS 2016).

Percentage of bauxite mines mined in 2014 (%) (see also Chapter 4.2.1) (BGS 2016)



Information on Deposits

Bauxit (aluminium ore) is lithophilic; bauxite (alumina) is an aluminium oxide (Al_2O_3) and a product of (lateritic) weathering in tropical climates. Thus near-surface loose rocks are mined. No paragenetic associations with sulfides.

4.5.2 Profile Bauxite

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	According to the Goldschmidt classification, aluminium (and thus also bauxite as Al ore) is a lithophilic element and is mostly oxidic.	high
Indicator 2: Paragenesis with heavy metals		
Medium EHP	The main constituents of bauxite are Al hydroxides and Fe oxides (not heavy metals). In accordance with the recommendations in the method document, an evaluation with medium EHP is carried out.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Average data on Chinese bauxite deposits (16.3 % of world production) suggest that in many cases aluminium is associated with slightly elevated concentrations of uranium and/or thorium.	medium
Indicator 4: Mine Type		
High EHP	Bauxite is extracted from tropical weathering horizons that are stored near the surface and therefore require loose rock surface mining as a method of extraction.	high
Indicator 5: Use of auxiliary substances		
Medium	If bauxite is regarded as the end product, no toxic auxiliary substances are used for processing. However, caustic soda is used for the further processing of bauxite into alumina (Bayer process - see evaluation of aluminium).	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for bauxite range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 39 % low, 38 % medium, 23 % high EHP.	medium

Environmental hazard potential	Explanation	Data quality
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for bauxite range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 72 % low, 0 % medium, 28 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for bauxite range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 95 % low, 5 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 58.36.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 348 million t/a results from the $CRD_{specific}$ of 1.3 t/t and the global annual production of 259,584,940 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 28 PJ/a results from the $CED_{specific}$ of 109 MJ-eq/t and the global annual production of 259,584,940 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for bauxite range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99.7 % low, 0.3 % medium EHP.	medium

4.6 Bentonite

4.6.1 General Information

Introduction and characteristics

Bentonites, which are mainly formed by igneous material, consist of aluminium phyllosilicate, composed predominantly of the clay mineral group smectite. The smectite in most bentonites is the mineral montmorillonite, but also other types of smectite occur. Bentonites have a unique composition of different properties in the field of hydration, swelling, water absorption, viscosity and thixotropy. They have the ability to act as a bonding agent and provide a significant exchange capacity. The major types of bentonite are calcium bentonite and sodium bentonite, which have different properties and thus applications (European Commission 2017a).

Application

Its properties make bentonite a suitable material for different uses e.g. pet litter, foundry sand, iron ore pelletizing, underground mining applications, fillers in various industries and others.

The shares of the different uses in the European Union are as follows: pet litter (36 %), foundry molding sand (27 %), underground mining (12 %), pelletizing of iron ore (9 %), food and wine production (6 %) and paper making (4 %). Bentonite is used in numerous other specialized end uses, for example in the pharmaceutical and cosmetics markets, where it is used as a filler in detergents, in paints and dyes, in catalysts and many more. Bentonite is used in several underground mining applications and related products, for example in geosynthetics, in pilling, in the construction of cut-off walls (as a barrier), in excavation and boreholes (European Commission 2017a).

Recycling

Pet litter, which is the main application of bentonite, is not recovered as pet litter is normally disposed of as municipal waste. When incinerated, fly ash from that stream is mostly reused in various industries, for example the wall board industry. The average European recycling rate for foundry sand made out of bentonite is estimated at 80 %. Bentonites used in the pelletising of iron ore are not recoverable and the major part ends up in the slag. This slag finds often use in the cement industry. Bentonite which is used in the construction sector often ends up in construction and demolition waste, which is widely recycled. Bentonite used in paper making is not recovered. The end of life recycling input rate for bentonite is 50 % (European Commission 2017a).

Substitution

Substitutes exist for the applications of pet litter, foundry moulding sands, pelletizing of iron ore and underground mining uses. Substitutes for bentonite used in pet litter include wood based litter and different other alternative substances. The substitutes account for about 5 % of the pet litter market. Wood based pet litter comprises wood pellets (.e.g. from pine) and it is often produced from sawdust and recycled wood. Other alternative pet litters include paper based, plant based or silica gel based products.

Alternative binders in foundry moulding sands are available, but bentonite is the most popular one and alternatives such as linseed oil, other vegetable oils and marine oils are used only to satisfy specific requirements.

In the pelletizing of iron ore, bentonite is widely used as a binding agent and it may be substituted by hydrated lime or organic binders. The use of hydrated lime as a binder finds application in the production of fluxed pellets. Organic binders provided good wet pellet strength; however, they have found limited application in industry.

In several underground mining applications and related products, polymer support fluids are used as alternatives to bentonite (European Commission 2017a).

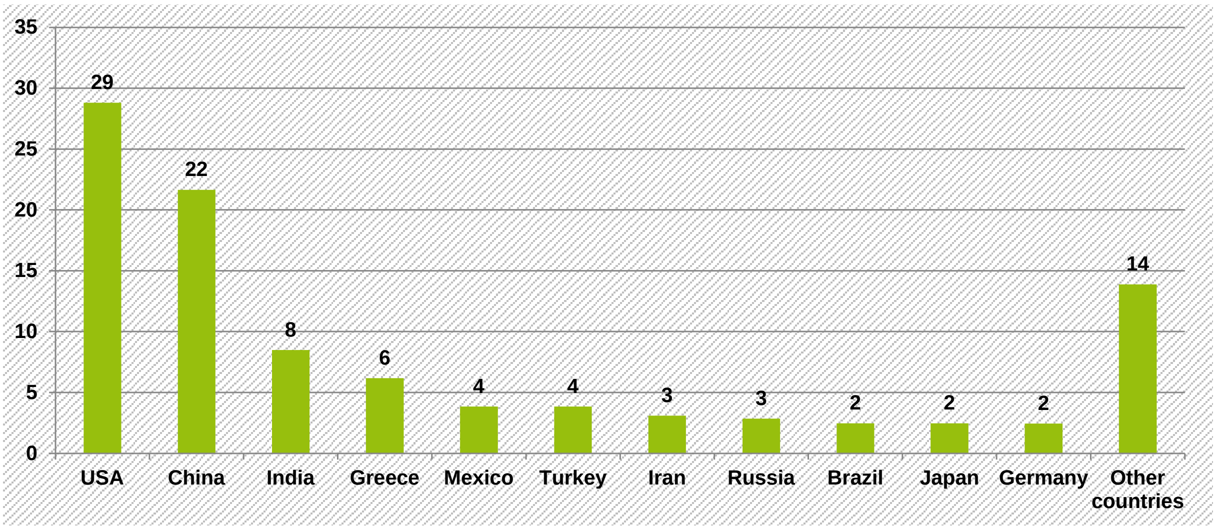
Main product, co-product or by-product

Bentonite is a main product (European Commission 2017a).

Primary production

Total global production: 2014 16,172,318 tonnes (BGS 2016).

Percentage of Bentonite mines mined in 2014 (%) (BGS 2016)



Information on Deposits

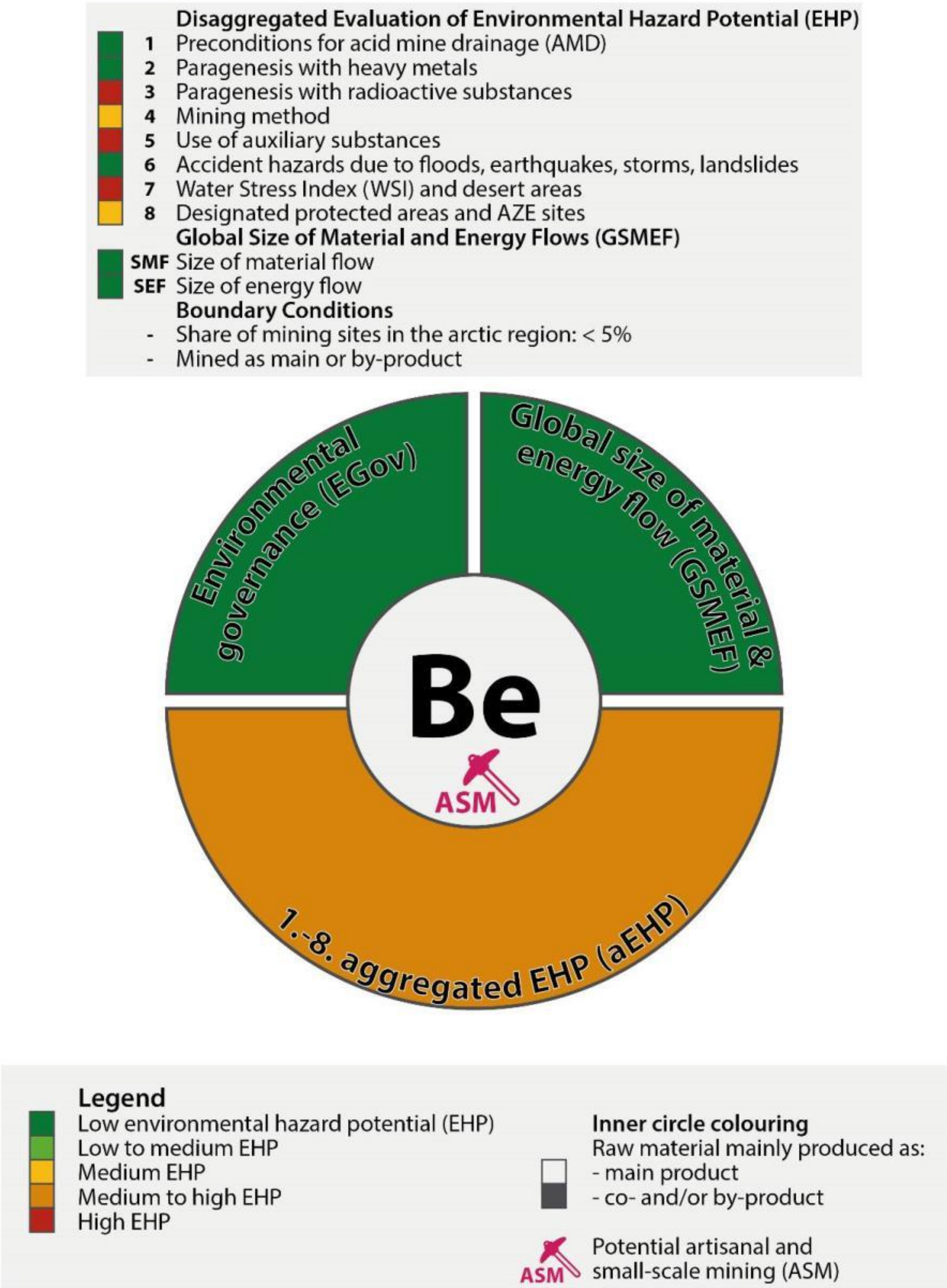
Bentonite is a mixture of different clay minerals (mainly montmorillonite) and other accessory sediment minerals (quartz, feldspar etc.). It is the weathering product of volcanic ashes.

4.6.2 Profile Bentonite

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Sedimentary weathering product: ergo no reactive components, which could have an acid-forming effect.	medium
Indicator 2: Paragenesis with heavy metals		
Low EHP	Bentonite is an abiotic non-metallic raw material. According to the recommendations in the method document, an evaluation with a low EHP was carried out.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Bentonite as a mixture of different clay minerals has the potential to bind ions of large radii such as U and Th due to its crystalline mineral structure. Nevertheless, it is assumed that bentonite as a mining raw material is largely free of radioactive substances.	low
Indicator 4: Mine Type		
Medium EHP	Opencast mining	medium
Indicator 5: Use of auxiliary substances		
High EHP	Digestion with acid	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
N/A	Information not available due to data restrictions	N/A
Indicator 7: Water Stress Index and desert areas		
N/A	Information not available due to data restrictions	N/A
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
N/A	Information not available due to data restrictions	N/A
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 60.34.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 16 million t/a results from the $CRD_{specific}$ of 1 t/t and the global annual production of 16,172,318 t/a.	high

Environmental hazard potential	Explanation	Data quality
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 5.7 PJ/a results from the $CED_{specific}$ of 354 MJ-eq/t and the global annual production of 16,172,318 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
N/A	Information not available due to data restrictions	N/A

4.7 Beryllium



4.7.1 General Information

Introduction and characteristics

Beryllium (Be) is an alkaline metal that occurs naturally only in combination with other elements and has the atomic number 4. Beryllium is light, bluish-white, shiny, hard and brittle and has a hexagonal-close-packed structure. A very low density combined with strength, high thermal stability and conductivity, flexural rigidity and resistance to acids make beryllium a useful material for structural parts that are exposed to great inertial or centrifugal forces, in aerospace and defence applications (European Commission, 2014). After extraction, beryllium ore is processed into beryllium oxides and hydroxides, master alloys, beryllium unwrought and powders that are used to produce mainly of beryllium alloys, metals and ceramics.

Application

The major end uses in the European Union are electronic and tele-communications equipment (42 %), road transport and defence (44 %), energy applications (8 %) and industrial components (6 %) – f. e. moulds for industry. Its main uses in the world are also mainly electronic and telecommunications equipment, transports and defence components, industrial components and energy applications. Because of the toxicity of inhaled beryllium-containing dusts causing berylliosis, a chronic life-threatening allergic disease, industrial risk mitigation measures are implemented (European Commission, 2014).

Recycling

No post-consumer recycling from old scrap takes place. Beryllium is not recycled from end finished products, therefore the end of life recycling input rate is set to 0 %. The recuperation is extremely difficult because of the small size of components and the tiny fraction of Beryllium contained in appliances.

However, beryllium can be recovered from new scrap generated during the manufacture of beryllium products. Between 94 % and 100 % of new scrap is sent back to the producer and recycled. In 2013 secondary beryllium production from new scrap recycling was between 100 and 135 tonnes, i.e. about 20 % of global demand. (European Commission, 2014)

Substitution

Substitution of beryllium always leads to a loss of performance. In addition, it is used only when it is absolutely needed as beryllium is extremely expensive. For example, copper-beryllium is only used when absolute reliability is essential to ensure safe operation in the defence, transport or energy sector. Pure beryllium and Al-Be alloys are used only in applications where the unique property combinations are essential for mission capabilities. Alternate materials for copper beryllium alloys could include, copper nickel silicon alloys, copper iron alloys, copper titanium alloys, copper nickel tin spinodal alloys, phosphor bronzes (Cu-Fe-P) and high performance bronzes (Cu-Pb-Sn + Al / Fe / Mn). Alternate materials for the mechanical properties provided by beryllium could include titanium alloys and magnesium alloys, aluminium alloys and carbon fibre composites. Alternate materials for the thermal properties provided by beryllium are aluminium metal matrix composites with silicon carbide / boron nitride and carbon reinforced composites. In all cases, the share of applications in which the beryllium can be substituted by these materials is extremely low. (European Commission, 2014)

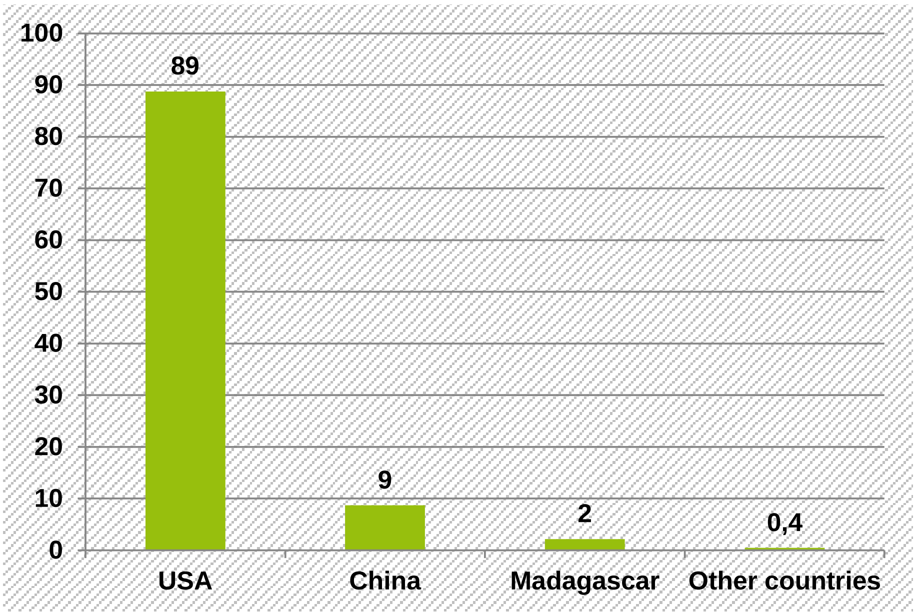
Main product, co-product or by-product

Most of the beryllium is produced as the main product (European Commission, 2014).

Primary production

Total global production: 231 tonnes in 2015 (USGS 2017).

Percentage of beryllium mines mined in 2015 (%) (USGS 2017)



ASM relevance

Global beryllium production share of ASM is according to BGR 5 % (BGR 2007) and SSM share given by GEUS 100 % (GEUS 2007). This number is misleading, as the largest beryllium producer is Spur Mountain, which is a highly mechanized and fully formalized mining operation. See case study provided under the ÖkoRess II project.

Important beryllium producing countries with prominent ASM production are China and Madagascar. 11 % of beryllium is produced in countries with ASM.

Information on Deposits

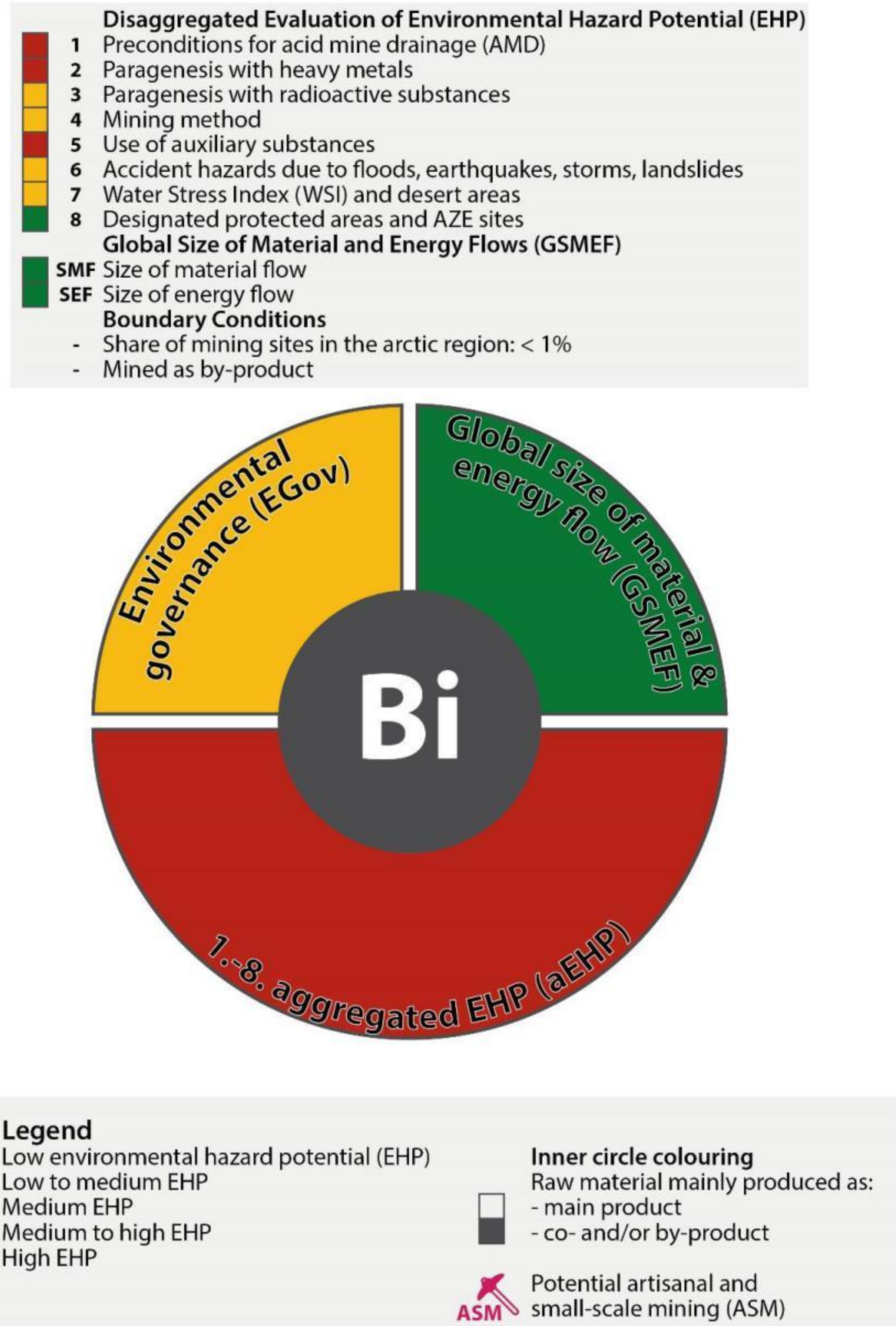
Beryllium is a lithophilic element and light metal. It occurs in nature in many minerals, but is only economically recoverable as bertrandite (4 BeO-2 SiO_2-H_2O) and beryl ($Be_3Al_2(SiO_3)6$). These minerals come from pegmatitic, pneumatolytic or metasomatic deposits. There they are associated with tourmaline, quartz, manganese oxides etc. (Ege 2005).

4.7.2 Profile Beryllium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Parageneses are low sulphide or sulphide free.	high
Indicator 2: Paragenesis with heavy metals		
Low EHP	Beryllium is largely extracted from a single mine in the USA (Spor Mountain). The deposit has increased concentrations of lead and zinc. These values (average 42ppm lead and maximum 1600 ppm zinc) are mostly below the critical thresholds for the use of the substitute for agricultural production according to the Federal Soil Protection Act.	medium
Indicator 3: Paragenesis with radioactive substances		
High EHP	Almost 90 % of the world's beryllium production comes from the Spor Mountain mine in the USA. Uranium has been mined in the	high

Environmental hazard potential	Explanation	Data quality
	immediate vicinity of the mine in recent decades. The deposit itself is also associated with uraniferous minerals that were mined in the past.	
Indicator 4: Mine Type		
Medium EHP	Open pit mining in hard rock	high
Indicator 5: Use of auxiliary substances		
High EHP	Hand picking, crushing in industrial extraction, grinding, acid digestion, then solvent extraction and hydrolysis for the production of beryllium hydroxide (which parts of the raw material value chain are to be assigned to processing and which parts of smelting require further clarification; the question is the traded product beryl/bertrandit ore or beryllium hydroxide?	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for beryllium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 84 % low, 8 % medium, 8 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for beryllium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 19 % low, 18 % medium, 63 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for beryllium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 96 % low, 3 % medium, 1 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 68.60. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 0.03 million t/a results from the $CRD_{specific}$ of 116 t/t and the global annual production of 231 t/a.	low
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 0.4 PJ/a results from the $CED_{specific}$ of 1,720,000 MJ-eq/t and the global annual production of 231 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for beryllium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 98 % low, 2 % medium EHP.	medium

4.8 Bismuth


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 1%
- Mined as by-product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Bi
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.8.1 General Information

Introduction and characteristics

Bismuth is a metal with the atomic number 83. It is a very brittle metal with a pinkish metallic lustre with a concentration of 0.16 ppm in the upper continental crust. It is mainly a by-product of lead and tungsten extraction and processing. (European Commission 2017a)

Applications

The main end-use markets for bismuth are the pharmaceutical and animal-feed industries (62 % of total uses for Bi chemicals). Other important applications are fusible alloys (28 %) and chemicals (10 %). (European Commission 2017a)

Recycling

Less than 1 % of bismuth from end-of-life products is recovered because it is mainly used in dissipative applications like in pigments and pharmaceuticals. Where bismuth is used in solder alloys in electronic equipment recycling could be possible since the process is relatively straight forward (European Commission 2017a).

Substitution

Because of its non-toxicity bismuth substitutes other materials in many applications. On the other hand bismuth is substituted by other low-melting alloys with other properties or prices as the main driver for substitution. (European Commission 2017a)

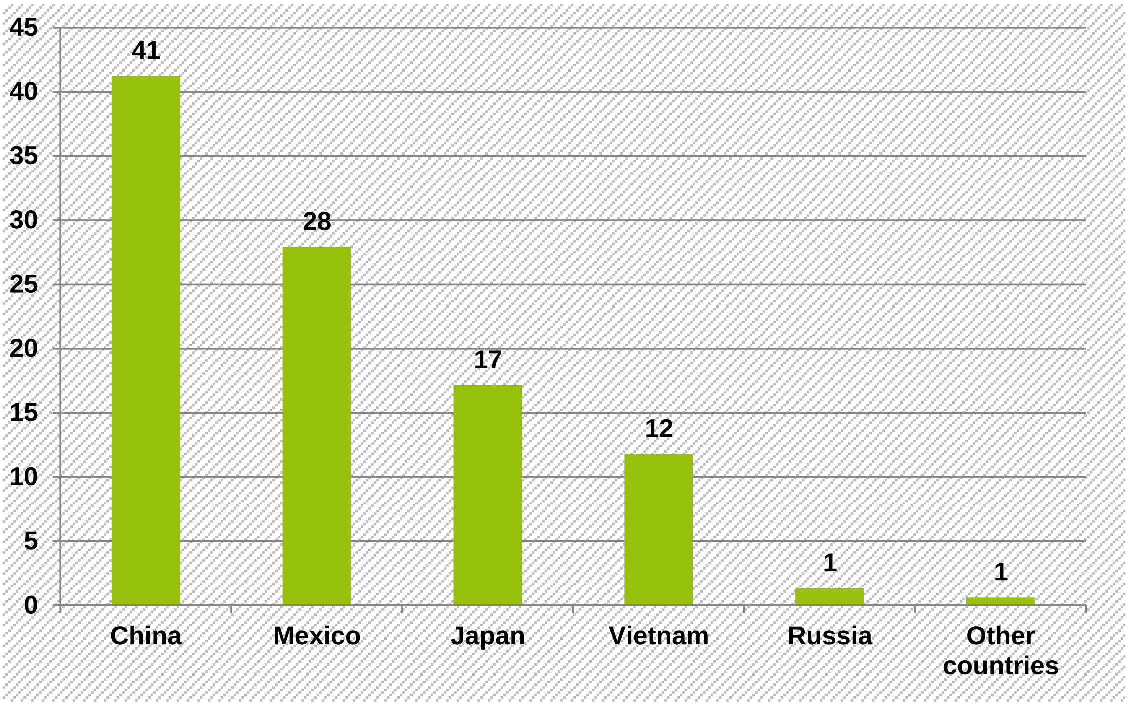
Main product, co-product or by-product

Bismuth can be a main product, but is mostly a by-product from the extraction of metals such as lead, copper, tin, molybdenum and tungsten (European Commission 2017a).

Primary production

Total global production: 3,396 tonnes in 2014 (BGS 2016).

Percentage of bismuth mines mined in 2014 (%) (BGS 2016)



Information on Deposits

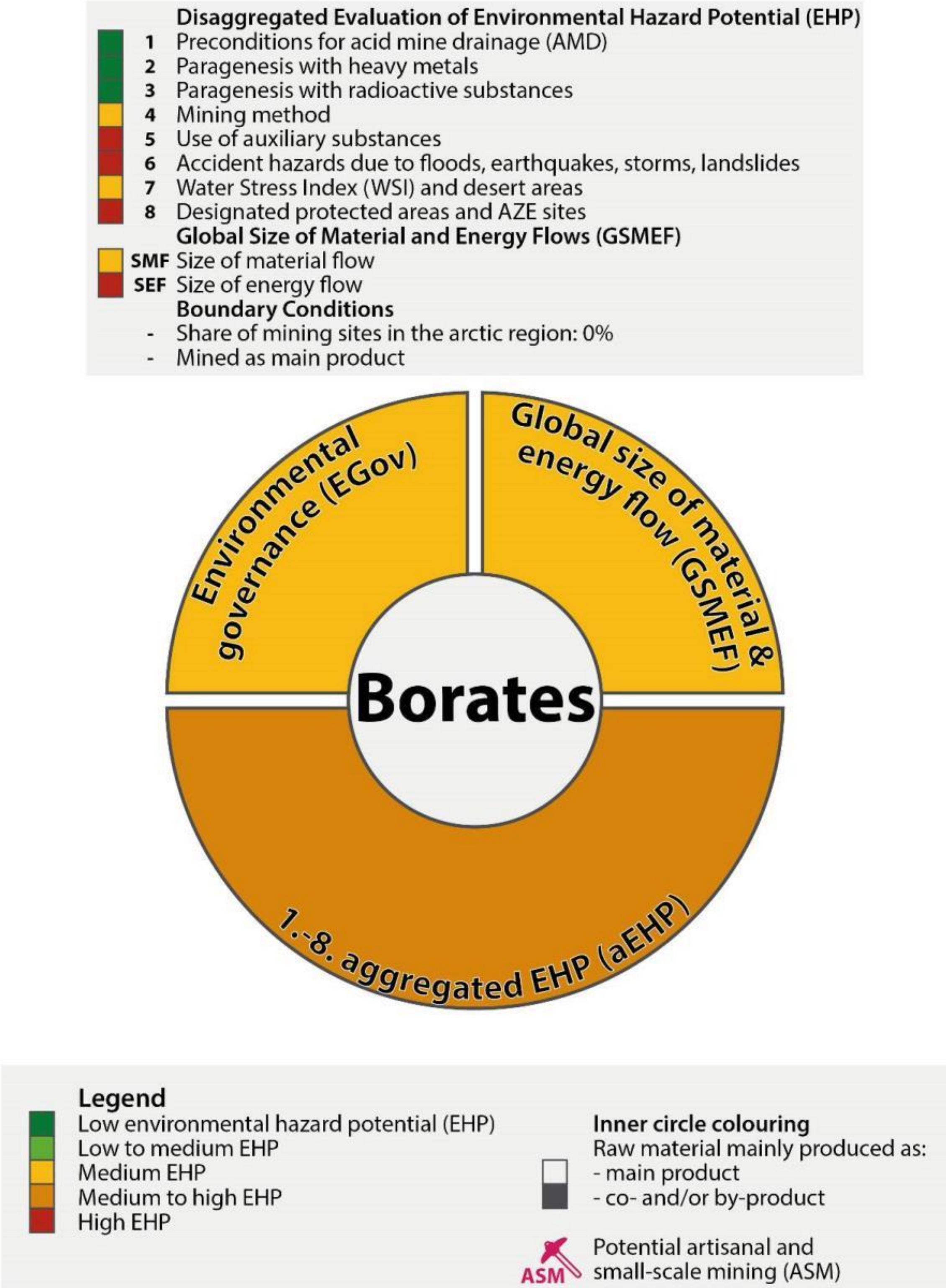
Bismuth is a chalkophilic element and forms deposits in plutonic and subvucan hydrothermal deposits (mostly ore deposits). The ore mineral is bismuth luster (bismuthinite), Bi_2S_3, subordinate also sulfosalts. Paragentially they are accompanied by other sulphide minerals.

4.8.2 Profile Bismuth

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	According to the Goldschmidt classification, bismuth is a chalcophilic element and is generally sulfidic.	medium
Indicator 2: Paragenesis with heavy metals		
High EHP	54 % of the bismuth extracted is a by-product of lead extraction.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Bismuth is mainly extracted from lead deposits and to a lesser extent from tungsten deposits in China. Chinese lead deposits show slightly higher concentrations of radioactive substances, especially uranium.	high
Indicator 4: Mine Type		
Medium EHP	Usually mined as a by-product, both open cast and in underground mines	low
Indicator 5: Use of auxiliary substances		
High EHP	Bismuth is separated by flotation, where potentially toxic flotation agents are added (Automistry 2018).	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for bismuth range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 33 % low, 47 % medium, 20 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for bismuth range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 68 % low, 0 % medium, 32 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for bismuth range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 57.13.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 0.3 million t/a results from the $CRD_{specific}$ of 79 t/t and the global annual production of 3,396 t/a.	low
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 0.1 PJ/a results from the $CED_{specific}$ of 21,367 MJ-eq/t and the global annual production of 3,396 t/a.	low

Indicator 12: Position of mining sites in the arctic region		
Medium	The results for bismuth range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99.7 % low, 0.3 % medium EHP.	medium

4.9 Borates



4.9.1 General Information

Introduction and characteristics

Minerals containing boron are summarized under the term borates. The industry defines borates as compounds containing boric oxide (B_2O_3). Borates have metabolizing, bleaching, buffering, dispersing, vitrifying properties making them useful in a variety of applications (European Commission 2017b).

Applications

Borates are used in both household and commercial products, such as insulation fiberglass, textile fiberglass and heat-resistant glass; detergents, soaps and personal care products; ceramic and enamel frits and glazes, ceramic tile bodies; agricultural micronutrients; other uses including wood treatments, polymer additives and pest control products (European Commission 2017b).

Recycling

Recycling plays a very minor role for borates, The End of life recycling input rate is 0 % (European Commission 2017b).

Substitution

Substitution of boron is feasible in a variety of application: In insulation applications it can be replaced by stone wools or polymer foams, in soaps it can be substituted with potassium salts and sodium or in detergents with sodium percarbonate. No substitution is possible in glass insulation applications (European Commission 2017b)

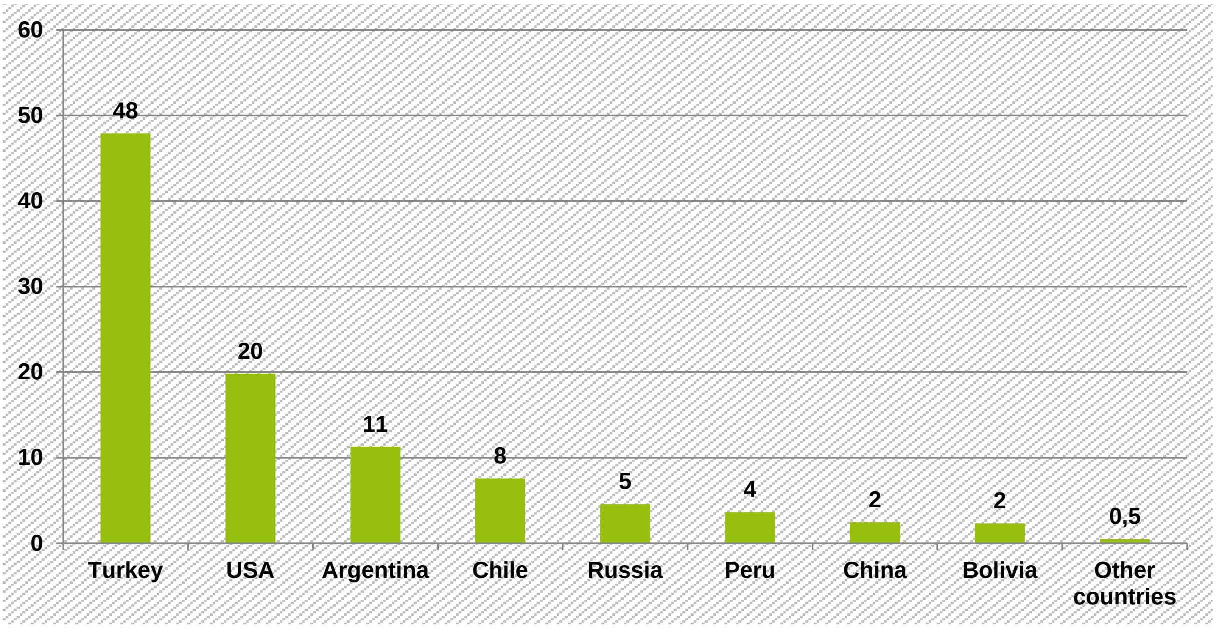
Main product, co-product or by-product

Borates are a main product (European Commission 2017b).

Primary production

Total global production: 6,562,615 tonnes in 2014 (BGS 2016).

Percentage of borates mines mined in 2014 (%) (BGS 2016)



Information on Deposits

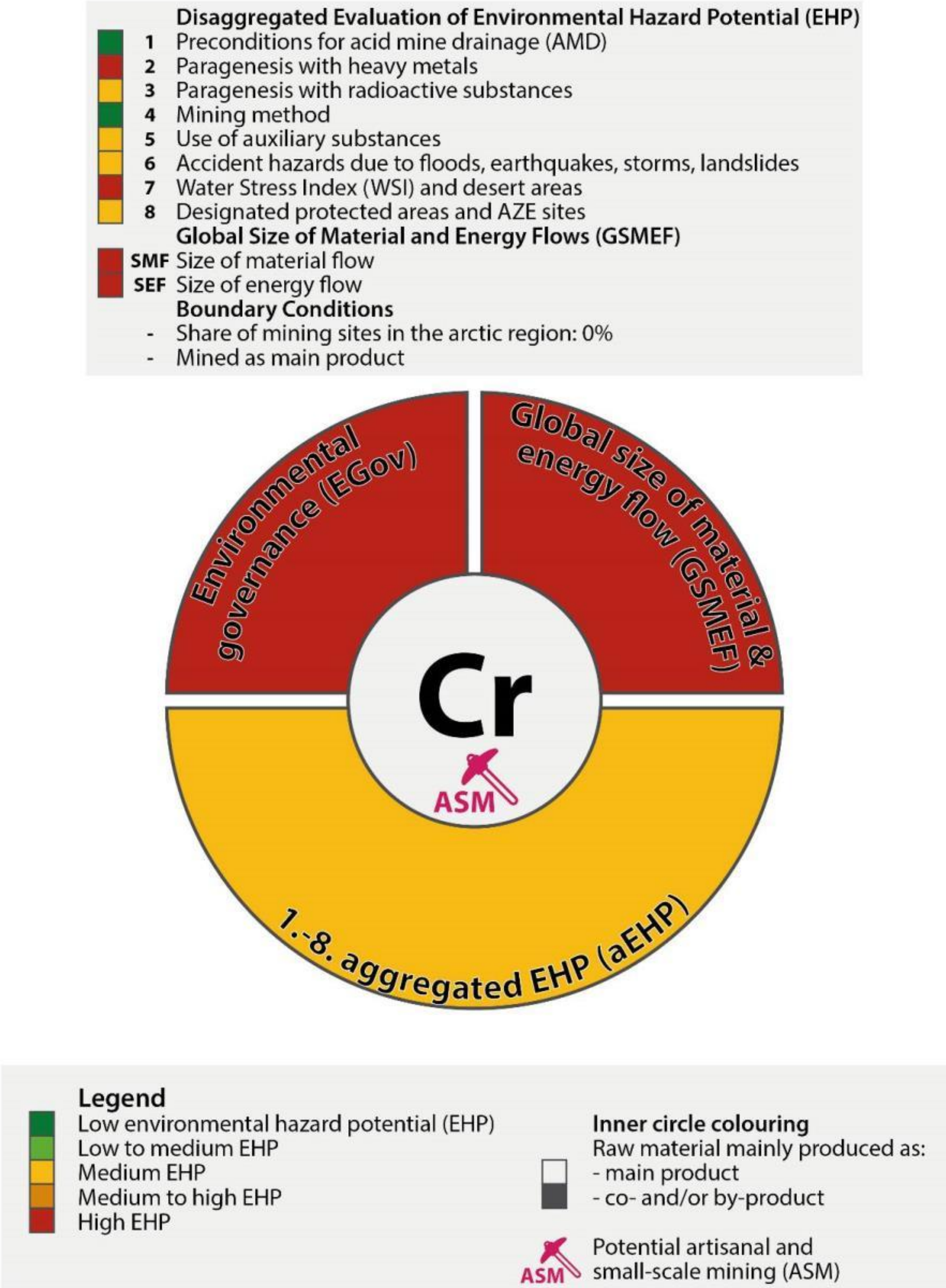
Boron is a lithophilic element and is a mineralogical component of many silicate minerals. The borate minerals boracite, borax, colemannite and ulexite are mined. These can be found in marine evaporation sediments and in arid weathering rocks and are not associated with minerals that tend to auto oxidize or dissolve heavy metals due to the conditions of formation.

4.9.2 Profile Borates

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Boron is a lithophilic element and is a mineralogical component of many silicate minerals. The borate minerals Boracit, Borax, Colemannit and Ulexit are mined. These can be found in marine evaporation sediments and in arid weathering rocks and are not associated with minerals that tend to autooxidise or dissolve heavy metals due to the conditions of formation.	high
Indicator 2: Paragenesis with heavy metals		
Low EHP	Borates are a group of abiotic non-metallic raw materials. According to the recommendations in the method document, an assessment with a low EHP was carried out.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	According to Hurley (2009), borates as representatives of the evaporite deposits are classified as largely free of radioactive elements due to the formation conditions.	high
Indicator 4: Mine Type		
Medium EHP	Brine extraction, solid rock mining e.g. Kernite	medium
Indicator 5: Use of auxiliary substances		
High EHP	Flotation	low
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	The results for borates range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 3 % low, 21 % medium, 76 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for borates range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 47 % low, 12 % medium, 41 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
High EHP	The results for borates range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 84 % low, 13 % medium, 3 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 58.48.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 19 million t/a results from the $CRD_{specific}$ of 2.9 t/t and the global annual production of 6,562,615 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 171 PJ/a results from the $CED_{specific}$ of 26,035 MJ-eq/t and the global annual production of 6,562,615 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Low	The results for borates range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment.	medium

	The results of the GIS assessment are: 100 % low, 0 % medium EHP.	

4.10 Chromium



4.10.1 General Information

Introduction and characteristics

Chromium with the atomic number 24 is a corrosion-resistant hard metal of lustrous, silvery-white colour. Its unique properties make Chromium an important alloying element in many steel alloys. Chromium(VI) compounds are highly toxic, carcinogenic and mutagenic (Baua 2018).

Applications

The main end-use for Chromium is the use as alloying element in steel production. Most of the chromium is used in stainless steel where different applications are possible e.g. for household consumer goods, such as cutlery, sinks etc. But it is also an essential material in hospitals, energy production and process industries. Chromium is also added to alloy steels to produce specialty and carbon alloys for machine parts or tools (European Commission 2017a).

Recycling

Post-consumer recycling of stainless steel which is the main application for chromium is well established reaching up to 92 % of recycling rate. Due to difficulties in detection and sorting of alloy steel most of the material is used in carbon steel. The end-of-life recycling input rate for chromium is 21 % in the EU (European Commission 2017a).

Substitution

No substitute in stainless steel or super alloy production.

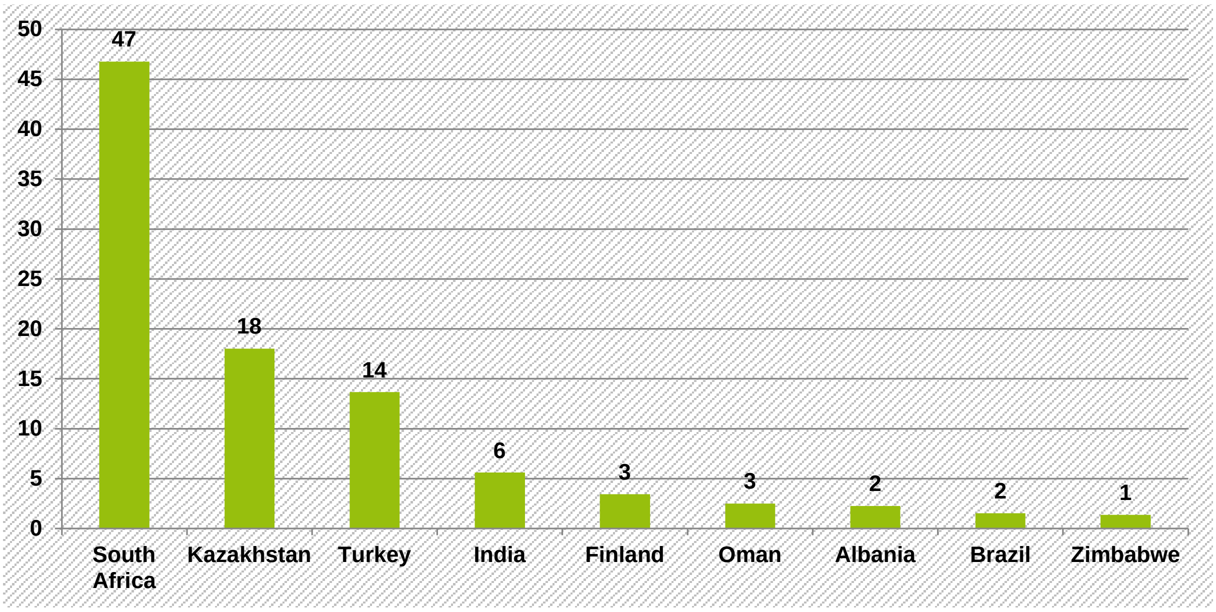
Main product, co-product or by-product

Chromium is a main product (European Commission 2017a).

Primary production

Total global production: 30,016,976 tonnes in 2014 (BGS 2016).

Percentage of chromium mines mined in 2014 (%) (BGS 2016)



ASM relevance

Global chromium production share of ASM is according to BGR (2007) 5 % and SSM production share according to GEUS (2007) 50 %.

Due to the geological conditions often ASM Chrome ore is the chromite, FeIICr2O4. This occurs, for example, in the Great Dike in Zimbabwe, in the form of thin vein deposits that require selective underground extraction, which is often carried out by small-scale mining. Due to the hardness, alluvial deposits are also less frequently formed, which are then also predominantly economically exploited by ASM.

In the case of chromite, the ASM poses less of an environmental problem than an underground safety problem (e.g. along the Great Dyke in Zimbabwe) and a challenge to the inspection and enforcement authorities.Important chromite producing countries with prominent ASM production are South Africa, India and Brazil. 58 % of chromium is produced in countries with ASM.

Information on Deposits

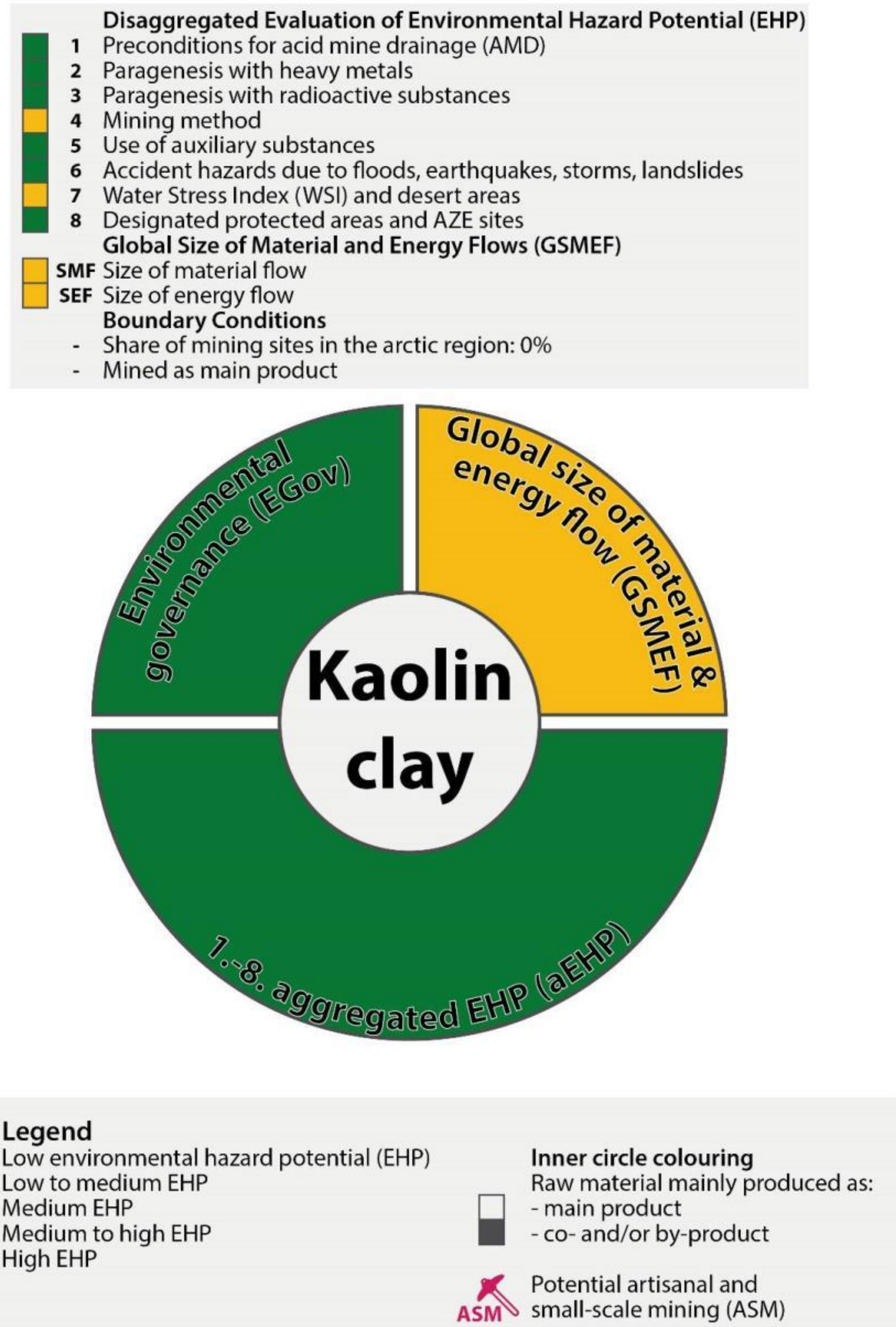
Chromium is a lithophilic element and occurs in nature as chromite, $FeIICr_2O_4$, which forms deposits. It is formed from basic magma as a crystallization differential or segregation from liquid magma. Magnetite and basic silicate minerals are associated paragenetically. Due to their hardness, soap deposits are less likely to form, although they reach dimensions that are hardly economically viable.

4.10.2 Profile Chromium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Chromium is usually present as lithophilic elements in oxidic deposits.	medium
Indicator 2: Paragenesis with heavy metals		
High EHP	The element chromium itself has toxic properties and is defined as a heavy metal in this method description.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	No specific data are available. In accordance with the procedure described in the method document, an evaluation with medium EHP is carried out.	low
Indicator 4: Mine Type		
Low EHP	underground engineering	low
Indicator 5: Use of auxiliary substances		
Medium EHP	heavy turbidity separation, gravimetry	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for chromium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 70 % low, 5 % medium, 25 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for chromium range in the high quantile area > 75 %, quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 32 % low, 1 % medium, 67 % high EHP.	medium

Environmental hazard potential	Explanation	Data quality
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for chromium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 95 % low, 4 % medium, 1 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 49.22. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 659 million t/a results from the $CRD_{specific}$ of 22 t/t and the global annual production of 30,016,976 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 1,207 PJ/a results from the $CED_{specific}$ of 40,200 MJ-eq/t and the global annual production of 30,016,976 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Low	The results for chromium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP.	medium

4.11 Clay (Kaolin and kaolinitic clay)



4.11.1 General Information

Introduction and characteristics

Clay is a finely-grained natural rock or soil material that combines one or more clay minerals with possible traces of quartz (SiO_2), metal oxides (Al_2O_3, MgO etc.) and organic matter. Geologic clay deposits are mostly composed of phyllosilicate minerals containing variable amounts of water trapped in the mineral structure. Clays are plastic due to particle size and geometry as well as water content, and become hard, brittle and non–plastic upon drying or firing. Depending on the soil's content in which it is found, clay can appear in various colours from white to dull grey or brown to deep orange-red. (European Commission 2014)

Applications

In Europe the most important fields of applications are the ceramic industry (61 % of total kaolin and clay consumption), the paper industry (16 %) used both as a filler and as a coating pigment and for the production of fibre glasses (5 %). Other uses (18 %) are in paints, rubber, plastics, refractory industries and cosmetics/pharmaceuticals. (European Commission 2014)

Recycling

Recycling rates of kaolin are not significant since the ceramic manufacturing process destroys the mineralogy and plastic properties of kaolin and kaolinitic material, recycling is not possible. However, recycling could be considered to be done indirectly through the recycling of paper or tiles and bricks which allows some of the mineral components to be recovered. (European Commission 2014)

Substitution

In the paper industry ground calcium carbonate is used as a substitute for kaolin. As the plate-structure of kaolin is highly desired for many paper applications, substitution by calcium carbonate may not always be feasible (European Commission 2014).

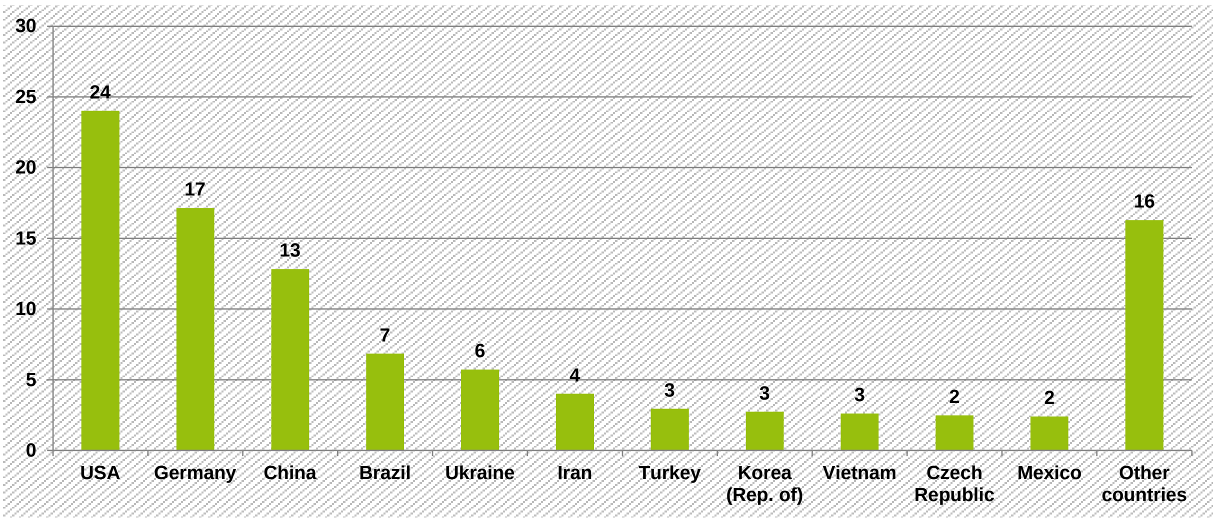
Main product, co-product or by-product

Clay is a main product (European Commission 2014).

Primary production

Total global production: 24,946,394 tonnes in 2014 (BGS 2016).

Percentage of clay mines mined in 2014 (%) (BGS 2016)



Information on Deposits

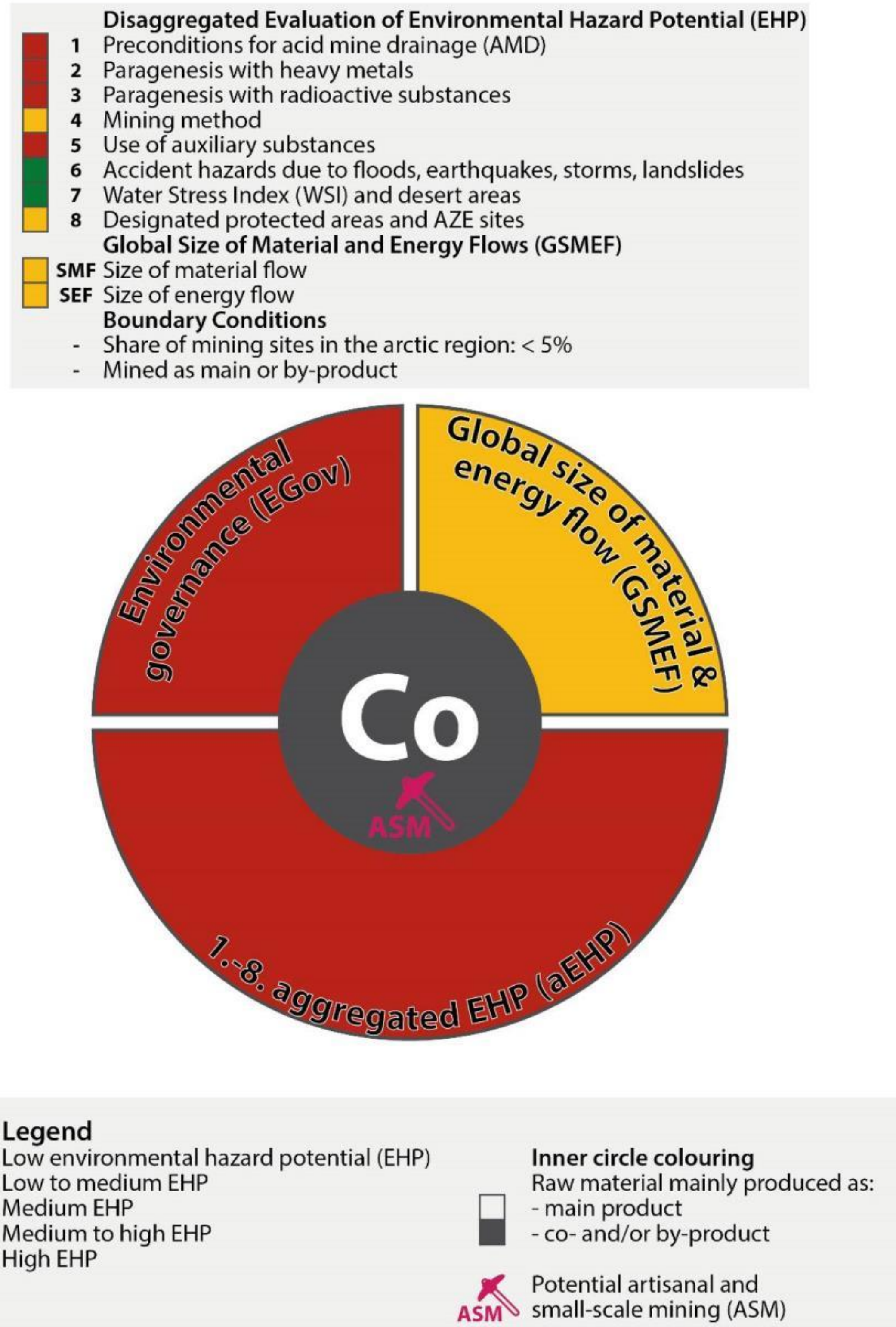
Kaolin is chemically an aluminium hydroxysilicate and is formed as a product of weathering of feldspars (from granite and nepheline syenite rocks) on the mainland mainly in temperate climates.

4.11.2 Profile Clay

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Inert material without components that tend to autooxidise.	medium
Indicator 2: Paragenesis with heavy metals		
Low EHP	Kaolin deposits are weathered products of feldspars and therefore predominantly free of heavy metals.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Due to their crystalline structure, clays may have increased concentrations of U and Th. However, measurements on various kaolinite samples have shown that the activity concentrations are generally low.	medium
Indicator 4: Mine Type		
Medium EHP	Surface mining	high
Indicator 5: Use of auxiliary substances		
Low EHP	Selective extraction, hydrocyclonation for finest kaolins	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for clay range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 70 % low, 20 % medium, 10 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for clay range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 80 % low, 1 % medium, 19 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for clay range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 64.82.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 118 million t/a results from the $CRD_{specific}$ of 4.7 t/t and the global annual production of 24,946,394 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of82 PJ/a results from the $CED_{specific}$ of 3,282 MJ-eq/t and the global annual production of 24,946,394 t/a.	high

Indicator 12: Position of mining sites in the arctic region		
Low	The results for clay range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP	medium

4.12 Cobalt



4.12.1 General Information

Introduction and characteristics

Cobalt is a silvery-blue, hard and brittle metal with the atomic number 27. Since it is ferromagnetic it can be magnetized keeping its magnetic properties at high temperatures. Low levels of cobalt are essential to human health since it is an important part of the vitamin B12. However, exposure to high levels of cobalt can be toxic (European Commission 2017b, JRC 2018).

Applications

Cobalt is either used as metal or cobalt-bearing chemical. With the increasing demand of electric vehicles and portables, the main end-use of cobalt is the application as cathode material in batteries, in particular lithium-ion batteries. The other main application is superalloys, where cobalt adds corrosion resistance at high temperatures to the material. These properties are often required in cutting tools. Other applications include carbides, catalysts, pigments and ceramics and magnets (European Commission 2017b).

Recycling

Cobalt containing post-consumer waste can be collected and recycled. In the case of alloys cobalt containing alloys are predominantly recycled into stainless steel not recovering the cobalt content. Separately collected parts that are cast from certified content alloys such as aero-engines can be recast. Spent batteries can be well recycled and the cobalt can be recovered and used in other applications. The end of life recycling rate for cobalt is estimated to be 68 %. The end of life recycling input rate is 0 % (European Commission 2017b, JRC 2018).

Substitution

Battery applications have a wide variety of chemistries and could therefore be considered substitutes. However cobalt shows performance enhancing properties and is therefore very often used in li-ion batteries. Currently cell manufactures are aiming at a reduction of cobalt to decrease the costs. In superalloys other alloying elements could be used at the cost of performance. Ruthenium could provide similar properties but is impractical due to significantly higher costs (European Commission 2017b).

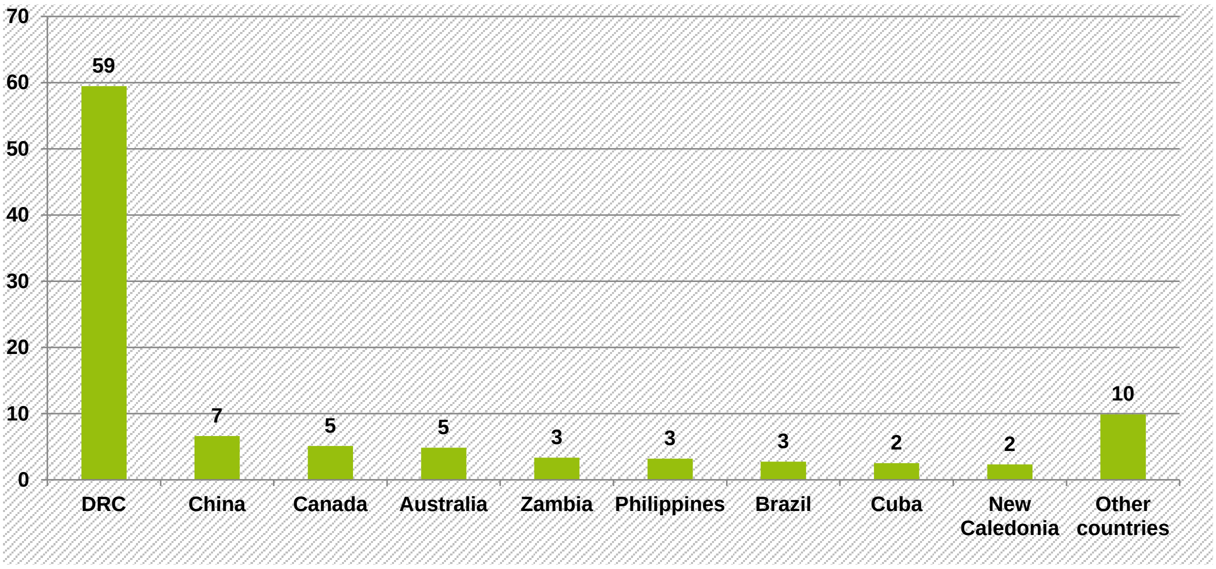
Main product, co-product or by-product

Cobalt is mostly a by-product of copper and nickel mining. Cobalt produced as the main product only has a minor share (Nassar et al. 2015).

Primary production

Total global production: 128,646 tonnes in 2014 (BGS 2016).

Percentage of cobalt mines mined in 2014 (%) (BGS 2016)



ASM relevance

Global cobalt production share of ASM is according to BGR 30 % and to GEUS (2007) (SSM) 10 %.

Cobalt is a resource, which is in some countries target of ASM, especially in DRC. Here the numbers on the production share vary between 35 and 90 % of the national production. The ASM is focusing on the oxidation zone of cobalt-nickel deposits, the so called cobalt caps, where the main ore mineral is heterogenite, a cobalt hydroxide (similar to the iron hydroxide limonite). As well veins and eluvial, colluvial and alluvial cobalt mineral enrichments are targeted by artisanal miners. The minerals are gravimetrically concentrated. ASM on cobalt may have an enormous importance for livelihood and local economies.

The Certified Trade Chain Instrument, that has been made obligatory for the 3TG minerals from ASM production in DRC is currently been expanded towards the cobalt sector in this country. Internationally the Cobalt Industry Responsible Assessment Framework is currently been established (Ames/Schurath 2018, BGR 2017a, Cobalt Institut 2019, Vetter 2018).

Important cobalt producing countries with prominent ASM production are Congo, China, Zambia, Philippines, Brazil and Madagascar. 84 % of cobalt is produced in countries with ASM.

Information on Deposits

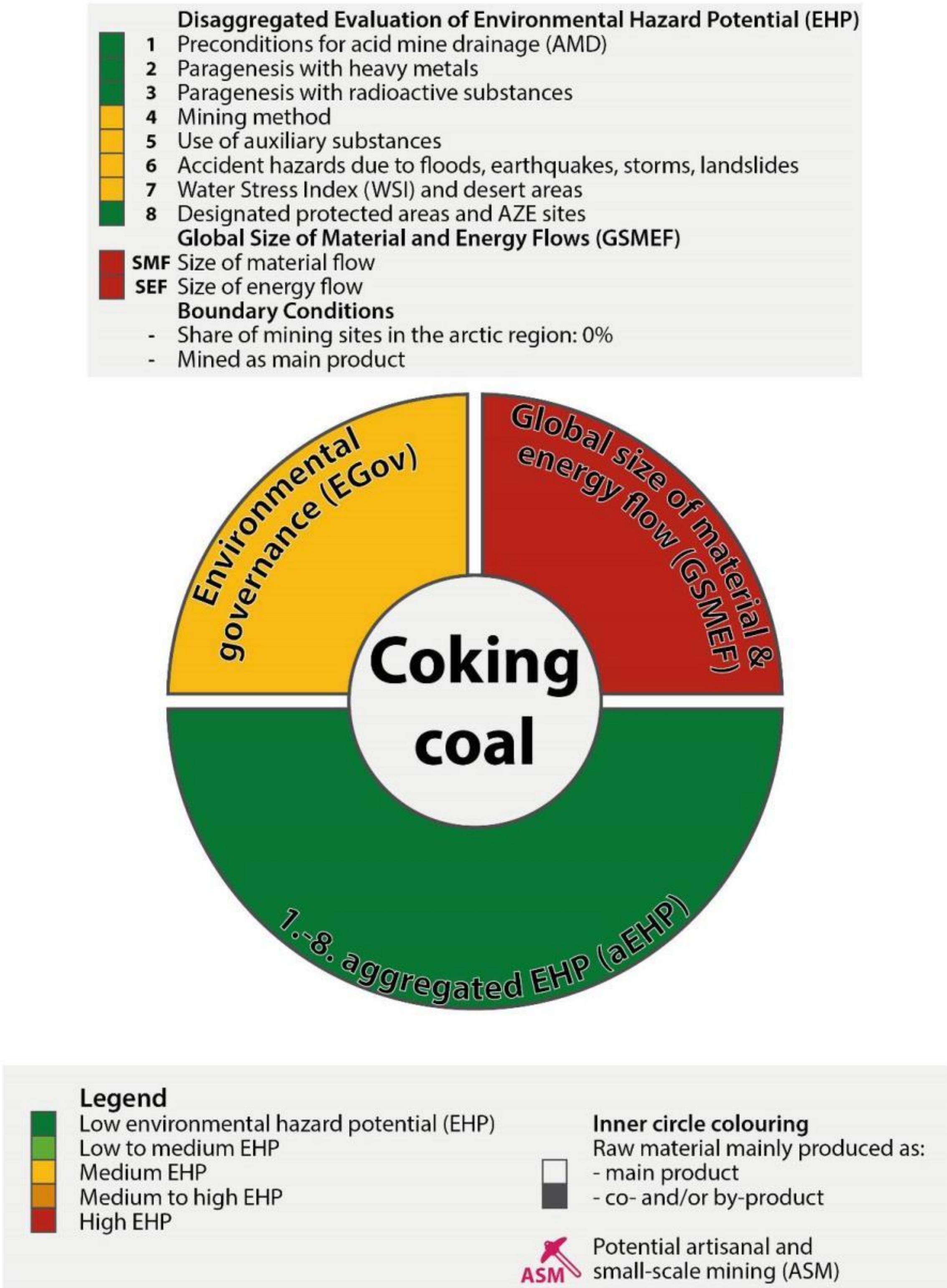
Cobalt is a siderophilic element and is closely associated with nickel in nature. It is formed as a segregation of basic and ultrabasic magmas, as a hydrothermal formation in the cobalt-nickel-silver-bismuth-uranium group (with copper ores), and as a weathering deposit (nickel-cobalt-laterite) with secondary cobalt minerals. Finally, the cobalt content of the manganese nodules on the seabed attracts interest. The most important ore mineral is the cobaltite luster, cobaltite, CoAsS. In addition to the elements mentioned above, it is often associated with copper.

4.12.2 Profile Cobalt

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Nickel and cobalt ores are in most cases present in the form of sulphidic iron-nickel-cobalt minerals (e.g. nickel magnetic gravel).	high

Environmental hazard potential	Explanation	Data quality
Indicator 2: Paragenesis with heavy metals		
High EHP	Cobalt is mainly extracted from nickel and copper ores. Both nickel and copper are considered heavy metals according to the method description.	medium
Indicator 3: Paragenesis with radioactive substances		
High EHP	Copper-cobalt deposits in the DR Congo and Arizona (USA) show high concentrations of uranium and/or thorium. A large part of world cobalt production comes from deposits in the DR Congo.	high
Indicator 4: Mine Type		
Medium EHP	Surface mining, underground mining	high
Indicator 5: Use of auxiliary substances		
High EHP	Cobalt-nickel-sulphide ores are processed by flotation to cobalt-nickel concentrates, followed by arc melting and hydrometallurgical separation of the metals; copper-cobalt ores if necessary roasting of the sulphides and acid leaching; weathered copper-cobalt ores are leached with sulphuric acid; in the case of laterite ores the digestion is carried out with acids (here too the question arises as to the boundary between processing and smelting).	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for cobalt range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 87 % low, 4 % medium, 9 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Low EHP	The results for cobalt range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 93 % low, 0 % medium, 7 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for cobalt range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 93 % low, 6 % medium, 1 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 41.68. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 7.3 million t/a results from the $CRD_{specific}$ of 57 t/t and the global annual production of 128,648 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 16,5 PJ/a results from the $CED_{specific}$ of 128,000 MJ-eq/t and the global annual production of 128,648 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for cobalt range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium EHP.	medium

4.13 Coking coal



4.13.1 General Information

Introduction and characteristics

Coal is carbon rich black to brownish rock consisting of fossil plants, minerals and water. Coking coal is a bituminous coal containing more carbon and less moisture and ash compared to lower ranked coals (JRC 2018).

Applications

The main use of coking coal is in steel production. The coking coal serves as a reduction medium of iron oxides and as fuel in blast furnaces. A variety of materials can be produced from the gases and vapors recovered in coke ovens e.g. Crude tar, crude light oil, ammonia, and coke oven gas (JRC 2018).

Recycling

Since coking coal dissipates after its use recycling is not applicable (JRC 2018).

Substitution

Currently there is no satisfactory material available to replace coking coal in steelmaking (European Commission 2017a), there is large scale industry research on alternative reduction mediums such as hydrogen generated from renewable energies (see for example Deutschlandfunk 2018).

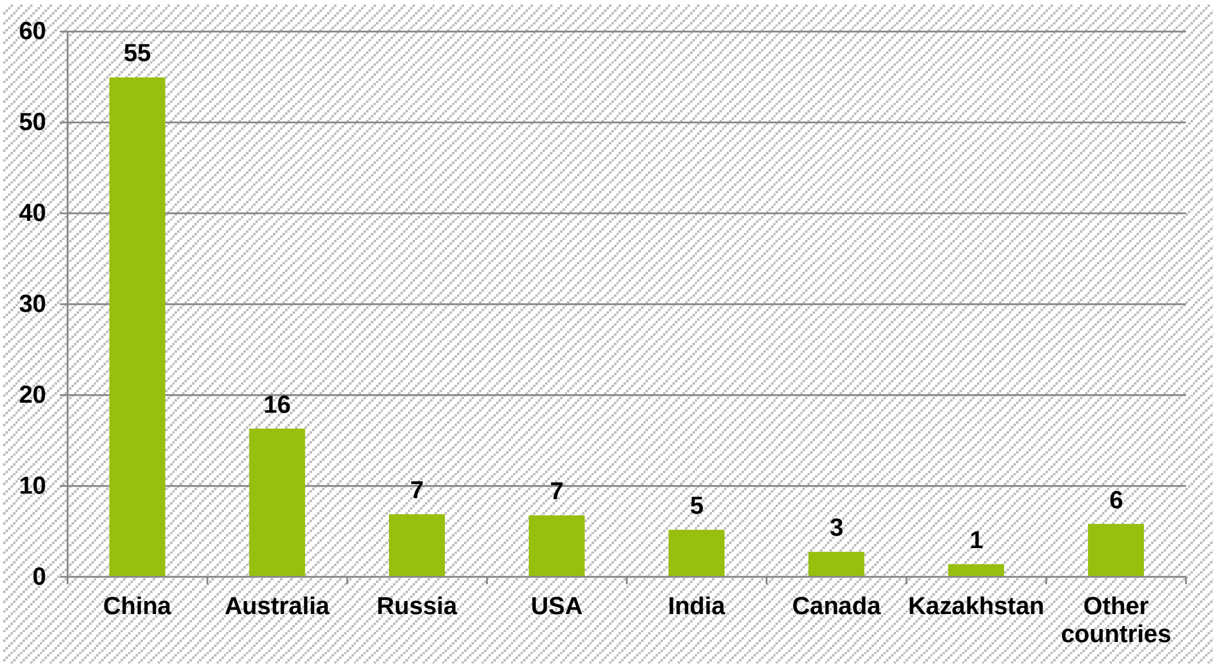
Main product, co-product or by-product

Coking coal is a main product (European Commission 2017a)

Primary production

Total global production: 1,109,406,245 tonnes in 2014 (Reichl et al. 2016).

Percentage of coking coal mines mined in 2014 (%) (Reichl et al. 2016)



Information on Deposits

Coking coal is a hard coal with special contents of volatile components and ashes and, like all hard coal, was formed by the coalification (under exclusion of air and pressure) of biomass in

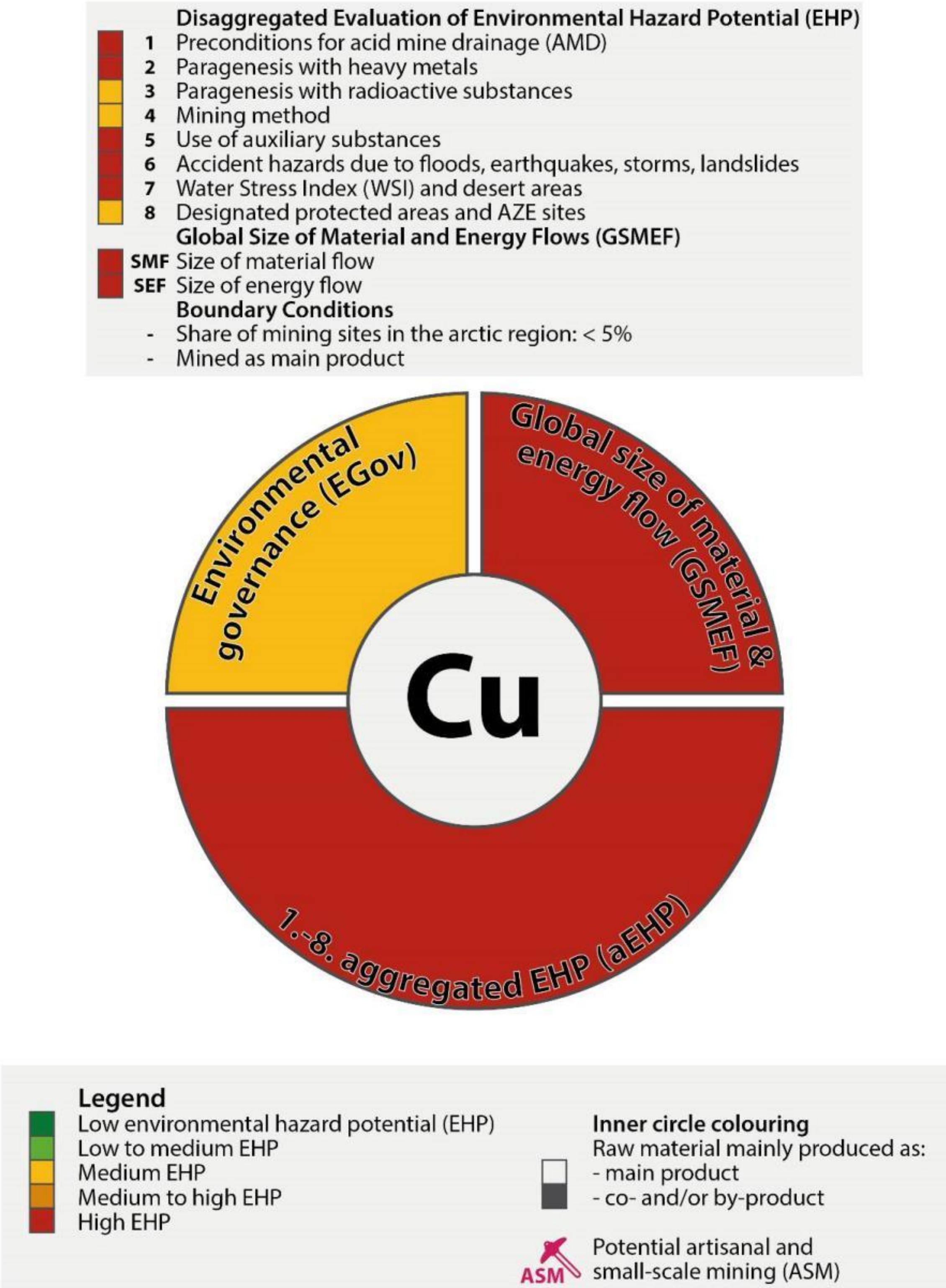
Perm and Karbo. Accordingly, coal is found in seams in claystones and slates as well as other sediments.

4.13.2 Profile Coking coal

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Only in exceptional cases is accessory pyrite found in the surrounding rock of coal deposits. This is only assumed to have a low acid formation potential..	low
Indicator 2: Paragenesis with heavy metals		
Low EHP	Coal is always associated with traces of various heavy metals, which can have considerable environmental consequences when large quantities of coal are converted into electricity. The relevant parameter for this assessment is the heavy metal concentration in the raw material / deposit itself (before combustion). Here data show that mercury concentrations in particular can reach levels that would exclude the use of the substrate for agricultural purposes according to the Federal Soil Protection Act. In most cases, however, the corresponding values remain below the corresponding threshold of 0.5ppm (Rentz & Martel 1998).	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Data from Chinese coal deposits' dyke rock suggests that many deposits have slightly elevated uranium and/or Th concentrations. However, data from WNA show that a majority of coal deposits have U and Th concentrations suggesting a low EHP rating.	medium
Indicator 4: Mine Type		
Medium EHP	Surface and underground mining	high
Indicator 5: Use of auxiliary substances		
Medium EHP	Gravimetry, flotation, cyclones, blast furnace	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for coking coal range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 28 % low, 45 % medium, 27 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for coking coal range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 43 % low, 12 % medium, 45 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for coking coal range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 56.94.	high

Environmental hazard potential	Explanation	Data quality
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 1,784 million t/a results from the $CRD_{specific}$ of 1.6 t/t and the global annual production of 1,109,406,245 t/a.	low
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 32,550 PJ/a results from the $CED_{specific}$ of 29,340 MJ-eq/t and the global annual production of 1,109,406,245 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Low	The results for coking coal range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP	medium

4.14 Copper


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 5%
- Mined as main product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Cu
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.14.1 General Information

Introduction and characteristics

Copper (Cu) is a metal with the atomic number 29. It is a ductile, reddish metal that occurs in over 150 identified copper minerals, but only around ten of them are of economic importance. It is moderately present in the upper earth crust (28 ppm). Copper has a very high thermal and electrical conductivity in combination with ductility and corrosion resistance. It is used as pure metal as well as in form of its two common alloys: brass and bronze. (European Commission 2017b)

Applications

The field of application for copper is very wide. Due to its high electrical conductivity, corrosion resistance and ductility, its main application is in all types of wiring (among others electric energy supply from the power plant to the wall socket, motor windings for electrical motors, connectors in computers). Because of its thermal conductivity it is also used in heat exchangers and radiators. It is also used in in buildings as wiring, pipes and fittings, electrical outlets, switches and locks as well as for roofing. Its alloys, mainly brass and bronze, are important raw materials for many kinds of mechanical parts (e.g. sleeve bearings and other forged parts). (European Commission 2017b)

Recycling

End of life recycling input rate for copper is estimated to be 55 % where most of the input originates from new or old primary scrap (not being end-of-life scrap). Since most copper is used in its metallic form or in copper alloys, nearly all copper products can be recycled over and over again. (European Commission 2017b)

Substitution

Because of its unique properties, copper is hard to substitute. In electric applications, aluminium can replace copper wiring. In telecommunication copper wires could be replaced by cables made from optical fibres. Pipes and plumping fixtures plastic can be used for copper. For heat exchangers, titanium, stainless steel, aluminium or plastics can substitute for copper. (European Commission 2017b)

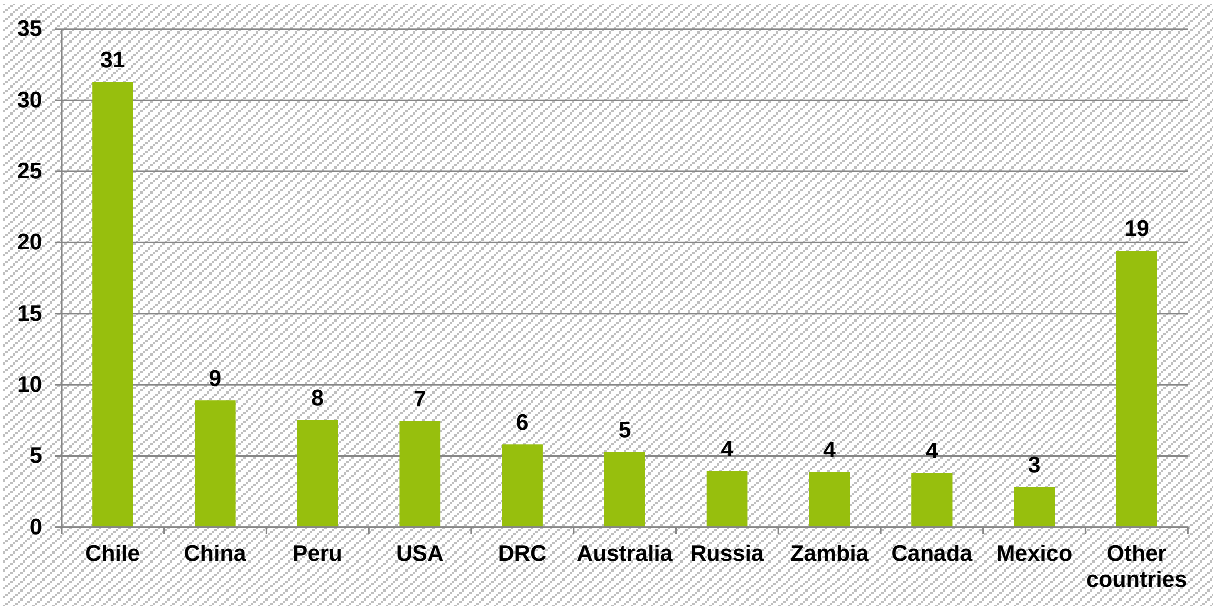
Main product, co-product or by-product

Copper is a main product (European Commission 2017b).

Primary production

Total global production 2014: 18,380,682 tonnes (BGS 2016).

Percentage of copper mines mined in 2014 (%) (BGS 2016)



Information on Deposits

Copper can be found in nature in a variety of deposits in a wide variety of educational conditions. The economically most important ore minerals are the copper luster (chalcosine), brochantite, copper pyrites (chalcopyrite), coloured copper pyrites (boronite), the sulfosalts tetraedrite and tennis ore (pale ore), as well as the weathering minerals chrysocolla, azurite and malachite, cuprite and solid copper. Of economic importance are the porphyry copper deposits, as well as hydrothermal (plutonic and sub-volcanic) deposits, submarine sedimentary formations and weathering deposits in arid regions. The subsequent enrichment of poor ores by chemical weathering has often led to the formation of building worthy contents in the cementation zones. Copper minerals are often associated with arsenic and antimony minerals.

4.14.2 Profile Copper

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	According to the Goldschmidt classification, copper is a chalkophilic element (sulfur-loving) and is mostly sulfidic. Today, 85 % sulphide ores are mined, only 15 % oxide ores.	high
Indicator 2: Paragenesis with heavy metals		
High EHP	The element copper itself has toxic properties and is defined as a heavy metal in the present method description.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Data from Chinese Cu deposits show low exposure to U and Th. Chinese deposits currently account for 8.9 % of world production (Hua 2011). Partially elevated concentrations in Arizona (EPA 1999), high U concentrations in some deposits in the copper belt of the DR Congo (Arno et al. 2010).	medium
Indicator 4: Mine Type		
Medium EHP	The standard Mine Type for copper is solid rock opencast mining from massive ores, e.g. in the subduction zones along the "ring of fire" (copper porphyries). Solid rock surface mining is assigned an average EHP according to the method description. According to Tudeshki, 75 % open pit mining, 25 % underground mining.	high

Environmental hazard potential	Explanation	Data quality
Indicator 5: Use of auxiliary substances		
High EHP	The standard treatment method is flotation with solvent extraction (sulphuric acid). A high EHP is assigned to the use of toxic excipients. Flotation, solvent extraction, (1) In case of high ore content, >6 % direct melt; (2) Flotation and subsequent electrolysis; (3) Concentration, roasting, flame furnace (Taggart 1953): 2-28) "roasting, smelting, converting, refining and electrorefining" (European Commission (2014): 197) Bioleaching during tailings pile preparation (Neale (2006): 1).	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	The results for copper range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 33 % low, 14 % medium, 53 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for copper range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 42 % low, 1 % medium, 57 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for copper range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 96 % low, 2 % medium, 2 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 57.95.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 2,354 million t/a results from the $CRD_{specific}$ of 128 t/t and the global annual production of 18,380,682 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 987 PJ/a results from the $CED_{specific}$ of 53,700 MJ-eq/t and the global annual production of 18,380,682 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for copper range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium EHP.	medium
Consolidation of the individual results		

4.15 Diatomite

4.15.1 General Information

Introduction and characteristics

Diatomite (synonyms are tripolite and kieselguhr) is a powdery, siliceous, sedimentary rock. It is of very low density, extremely porous and chemically inert. Since it is created from many different fossilized species, at least 15,000-20,000 different forms of diatoms exist. There are many diatomite deposits throughout the world, but those of high-purity which are commercially viable are rare. With its outstanding filtration properties, and low thermal and acoustic conductivity, it is a very versatile raw material. (European Commission 2017a)

Applications

Diatomite has a wide range of applications. It is used for filter aids (for beverages, wastewater and paints), as absorbents (in gas purification, pet litter), clean-up of spills in different industries, in the production of explosives or seed coating, as functional filler in a variety of products from paints to dry chemicals and in cosmetics. (European Commission 2017a)

Recycling

End of life recycling input rate for diatomite is estimated to be 0 %. (European Commission 2017a)

Substitution

Diatomite can be substituted in nearly all applications. Expanded perlite, silica sands and synthetic filters can replace diatomite as filter aid. Cellulose or potato starch substitute it in the beverage industry, as well as other filter methods such as mechanical centrifuging. Possible substitutes for the filler applications are kaolin clay, Ground Calcium Carbonate (GCC), ground mica, perlite or talc. (European Commission 2017a)

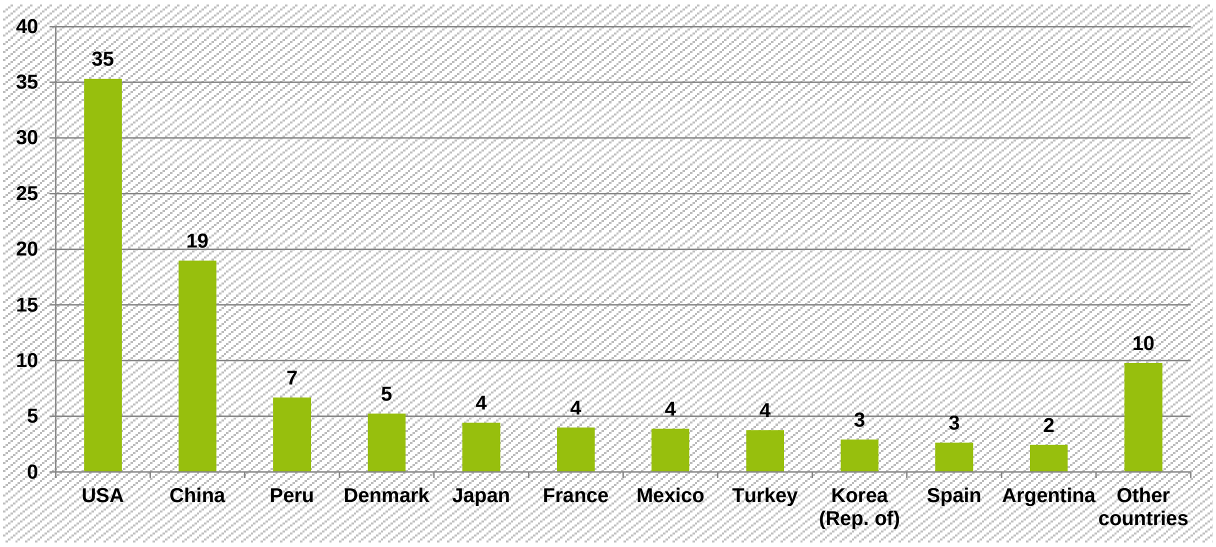
Main product, co-product or by-product

Diatomite is a main product (European Commission 2017a).

Primary production

Total global production: 2,265,044 tonnes in 2014 (BGS 2016).

Percentage of diatomite mines mined in 2014 (%) (BGS 2016)



Information on Deposits

Diatomite is a sedimentary rock from fossil diatom skeletons (diatom algae). According to the sedimentary genesis, diatomite is usually present near the surface as loose rock.

4.15.2 Profile Diatomite

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	inert material without sulfidic companions	high
Indicator 2: Paragenesis with heavy metals		
Low EHP	Diatomite is an abiotic non-metallic raw material. According to the recommendations in the method document, an assessment with a low EHP was carried out.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	As a biogenic marine sediment, diatomite is mostly free of radioactive companions.	high
Indicator 4: Mine Type		
Medium EHP	surface mining	medium
Indicator 5: Use of auxiliary substances		
Medium EHP	Drying Special process for high degrees of purity: digestion with acid, calcination, leaching	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
N/A	Information not available due to data restrictions	N/A
Indicator 7: Water Stress Index and desert areas		
N/A	Information not available due to data restrictions	N/A
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
N/A	Information not available due to data restrictions	N/A
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-sore of 66.14.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 5.2 million t/a results from the $CRD_{specific}$ of 2.3 t/t and the global annual production of 2,265,044 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 14 PJ/a results from the $CED_{specific}$ of 6,214 MJ-eq/t and the global annual production of 2,265,044 t/a.	low
Indicator 12: Position of mining sites in the arctic region		
N/A	Information not available due to data restrictions	N/A

4.16 Feldspar

4.16.1 General Information

Introduction and characteristics

Feldspar is a group of non-metallic minerals which are by far most common in the Earth's crust, forming about 60 % of terrestrial rocks. Only a part of feldspar is suitable for industrial use. Most feldspars have the mineralogical composition $AlSi_3O_8$, $NaAlSi_3O_8$ or $CaAl_2Si_2O_8$. (European Commission 2017a)

Applications

Feldspar is used as fluxing agents in ceramics (36 %) and for container and flat glass (60 %), and also as functional fillers and extender in the paint, plastic, rubber and adhesive industries. Other uses are in mild abrasives, urethane, welding electrodes in the production of steel, latex foam and road aggregate. (European Commission 2017a)

Recycling

Producers of feldspar containing products don't use recycled feldspar. Recycling could be considered to be done indirectly through the recycling of glass and ceramic which allows some of the mineral components to be recovered. But to achieve optimal recycling, it is important to separate glass containers from other kinds of glass such as windows. The end-of-life recycling input rate is set at 10 %. (European Commission 2017a)

Substitution

The possible substitutes for feldspar depend on its end-use. In the ceramic and glass industry feldspar can be substituted by nepheline (a silica-under saturated aluminosilicate). Borates can be used in glass industry but not as substitute. This fact has been used to apply substitution options for the use of feldspar, resulting in a lower supply risk related to the substitution rate. In the US nepheline syenite is used as a substitute. It can also be replaced byclays, electric furnace slag, feldspar-silica mixtures, pyrophyllite, spodumene or talc. (European Commission 2017a)

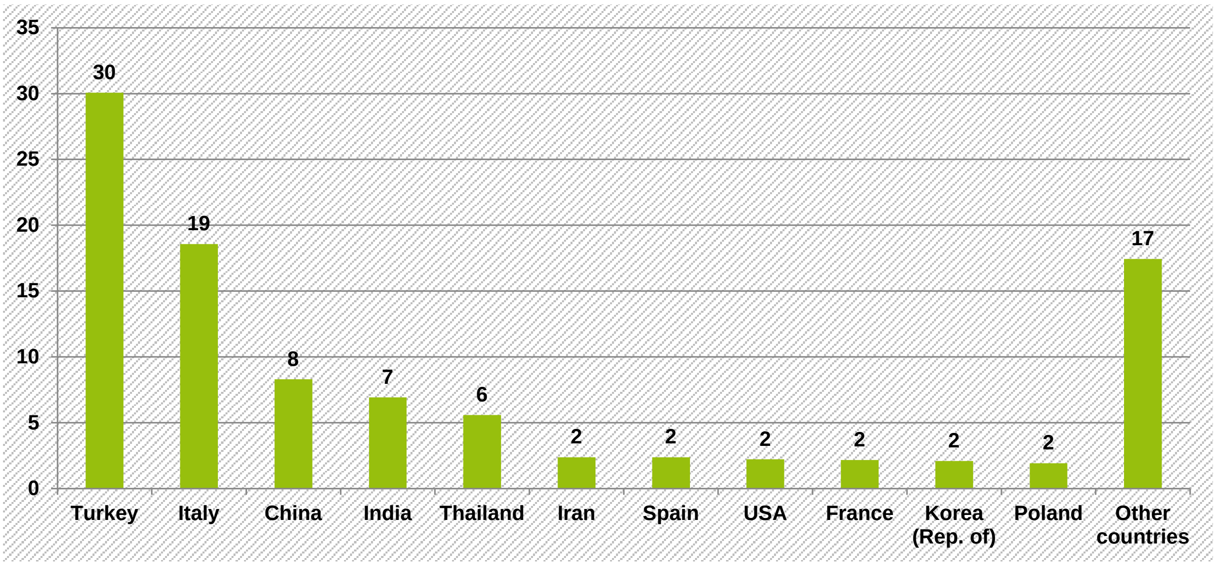
Main product, co-product or by-product

Feldspar is a main product (European Commission 2017a).

Primary production

Total global production: 25,312,685 tonnes in 2014 (BGS 2016).

Percentage of feldspar mines mined in 2014 (%) (BGS 2016)



ASM relevance

GEUS (2007) estimates the global feldspar production of SSM as 80 % of the total production. This is due to small dimensions of the deposits (mostly pegmatites) and separation by handpicking.

Important feldspar producing countries with prominent ASM production are China and India.

20 % of feldspar is produced in countries with ASM.

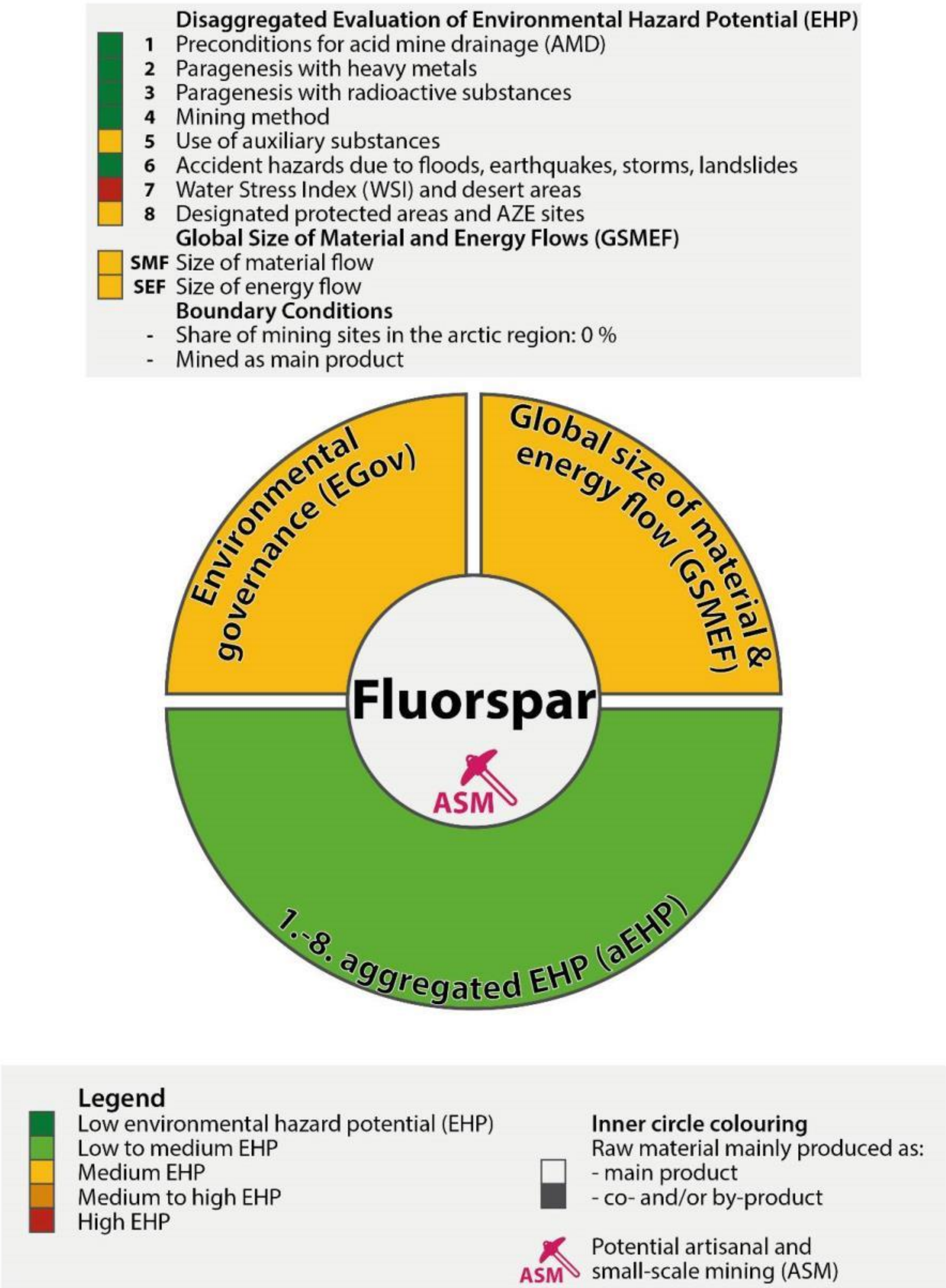
Information on Deposits

Feldspars are alkali and alkaline earth silicates and are among the most common minerals in the earth's crust. They are usually extracted economically from pegmatite deposits, where they occur as large crystals that can be hand-picked in order to maintain the corresponding product qualities.

4.16.2 Profile Feldspar

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Sulfide-free parageneses from pegmatites	medium
Indicator 2: Paragenesis with heavy metals		
Low EHP	Is obtained from pegmatitic deposits which are predominantly free of heavy metals.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Feldspars often contain elevated concentrations of K40, which is mostly insignificant from a radiological point of view. However, feldspar deposits can also contain U- and Th-containing companions due to the conditions of formation in the pegmatites.	medium
Indicator 4: Mine Type		
Medium EHP	Surface mining, underground mining	medium
Indicator 5: Use of auxiliary substances		
Medium EHP	Foam flotation	low
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
N/A	Information not available due to data restrictions	N/A
Indicator 7: Water Stress Index and desert areas		
N/A	Information not available due to data restrictions	N/A
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
N/A	Information not available due to data restrictions	N/A
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 59.29. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 31 million t/a results from the $CRD_{specific}$ of 1.2 t/t and the global annual production of 25,312,685 t/a.	medium
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 15 PJ/a results from the $CED_{specific}$ of 606 MJ-eq/t and the global annual production of 25,312,685 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
N/A	Information not available due to data restrictions	N/A

4.17 Fluorspar



4.17.1 General Information

Introduction and characteristics

Fluorspar (commercial name for fluorite) is the mineral form of calcium fluoride, CaF_2. It is a colourful, widely occurring mineral that occurs globally with significant deposits in over 9,000 areas. Most fluorspar occurs as vein filling in rocks exposed to hydrothermal activity. Fluorspar is usually produced in a fluorspar acid grade (97 % CaF_2 content) and metallurgical grade (84 % CaF_2 content). (European Commission 2017b)

Applications

Fluoraspar is mainly used as metspar in the iron and steel making (33 %), in aluminium making and other metallurgy (14 %), in refrigeration, air conditioning and heat-pumps (17 %) and as fluorchemicals e.g. in the pharmaceuticals and agrochemicals industry (9 %). It is also used as solid fluoropolymers for cookware coating, cable insulation and membranes (10 %), as UF6 in nuclear uranium fuel (6 %) and as HF in alkylation process for oil refining (3 %). (European Commission 2017b)

Recycling

Fluorspar itself is not recyclable and usually ends up in landfill. Nevertheless, during uranium enrichment, stainless steel pickling and petroleum alkylation several thousand tons of synthetic fluorspar are recovered. During aluminium smelting HF and flourides are recovered. Almost 60-70 % of fluorochemicals are recycled in the air conditioning and refrigeration sector. (European Commission 2017b)

Substitution

There are currently activities to replace fluorine, which is especially used in the air conditioning and refrigeration sectors, with more environmentally friendly hydrocarbons such as propane. Alternatives for solid fluoropolymers could be plastics, stainless steel, ceramics or aluminium. In the iron and steel sector calcium aluminate or aluminum smelting dross could be alternatives. (European Commission 2017)

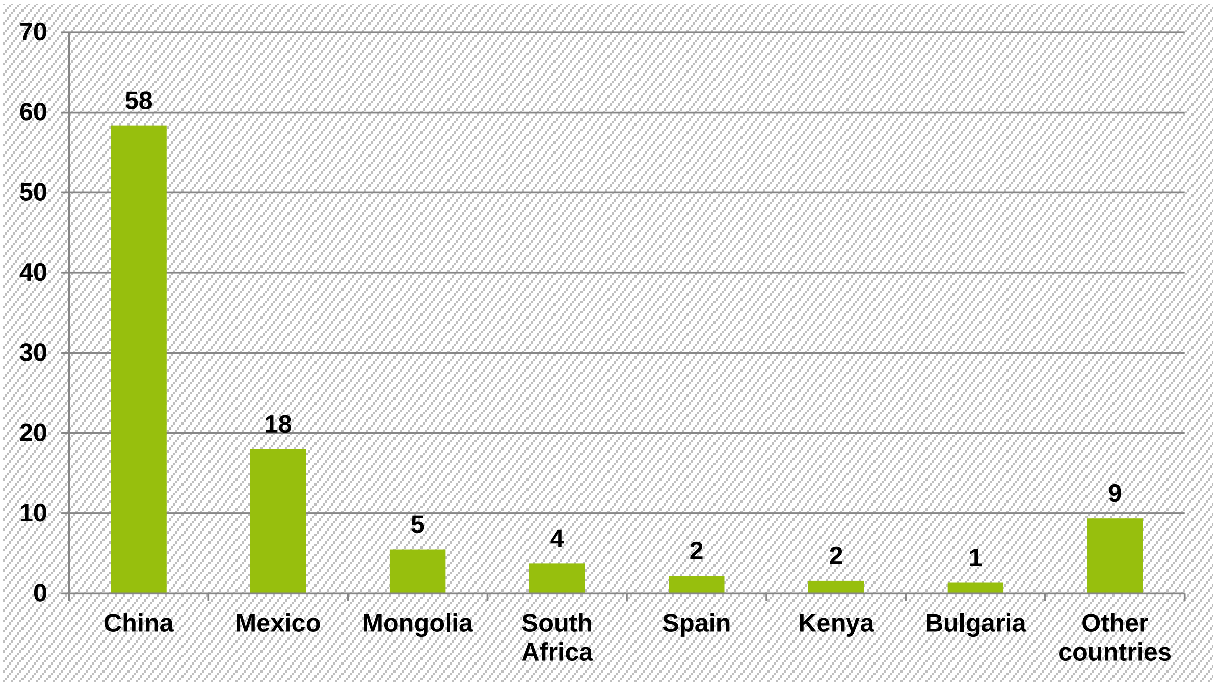
Main product, co-product or by-product

Fluorspar is a main product (European Commission 2017b).

Primary production

Total global production: 6,170,388 tonnes in 2014 (BGS 2016).

Percentage of fluorspar mines mined in 2014 (%) (BGS 2016)



ASM relevance

According to GEUS (2007) SSM contributes 90 % of the global production. Larger companies are collecting and marketing the product. A good example is the ASM community at Bor-Undur in Mongolia, where ASM is working in small underground mines for larger formal companies holding the mining title and marketing the product (see Baatar/Grayson 2009).

ASM typical processing method is handpicking (while formal industrialized mines besides handpicking use the flotation process).

Health problems die to fluorine exposure and occupational safety issues are the most serious governance challenges.

Important fluorspar producing countries with prominent ASM production are China, Mexico, Mongolia, South Africa and Kenya. 91 % of fluorspar is produced in countries with ASM.

Information on Deposits

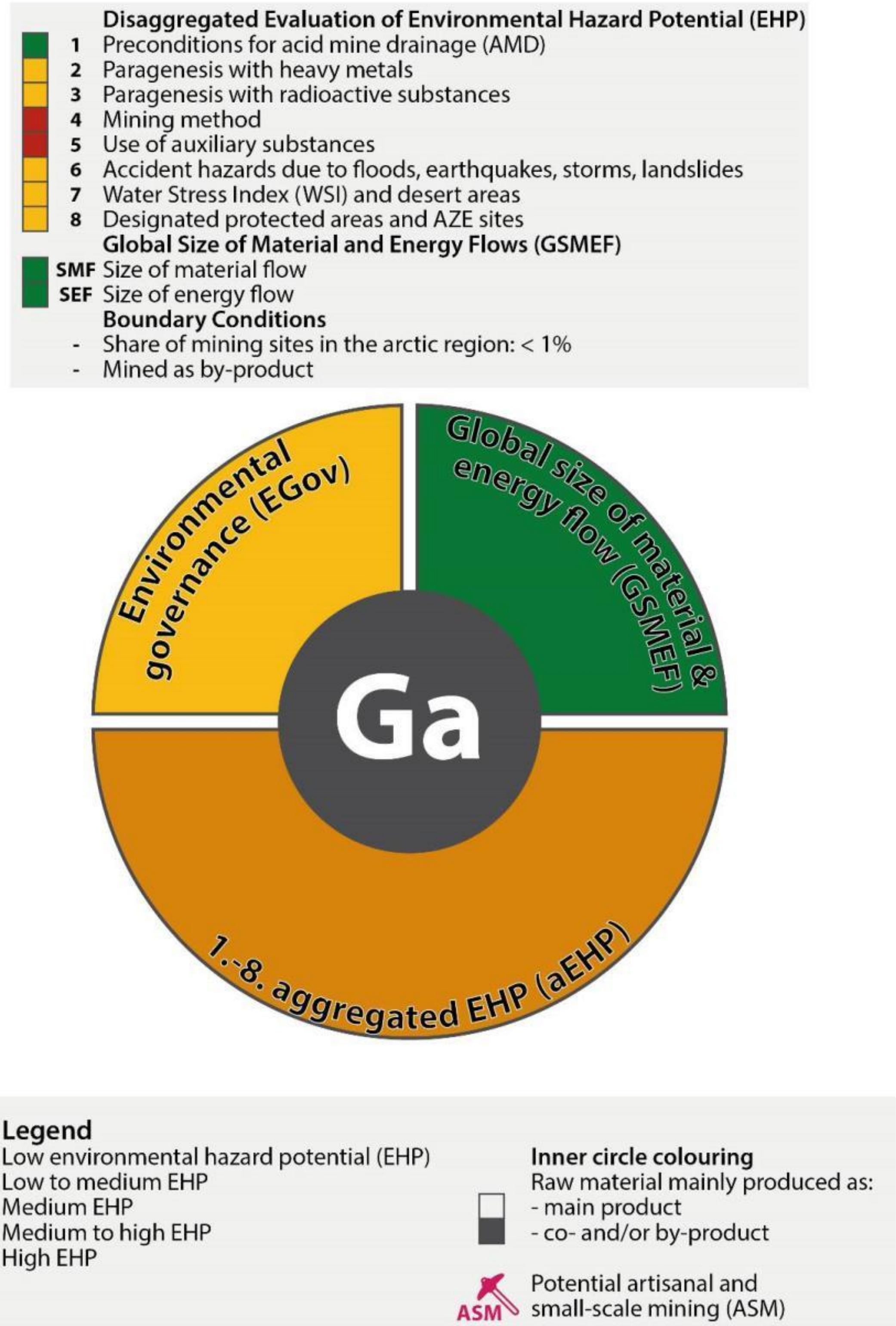
Fluorine is a lithophilic element and occurs geologically in many minerals, but is only mined from fluorspar, fluorite, CaF_2. This mineral is found in hydrothermal (deep-thermal) vein deposits.

4.17.2 Profile Fluorspar

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Inert raw material, extraction from deep-thermal vein deposits without sulfidic companions	medium
Indicator 2: Paragenesis with heavy metals		
Low EHP	Fluorspar itself is inert and is extracted from ore free hydrothermal ore deposits.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Data from fluorspar concentrates show low uranium concentrations in the range of natural background concentrations.	low

Environmental hazard potential	Explanation	Data quality
	According to the authors of the study, however, it cannot be excluded that deposits and processing residues have higher concentrations, which is confirmed by a general statement by Valkovic (2000), among others. The classification with a low EHP is therefore to be regarded as a borderline case.	
Indicator 4: Mine Type		
Low EHP	underground mining	low
Indicator 5: Use of auxiliary substances		
Medium EHP	laubing by hand, flotation, gravimetry	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for fluorspar range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 87 % low, 8 % medium, 4 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for fluorspar range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 12 % low, 3 % medium, 85 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for fluorspar range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 95 % low, 5 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 54.34. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 7.3 million t/a results from the $CRD_{specific}$ of 1.2 t/t and the global annual production 6,170,388 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 8.4 PJ/a results from the $CED_{specific}$ of 1,356 MJ-eq/t and the global annual production of 6,170,388 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Low	The results for fluorspar range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP.	medium

4.18 Gallium


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 1%
- Mined as by-product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Ga
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.18.1 General Information

Introduction and characteristics

Gallium is a silvery-white metal with symbol Ga and atomic number 31. It is a very good heat and electricity conductor, has a low melting point and is also magnetic. Its abundance in the upper continental crust is 17.5 ppm (similar to that of lead) but it does not occur in its elemental form and is currently almost exclusively extracted as a by-product of aluminium production (and a bit from zinc). (European Commission 2017b)

Applications

Currently, the greatest consumption of gallium is in semiconductors. 70 % of gallium consumption has been for Integrated Circuits (e.g. in cell phones), 25 % for lighting applications (mostly LED technology) and around 5 % in the Copper-Indium-Selenium-Gallium photovoltaic technology. Other applications include eutectic alloys, pharmaceutical compounds (gallium nitrate) or NdFeB magnets, which remain minor at the industrial level. (European Commission 2017b)

Recycling

The recovery rate of gallium from old products is almost 0 %. The current recycling processes of WEEE containing gallium tend to favour the recovery of precious metals or copper, while gallium ends up as a contaminant in recycled metals or waste slags. However, pre-consumer recycling is a consequent source of secondary supply for gallium. In the EU there are a few companies active in Gallium recycling, in particular in Germany and Slovakia. (European Commission 2017b)

Substitution

Silicon or silicon-based substrates are usually the main substitutes for gallium in semiconductors, albeit for a limited number of applications since silicon is significantly less efficient. Organic LEDs (OLEDs) could be a substitute for LEDs, but they are not yet competitive. In photovoltaics, crystalline silicon technologies currently account for more than 90 % of the market for terrestrial applications, although the conversion efficiency is reduced when silicon is used instead of CIGS. Other thin film technologies include cadmium telluride (CdTe) and copper indium selenide (CIS). (European Commission 2017b)

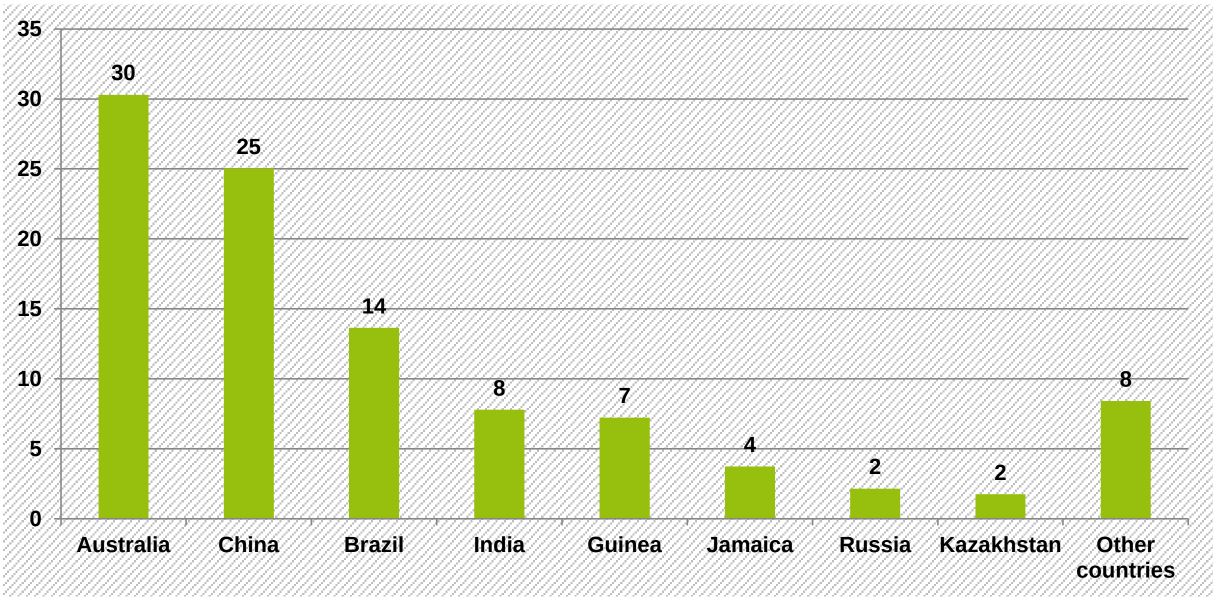
Main product, co-product or by-product

Gallium is a by-product extracted from bauxite and partly Zinc (European Commission 2017b).

Primary production

Total global production: 437 tonnes in 2014 (BGS 2016).

Percentage of gallium mines mined in 2014 (%) (BGS 2016)



Information on Deposits

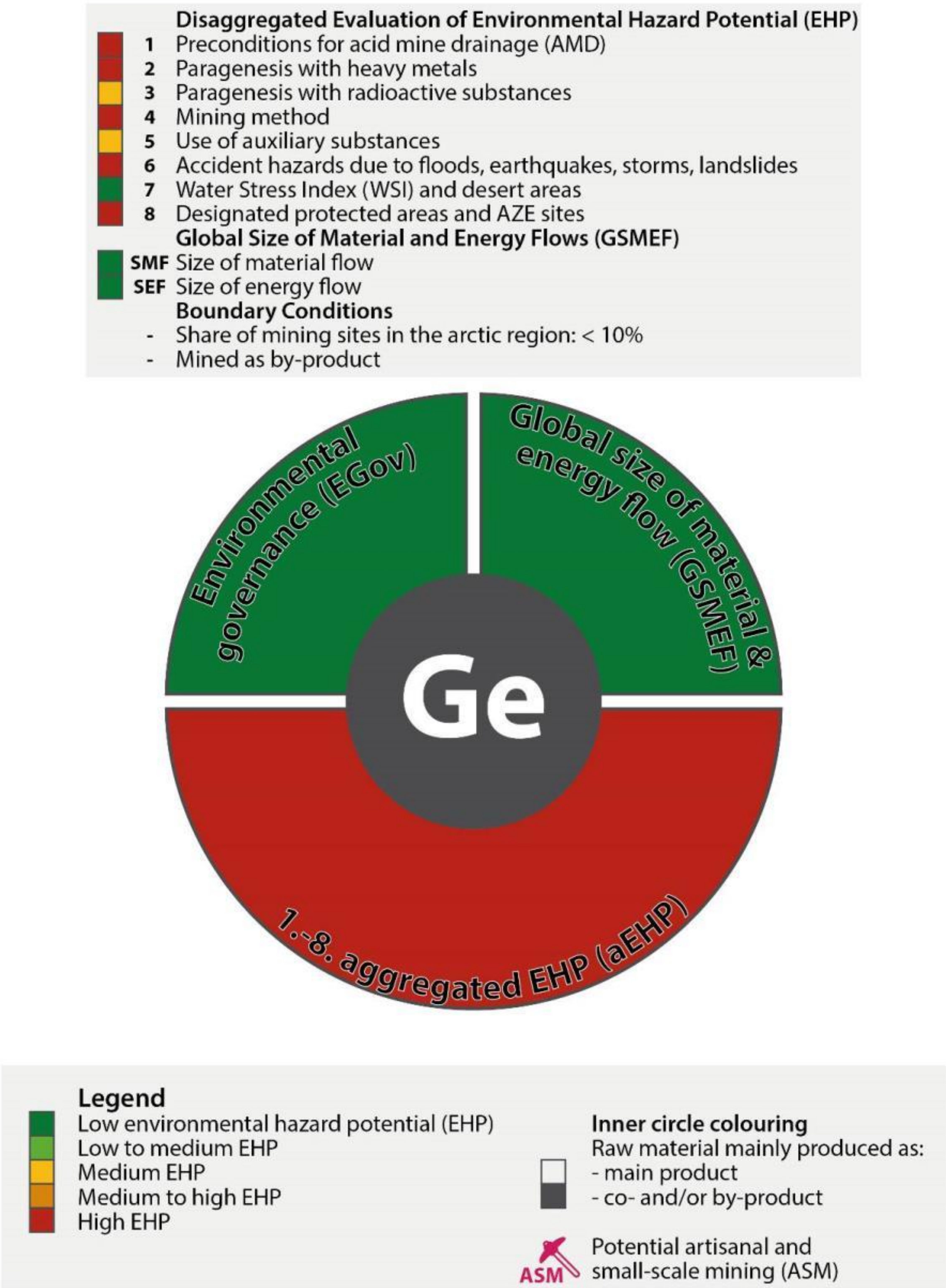
Gallium occurs as a trace element (not in own minerals) in bauxites and zinc ores and is only extracted from the corresponding intermediate products by metallurgy.

4.18.2 Profile Gallium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Gallium is extracted from bauxite (Al ore), an oxidic ore.	high
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Gallium is a by-product of bauxite and aluminium extraction. Accordingly, the assessment for Al and bauxite is also applicable to gallium.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Average data on Chinese bauxite deposits (16.3 % of world production) suggest that in many cases aluminium and gallium are associated with slightly elevated concentrations of uranium and/or thorium.	medium
Indicator 4: Mine Type		
High EHP	Bauxite is extracted from tropical weathering horizons that are stored near the surface and therefore require loose rock surface mining as a method of extraction.	high
Indicator 5: Use of auxiliary substances		
High EHP	Digestion using sodium hydroxide solution in the Bayer process.	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for gallium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 39 % low, 38 % medium, 23 % high EHP.	low
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for gallium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results	low

Environmental hazard potential	Explanation	Data quality
	for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 72 % low, 0 % medium, 28 % high EHP.	
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for gallium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 95 % low, 5 % medium, 0 % high EHP.	low
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 58.36.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 0.7 million t/a results from the $CRD_{specific}$ of 1,667 t/t and the global annual production of 437 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 1.3 PJ/a results from the $CED_{specific}$ of 3,030,000 MJ-eq/t and the global annual production of 437 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for Gallium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99.7 % low, 0.3 % medium EHP.	low

4.19 Germanium



4.19.1 General Information

Introduction and characteristics

Germanium is a hard, brittle and greyish-white metalloid with symbol Ge and atomic number 32. It is similar to a metal, but also has non-metallic properties such as semiconductor capability. It is too reactive to exist naturally on earth in a free (native) state. It is contained in zinc ores and coal ashes. With an average concentration in the Earth's crust of 1.6-2 ppm it is a rather rare element. (European Commission 2017b)

Applications

The most important global applications of germanium are fiber optics, infrared optics, polymerisation catalysts for PET plastics, electronic applications and satellite solar cells. In the EU, however, germanium is neither used as a PET polymerisation catalyst nor in the electronics industry but in fibre-optics (39 %), infrared optics (47 %) and satellite solar cells (13 %). (European Commission 2017b)

Recycling

Around 30 % of the world's germanium production is covered by recycling of new scraps and tailings. Although recycling of old scrap has increased over the last decades, only very little old scrap is recycled today. The functional recycling rate is assumed to be around 12 % and the end-of-life recycling input rate is estimated to be 2 %. (European Commission 2017b)

Substitution

Silicon can substitute germanium in some electronic applications but due to the miniaturization of electronics, more germanium has been used in recent times. For infrared optics, zinc selenide, zinc sulphide and tellurium can be used as substitutes. Due to performance losses, substitutes are not really used in optical fibres. No substitute for germanium in satellite solar cells exist. (European Commission 2017b)

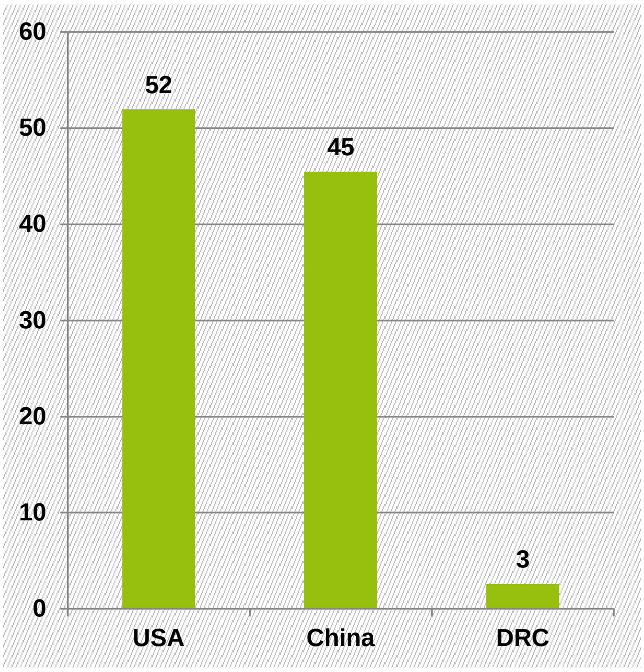
Main product, co-product or by-product

Germanium is extracted from copper and zinc ores by metallurgy and is therefore a by-product (European Commission 2017b).

Primary production

Total global production: 77 tonnes in 2014 (Melcher/Buchholz 2014).

Percentage of germanium mines mined in 2014 (%) (Melcher/Buchholz 2014)



Information on Deposits

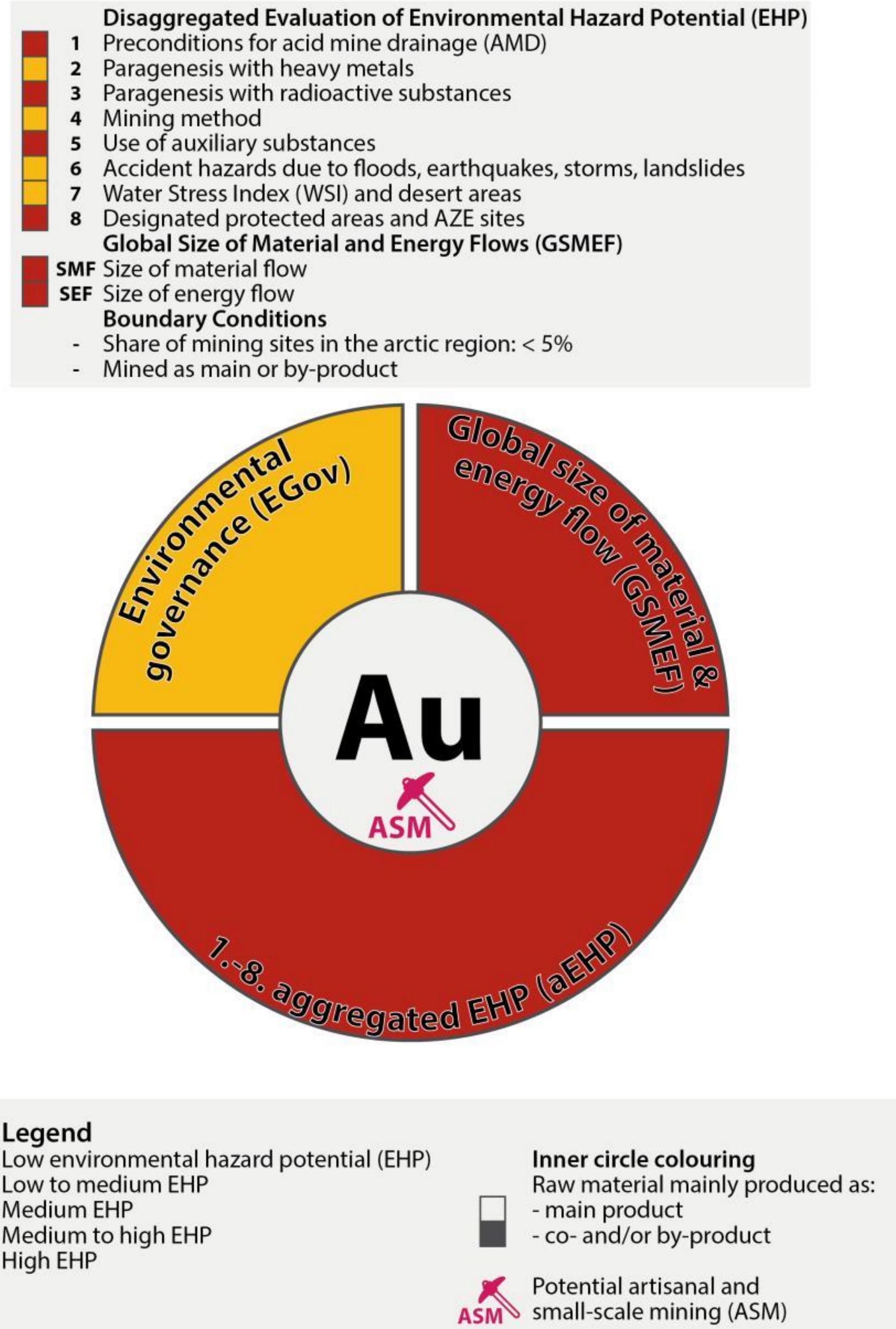
Like gallium, germanium is an element that is not mined independently. Although there are some independent germanium minerals, they do not have any mining significance. Instead, germanium is extracted from copper and zinc ores by metallurgical methods. The most important types of deposits currently rich in germanium are lead-zinc in carbonate rocks and massive sulphide ores in sediments. But also the extraction from hard coal and lignite ashes is currently of great economic importance. In the future, non-ferrous metal deposits in carbonates, sub-volcanic marine sedimentary deposits, storey mineralization and ore deposits could be added.

4.19.2 Profile Germanium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Germanium is extracted as a by-product from complex copper and zinc sulphide ores. Germanium is extracted as a by-product from sulphide deposits.	high
Indicator 2: Paragenesis with heavy metals		
High EHP	Mainly a by-product of lead-zinc ores.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Mainly by-product from lead-zinc ores (see evaluation for lead and zinc).	medium
Indicator 4: Mine Type		
High EHP	By-product (Cu, Zn), mining of the main product both in surface and underground mining	medium
Indicator 5: Use of auxiliary substances		
High EHP	Chlorine leaching of high content precursors (flotation concentrates, ashes)	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		

Environmental hazard potential	Explanation	Data quality
High EHP	The results for germanium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 3 % low, 23 % medium, 74 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Low EHP	The results for germanium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium, 0 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
High EHP	The results for germanium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 78 % low, 7 % medium, 15 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 60.84.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 0.7 million t/a results from the $CRD_{specific}$ of 8,621 t/t and the global annual production of 77 t/a.	low
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 0.2 PJ/a results from the $CED_{specific}$ of 2,890,000 MJ-eq/t and the global annual production of 77 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
High	The results for germanium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 93 % low, 7 % medium EHP.	medium

4.20 Gold


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 5%
- Mined as main or by-product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Au
ASM
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.20.1 General Information

Introduction and characteristics

Gold is a dense, soft, malleable and ductile metal with high thermal and electrical conductivity. It occurs very rarely with an estimated abundance of 1.3 ppb in the earth's crust and 1.5 ppb in the uppercrust. Gold occurs mainly as a native metal, sometimes in a mixed crystal series with silver or alloyed with copper and palladium. (European Commission 2017a)

Applications

Investments in gold account for around one third of global demand. For non-monetary, industrial uses the major application of gold is in jewellery (83 %). Other uses are for electronic devices (11 %), dentistry (2 %) and other minor industrial uses. (European Commission 2017a)

Recycling

The recycled content of gold depends heavily on the price of gold. In 2009 it peaked at 42 % of the total gold supply due to high prices. Since prices have fallen, gold recycling has declined (26 % of total gold supply in 2014). Most recycled gold (around 90 %) comes from jewellery, gold bars and coins. The remaining 10 % of recycled gold comes from other applications (e.g. electronic devices). UNEP (2011) estimates the average global EOL recycling rate for gold at 15-20 %. This estimate does not include the recycling of jewellery and coins. (European Commission 2017a)

Substitution

Depending on their current market prices, platinum, palladium and silver are possible substitutes for gold in electronic devices. For some time now, base metals plated with gold alloys have been used to reduce gold consumption in electronic devices. In dentistry, gold is increasingly being replaced by ceramics and cheaper base metal alloys. (European Commission 2017a)

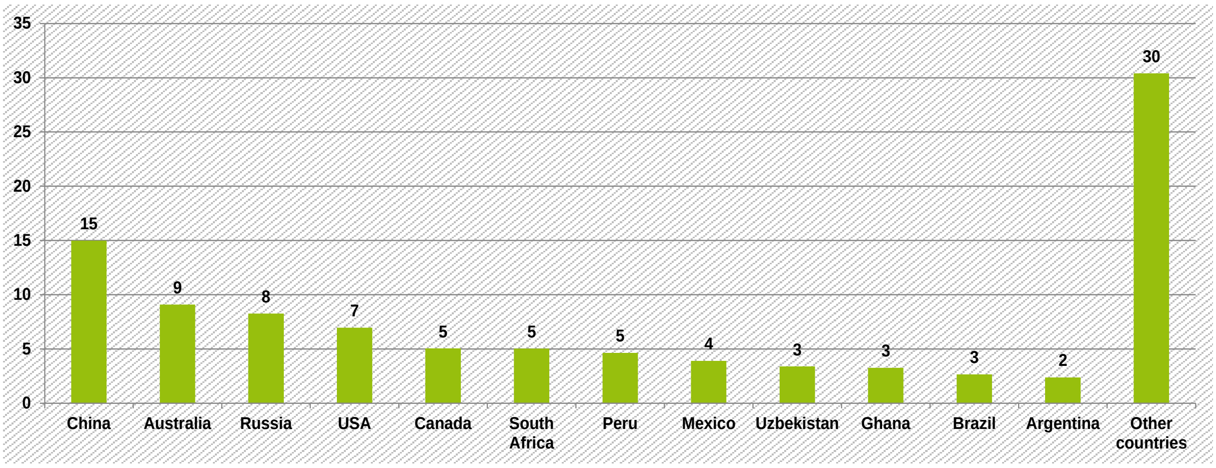
Main product, co-product or by-product

Gold is often the main product but can also be a by-product e.g. in copper mining (see for example European Commission 2017a).

Primary production

Total global production: 3,015 tonnes in 2014 (BGS 2016).

Percentage of gold mines mined in 2014 (%) (BGS 2016)



ASM relevance

Global gold production share of ASM is according to BGR (2007) 10 %, to GEUS (2007) 10 % and to Dorner et al. (2012) 25 %. The global ASM population is in the range of 5 million miners

Gold is currently the main product of ASM worldwide (second is coal, especially in China). Mined from hardrock vein mines and from alluvial deposits. Environmentally a big challenge: the extensive use of the amalgamation process is related to large amounts of mercury lost. Alluvial mining is threatening the river courses and alluvial lowlands (young terraces), going along with river siltation, erosion, forest degradation, induced settlements etc., especially serious in preserved areas (i.e. in Madre de Dios, Peru or in National Parks in DRC).

Alluvial miners tend to have a nomadic nature and are a "moving target" for resources governance, which is focusing on immobile mining titles. Gold rushes are a special problem for governance given the casino mentality of many ASGM. Besides this the activity is mostly poverty driven, offering income opportunities and access to resources for low qualified and landless people in multi-actor networks (see also: Greenen 2015).

Hardrock mining uses amalgamation and/or leaching, sometimes in combination, leading to even more toxic effluents (mercury cyano complexes). Gold mining is "money mining". The product is easily commercialized and transported cross-boarders, even sometimes used for money-laundry purposes.

Informal gold ASM is often related to social conflicts, strong socio-economic dependencies of the miners, lack of environmental concern and management as well as serious occupational and public health risks. Conflicts with industrial producers are regularly occurring, due to modern mining titles overlapping traditional "cultural" mining areas. Large scale companies often benefit from the artisanal miners as barefoot geologist, without recognizing the benefit.

The Minamata convention recently adopted by a number of ASGM countries drives most traditional operators further into informality, consequently avoiding government supervision and control due to a lack of economically feasible alternative mercury-free technologies.

Many countries have rolled out extensive formalization campaigns, regularly with rather limited success: increasingly higher barriers, decreasing level of skills among the ASM, lacking presence of the administration in the ASM areas contribute to this. ASM gold production is still one of the most serious resource governance challenges and bears the risk of producing uncontrolled and uncontrollable environmental damage.

There are a number of ASM certification systems focusing on gold, such as ARM/Fairmined, ARM/CRAFT, FairTrade, RJC, etc. Nevertheless the volume of certified material is still neglectable on a global scale. There are enormous amounts of illicitly traded gold.

Important gold producing countries with prominent ASM production are China, South Africa, Peru, Mexico, Ghana, Brazil, Sudan, Indonesia, Colombia, Papua New Guinea and Mali. 55 % of gold is produced in countries with ASM.

Information on Deposits

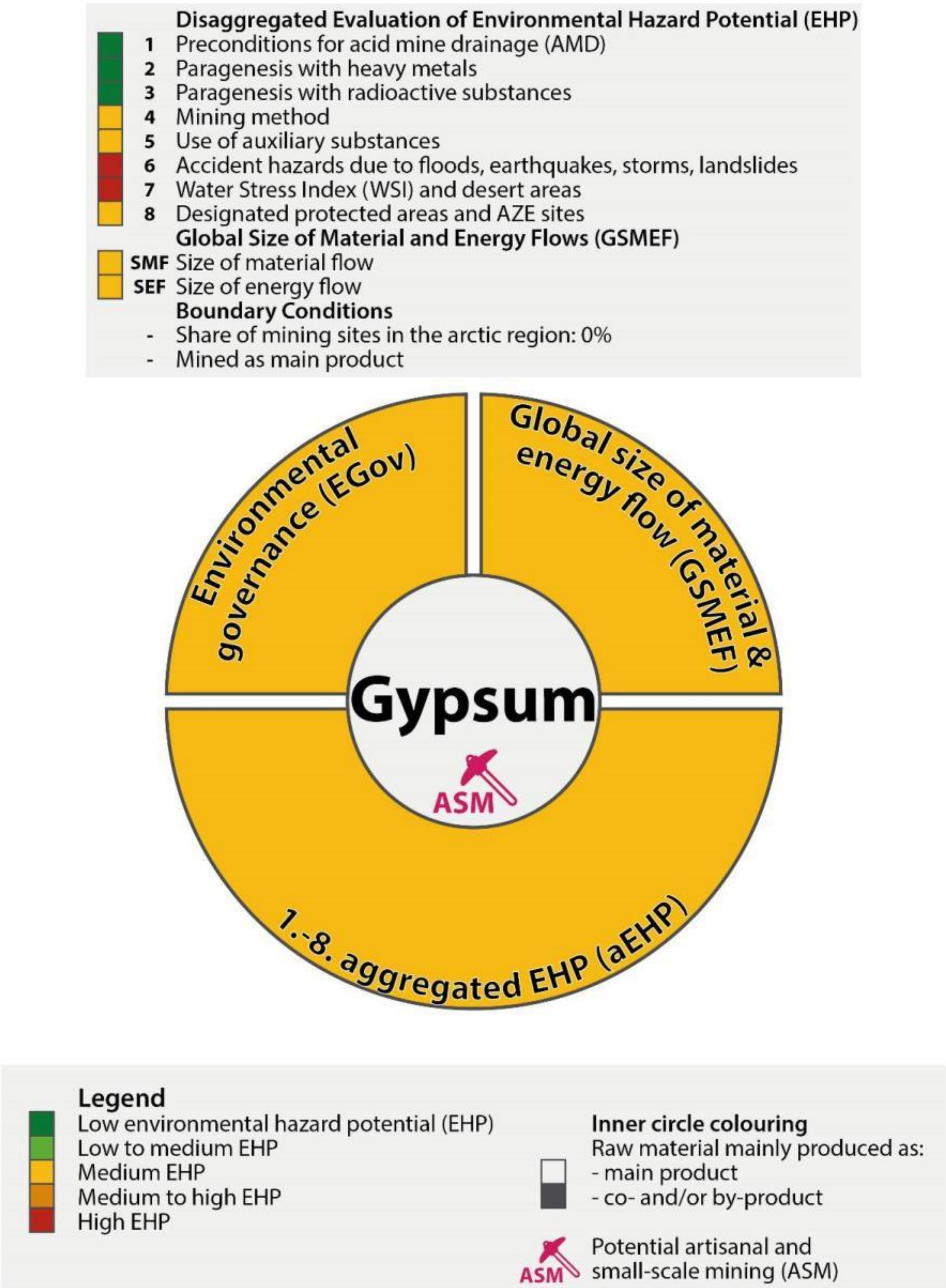
Gold is a siderophilic element and occurs in solid form, as tellurides and selenides, as free gold in sulfide parageneses and as gold dissolved in the crystal lattice of sulfides. Genetically, gold is known from all educational conditions except limes. Economically significant are segregation deposits, where gold occurs with magnetic gravel, in pneumatolytic and hydrothermal deposits (as free gold and telluride associated with pyrite), from sub-volcanic gold ores, from marine sedimentary reduction deposits in paragenesis with sulfides and as soap deposits (ged. gold).

4.20.2 Profile Gold

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	According to the Goldschmidt classification, gold is a siderophilic element (sulfur-loving), but it is present both sulfidically and in a dignified form. Due to the high production shares from copper-gold deposits (porphyries), there is a significant potential for the formation of sour waters from the outflows.	high
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Gold itself is non-toxic, but is predominantly extracted from Cu deposits and is often associated with arsenic. Shear metal contents are usually relatively low compared to other ore deposits.	medium
Indicator 3: Paragenesis with radioactive substances		
High EHP	Gold from underground mining in South Africa (about 5.0 % of world production) is associated with high concentrations (0.02 %) of uranium.	low
Indicator 4: Mine Type		
Medium EHP	The standard extraction method is solid rock opencast mining from massive ore deposits (stockworks, porphyries). Solid rock open pit mining is assigned to a medium EHP. Surface mining, Ganger ore underground mining, alluvial mining, stockpile preparation.	high
Indicator 5: Use of auxiliary substances		
High EHP	Processing takes place in large industrial mines with cyanide leaching, in small mines usually with amalgamation (mercury). Processes such as chlorine leaching, thiourea leaching, flotation, tailings pile leaching and in-situ leaching are of secondary importance. A high EHP is assigned to the use of toxic excipients.	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for gold range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 47 % low, 27 % medium, 26 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for gold range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 58 % low, 4 % medium, 38 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
High EHP	The results for gold range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 90 % low, 6 % medium, 4 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 57.64. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		

Environmental hazard potential	Explanation	Data quality
High	CRD_{global} of 2,232 million t/a results from the $CRD_{specific}$ of 740,318 t/t and the global annual production of 3,015 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 627 PJ/a results from the $CED_{specific}$ of 208,000,000 MJ-eq/t and the global annual production of 3,015 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
High	The results for gold range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 97 % low, 3 % medium EHP.	medium

4.21 Gypsum


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: 0%
- Mined as main product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Gypsum
ASM
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.21.1 General Information

Introduction and characteristics

Gypsum ($CaSO_4$-$2H_2O$) is an evaporite mineral. Natural deposits, however, usually contain impurities and can appear grey, yellow, red or brown. European industry is not only reliant on natural gypsum. Currently, the industry uses about 38 % FGD (flue gas desulfurization), 3 % recycled and 2 % other synthetic gypsum, while the remaining 57 % is natural gypsum. (European Commission 2017a)

Applications

Gypsum is used in the production of plasterboard and wallboard products (51 %) as well as in the production of building plaster (26 %), in cement production (17 %) and in agriculture as a soil conditioner (6 %). (European Commission 2017a)

Recycling

Recycled gypsum is produced during the processing of gypsum plasterboard waste. Three categories of gypsum waste can be distinguished according to their origin: Production waste (recycling rate approx. 3.5-5 %), construction waste (recycling rate 7 %), demolition waste (estimated recycling rate approx. 1.5 %). Recycling in Europe varies greatly from country to country. At the European level, there are currently no end-of-life criteria that could further promote gypsum recycling (European Commission 2017a).

Substitution

Substitutes for gypsum used in plasterboard and wallboard are synthetic or recycled gypsum, wood based wall panels, renewable material wall panels, plastic and metal panels, brick and glass. For building plaster and stucco, gypsum could be substituted by cement and lime plaster. FGD gypsum is used as an alternative in the production of cement and as a soil conditioner in agricultural applications. (European Commission 2017a)

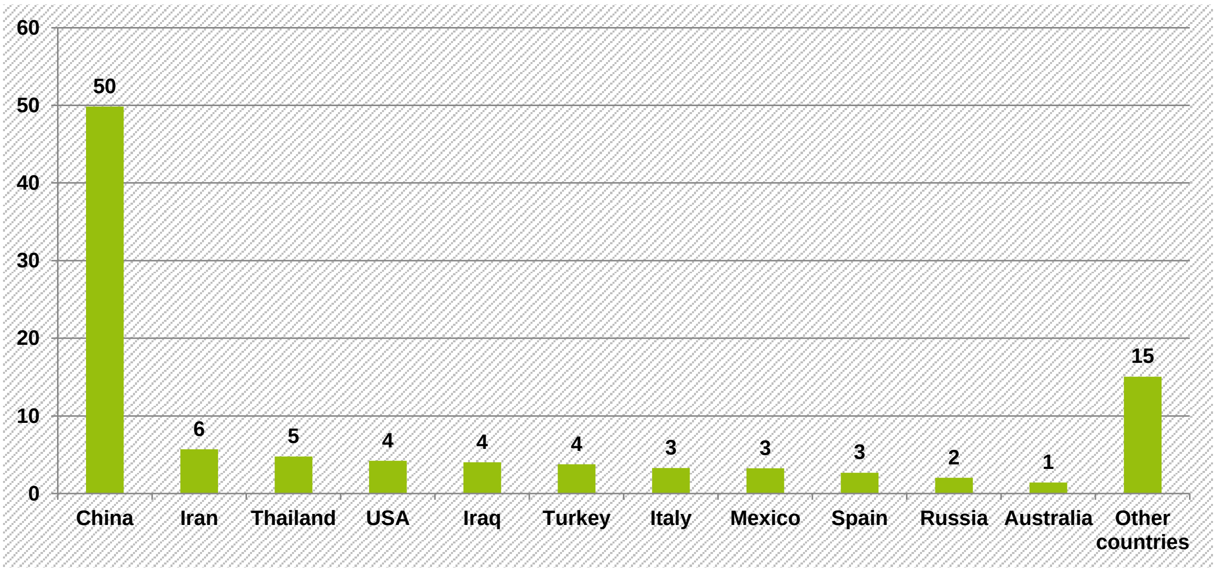
Main product, co-product or by-product

Gypsum is a main product (European Commission 2017a).

Primary production

Total global production: 260,888,901 in 2014 (BGS 2016).

Percentage of gypsum mines mined in 2014 (%) (BGS 2016)



ASM relevance

Due to market considerations as well as geological conditions the exploitation of gypsum is mostly done on a small, but mechanized scale. GEUS (2007) estimated 70 % of the global prevenient from small producers.

Despite ASM, the environmental hazard potential is rather low due to inert chemistry, low accessories in mined deposits and absence of toxic heavy metals. Hardrock mining in quarries mostly even in ASM in a mechanized or semi-mechanized form.

Low amount of mining residues due to the high grade of gypsum deposits.

Important gypsum producing countries with prominent ASM production are China and Mexico. 57 % of gypsum is produced in countries with ASM.

Information on Deposits

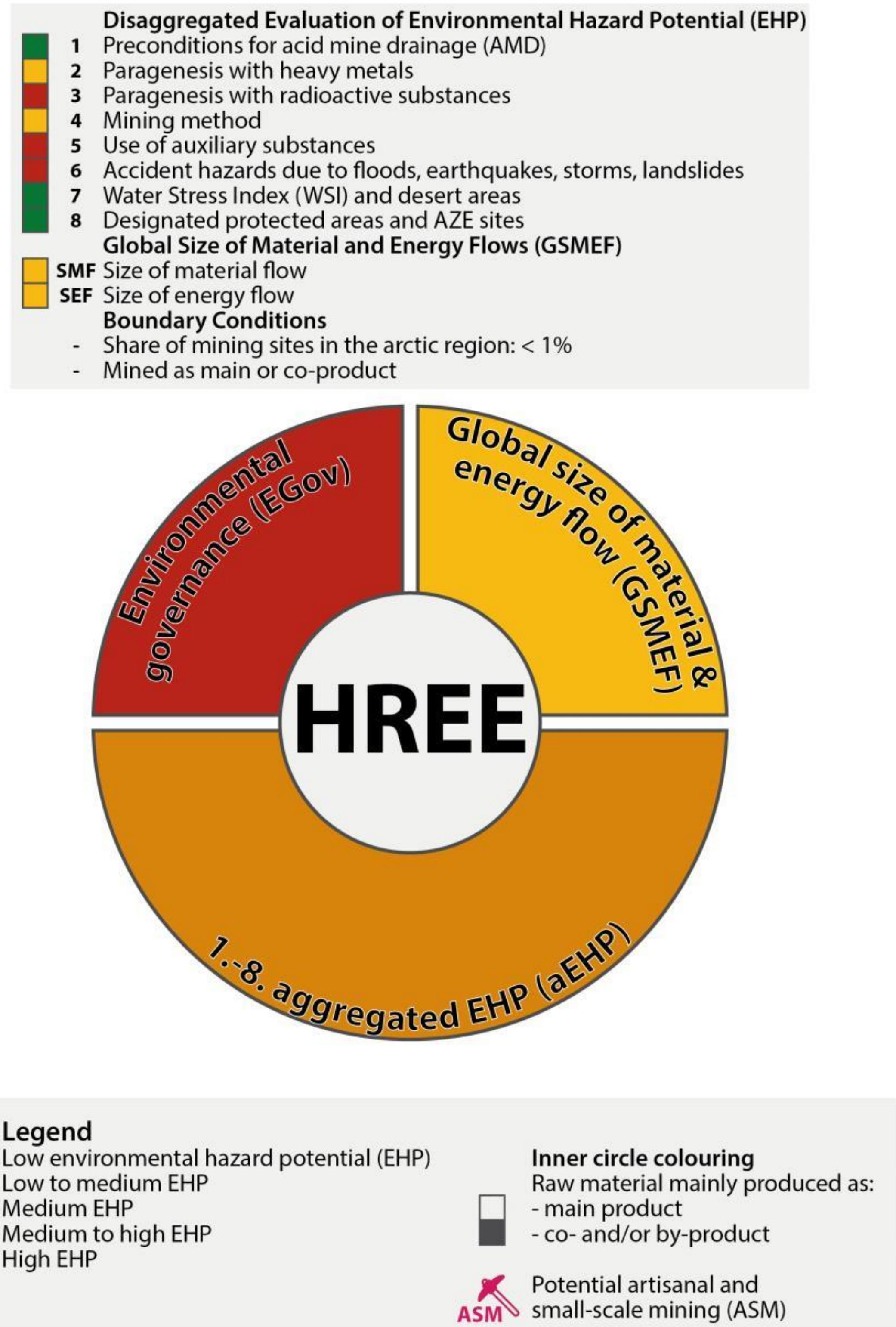
Gypsum is a calcium sulphate mineral with water of crystallization, $Ca[SO_4]\ 2H_2O$, its anhydrous counterpart is anhydrite. It occurs genetically in marine sedimentary evaporation deposits, but is often present as solid rock. It is associated with other salts, limestones etc..

4.21.2 Profile Gypsum

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	No potential for acid formation due to sedimentary evaporitic genesis	medium
Indicator 2: Paragenesis with heavy metals		
Low EHP	Gypsum is extracted from marine evoporitic sedimentary deposits and is therefore largely free of heavy metals.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	As a marine sediment, gypsum is mostly free of radioactive companions.	high
Indicator 4: Mine Type		
Medium EHP	Surface mining	medium
Indicator 5: Use of auxiliary substances		
Medium EHP	Calcination	high

Environmental hazard potential	Explanation	Data quality
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	The results for gypsum range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 11 % low, 47 % medium, 42 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for gypsum range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 10 % low, 3 % medium, 87 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for gypsum range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 96 % low, 1 % medium, 3 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 55.56. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 264 million t/a results from the $CRD_{specific}$ of 1 t/t and the global annual production of 260,888,901 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 7.5 PJ/a results from the $CED_{specific}$ of 29 MJ-eq/t and the global annual production of 260,888,901 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Low	The results for gypsum range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP.	medium

4.22 Heavy rare earth elements (HREE)



4.22.1 General Information

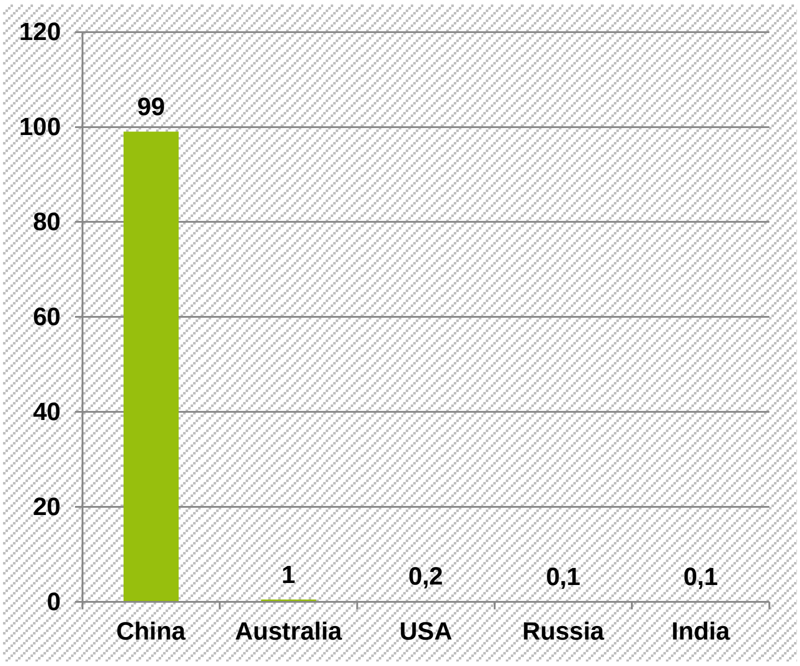
Introduction and characteristics till Main product, co-product or by-product

See Rare Earths (Chapter 4.43.1)

Primary production

Total global production 2012: 16,901 tonnes (European Commission 2015b)

Percentage of HREE mines mined in 2012 (%) (European Commission 2015b)



Information on Deposits

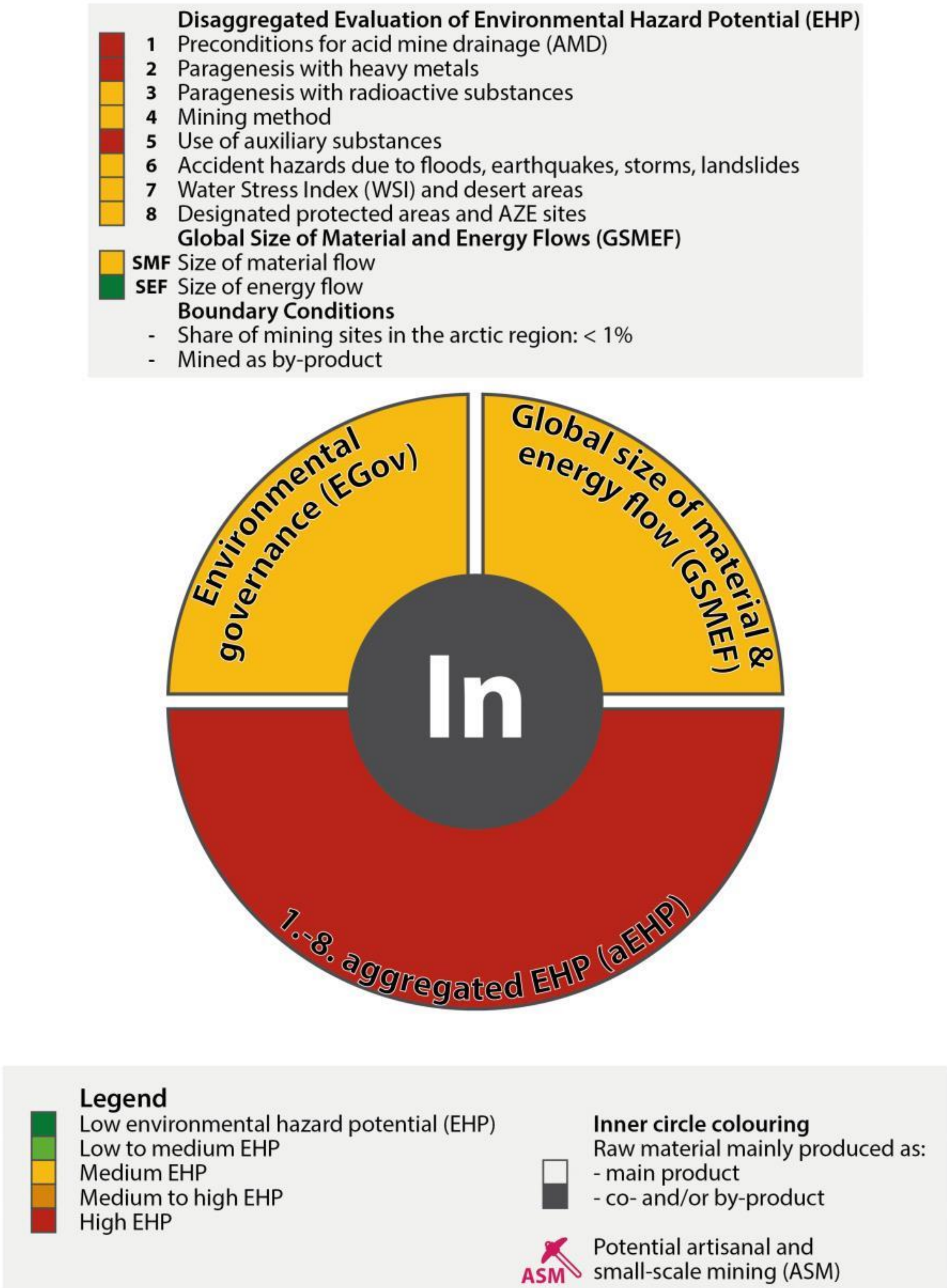
See Rare Earths (Chapter 4.43.1)

4.22.2 Profile Heavy rare earth elements (HREE)

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Due to the lithophilic properties and the formation conditions of SE, the prerequisites for the formation of acid waters or for autooxidation are low.	low
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Due to the deposit's genesis, only low heavy metal contents are to be expected.	medium
Indicator 3: Paragenesis with radioactive substances		
High EHP	Rare earths are usually associated with high concentrations of U and Th. This is confirmed by data from Chinese deposits (86.4 % of world production).	high
Indicator 4: Mine Type		
Medium EHP	Open pit mining, rarely underground mining	high
Indicator 5: Use of auxiliary substances		
High EHP	Flotation, physical-chemical separation processes Roasting, carbonate precipitation, acid leaching, solvent extraction, in-situ leaching	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		

Environmental hazard potential	Explanation	Data quality
High EHP	The results for HREE range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 0 % low, 45 % medium, 55 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Low EHP	The results for HREE range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 78 % low, 11 % medium, 11 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for HREE range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 50.90.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
N/A	Information not available due to data restrictions	
Indicator 11: Cumulated energy demand of global production CED_{global}		
N/A	Information not available due to data restrictions	
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for HREE range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium EHP.	medium

4.23 Indium


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 1%
- Mined as by-product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
In
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.23.1 General Information

Introduction and characteristics

Indium is a very soft, ductile and malleable silvery metal with the atomic number 49. The abundance of Indium in the upper crust is estimated at 0.056 ppm. Indium is found as a trace element in some zinc, copper, lead and tin minerals but the main commercial source of indium is zinc mineral sphalerite. (European Commission 2017b)

Applications

Indium is mainly used in the form of indium tin oxide as a transparent conductive oxide. Its major application is in flat panel displays for televisions, laptops, notebooks and mobile phones (56 %). It is also used as a solder, in PV cells, in thermal interface materials in electronic devices, batteries, in different alloys and compounds as well as in semiconductors and LEDs. (European Commission 2017b)

Recycling

The recycling rate from old scrap is only 1 %. The secondary refined indium production results almost exclusively from the recycling of new scrap rather than recovery from end-of-life. Precise data on the amount are not available, but are estimated to exceed virgin indium production. (European Commission 2017b)

Substitution

In flat panel displays and in amorphous silicon and CdTe PV cells, indium can be replaced by aluminium doped zinc oxide (AZO) and fluorine doped tin oxide (FTO) or silver nanowires. Crystalline silicon technologies which hold more than 90 % of the PV market, and thin-film technologies such as CdTe and Amorphous silicon (a-Si) are available substitutes for CIGS. Tin-indium alloys can be replaced by tin-bismuth alloys in low temperature bonding and soldering applications. Lead-based alloys could replace indium and indium-tin alloys used for sealing at cryogenic temperatures. (European Commission 2017b)

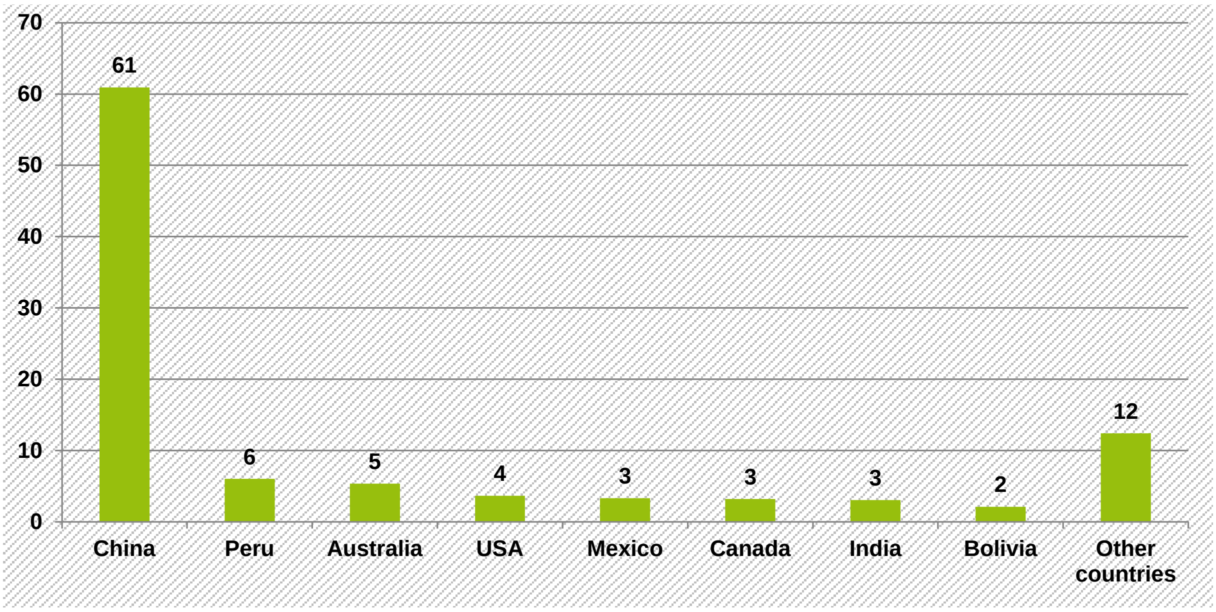
Main product, co-product or by-product

Indium is a by–product, mainly from zinc mining (European Commission 2017b).

Primary production

Total global production: 640 tonnes in 2014 (BGS 2016, Schwarz-Schampera 2014).

Percentage of indium mines mined in 2014 (%) (BGS 2016, Schwarz-Schampera 2014)



Information on Deposits

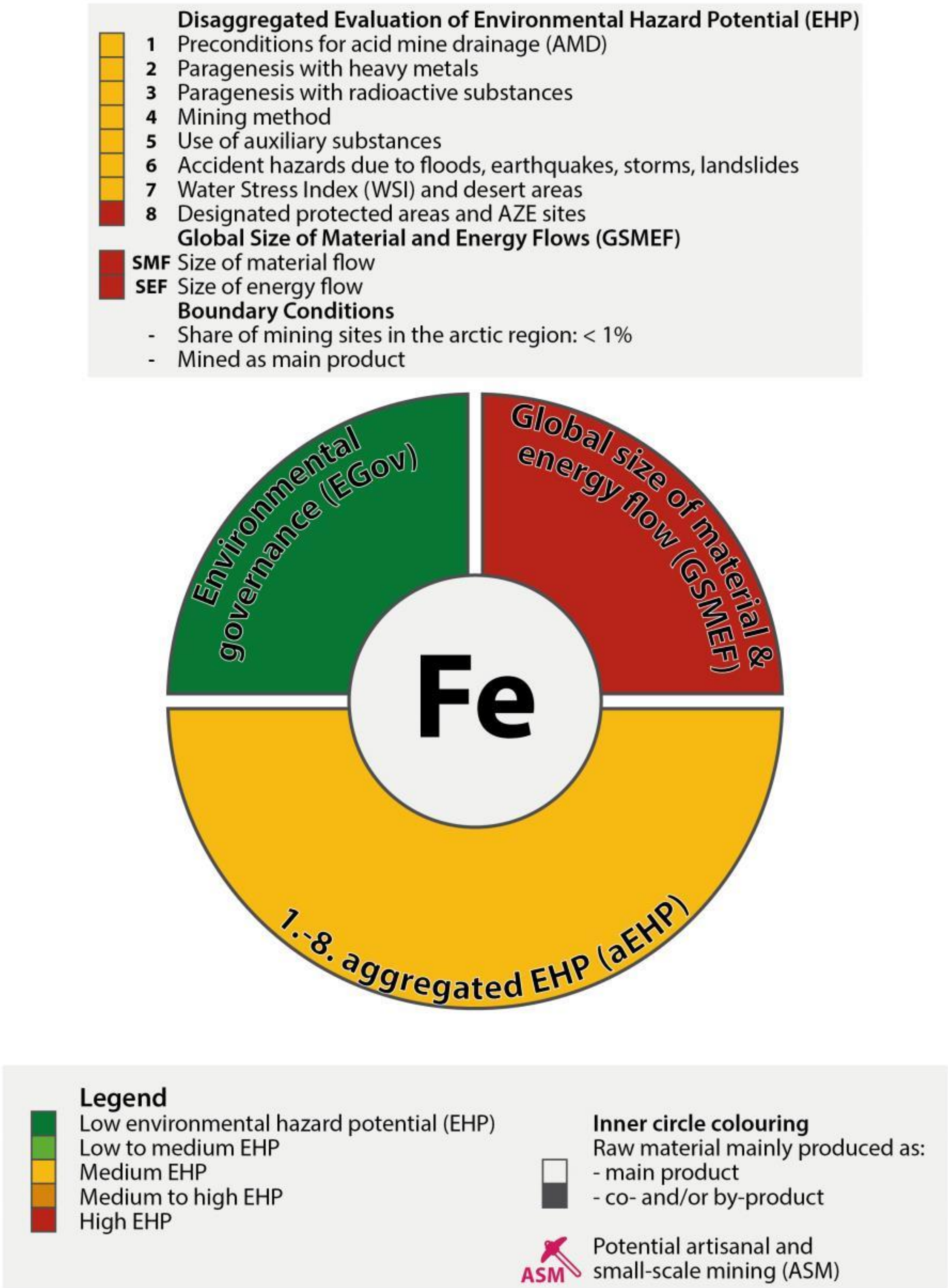
Indium is currently known in 12 independent indium minerals. These are often found on gussets of other sulphides. Indium also replaces other elements such as iron, copper, tin or arsenic in the crystal lattice. Currently, zinc blende is the most important starting material for indium extraction. Massively sulphide ores in vulcanites or in sediments, epithermal deposits, tin-tungsten porphyries and vein deposits are important from the point of view of deposit science.

4.23.2 Profile Indium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Indium is a chalcophilic element according to the Goldschmidt classification. In is also obtained as a by-product from lead-zinc ores, some of which are sulphidic.	high
Indicator 2: Paragenesis with heavy metals		
High EHP	Indium is mainly extracted from lead-zinc ores. Lead is a heavy metal.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Indium is mainly obtained from lead-zinc ores (see evaluation for lead and zinc).	medium
Indicator 4: Mine Type		
Medium EHP	Underground mining, open pit mining	high
Indicator 5: Use of auxiliary substances		
High EHP	Separation only in the smelting processes by roasting and leaching of zinc concentrates	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for indium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 35 % low, 31 % medium, 34 % high EHP.	medium

Environmental hazard potential	Explanation	Data quality
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for indium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 66 % low, 4 % medium, 30 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for indium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 93 % low, 5 % medium, 2 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 55.29.	high
Indicator 10: Cumulated raw material demand of global production CRDglobal		
Medium	CRDglobal of 16 million t/a results from the CRDspecific of 25,754 t/t and the global annual production of 640 t/a.	high
Indicator 11: Cumulated energy demand of global production CEDglobal		
Low	CED_{global} of 1.1 PJ/a results from the $CED_{specific}$ of 1,720,000 MJ-eq/t and the global annual production of 640 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for indium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium EHP.	medium

4.24 Iron


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 1%
- Mined as main product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Fe
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.24.1 General Information

Introduction and characteristics

Iron is a silvery-grey and lustrous metal which is relatively soft in pure form. In air it oxidizes and quickly forms rust (hydrated iron oxides). Iron is therefore generally used in alloys to improve its properties by adding other elements (JRC 2018).

Applications

Steel is the most important industrial material making it almost ubiquitous in everyday life, accordingly the variety of applications is very large. The main application by volume is the use in construction in structural parts such as building frames as well as in non-structural parts like cooling or heating equipment. Steel is used in all motorized vehicles, in the transport sector for building ships, in domestic applications e.g. washing machines, in metal products etc. (JRC 2018)

Recycling

Steel is recyclable to 100 % and has a potentially infinite life cycle without losing its properties. Recycling is already well established and plays an important role in steel manufacturing. The amount of energy required to produce steel from scrap is significantly lower than producing it from primary ore. The End of life recycling input rate (EOL-RIR) is 24 % (JRC 2018).

Substitution

Steel can be substituted in construction with a variety of construction materials, such as concrete, timber or masonry. However depending on the structural requirements, steel is hard to substitute. In automotive applications aluminum or plastic composites can be used instead of steel. In metal-ware plastics, silver, bronze, copper or aluminium could potentially substitute steel (European Commission 2017a)

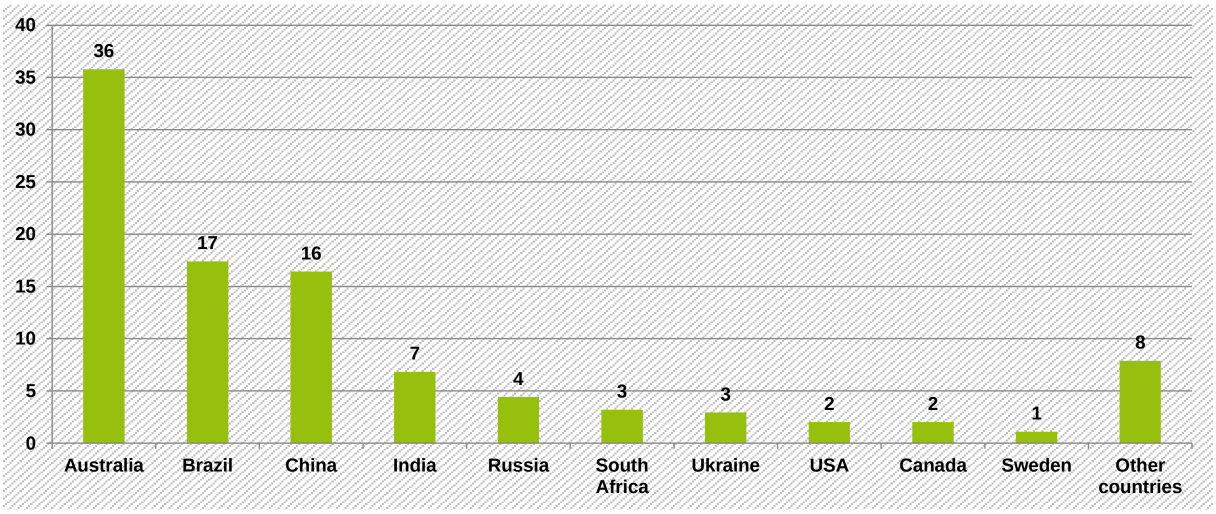
Main product, co-product or by-product

Iron is a main product (European Commission 2017a).

Primary production

Total global production: 1,160,000,000 tonnes in 2015 (USGS 2017).

Percentage of iron mines mined in 2015 (%) (USGS 2017)



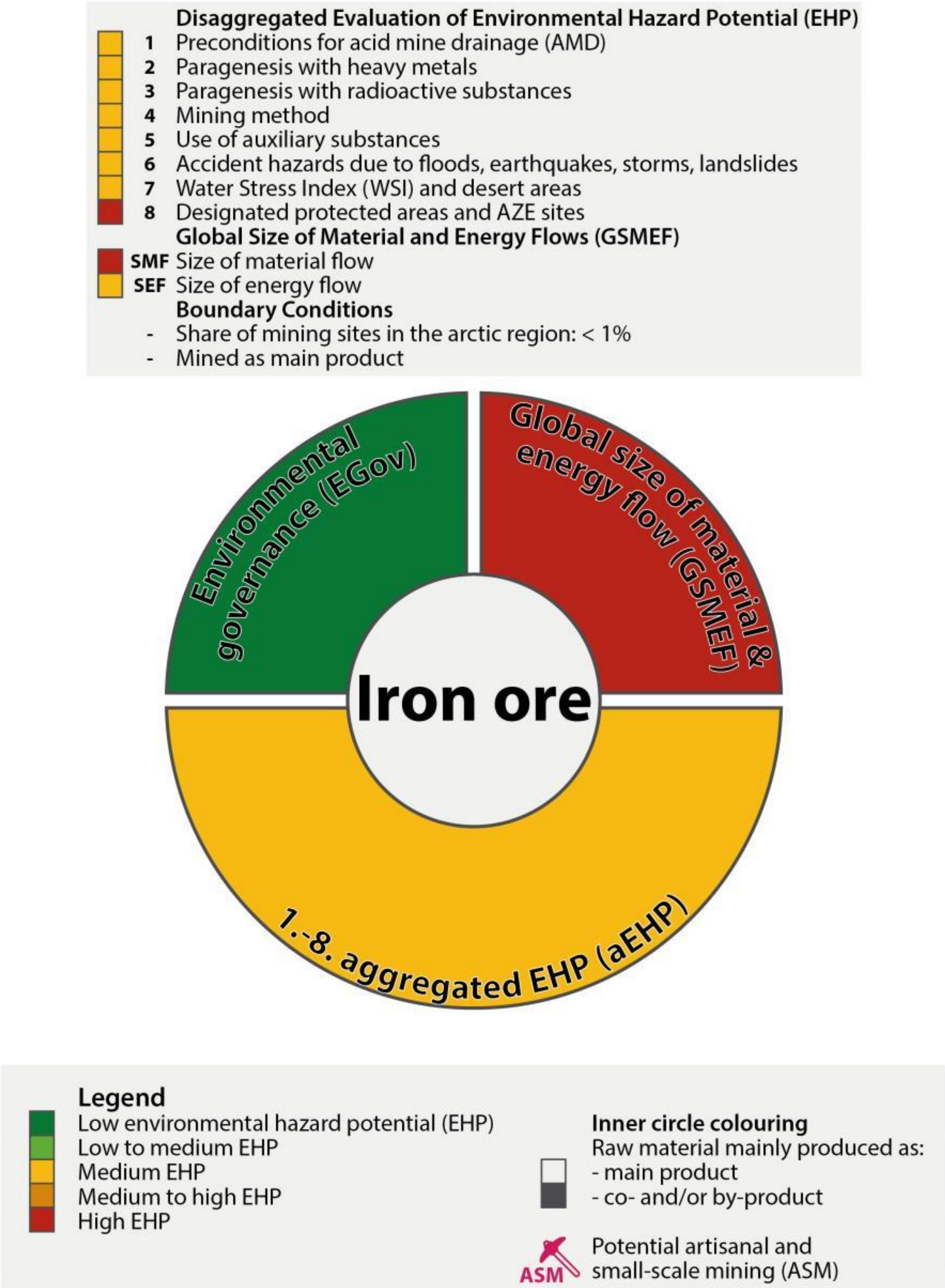
Information on Deposits

See iron ore (Chapter 4.25.1.)

4.24.2 Profile Iron

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Medium EHP	Occasionally sulphidic ores are processed (magnetic gravel, pyrite etc.)	high
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Iron itself is not a heavy metal, but according to Reuterrad it is often associated with heavy metals such as lead, zinc, chromium, copper and arsenic in deposits (Reuter et al. 2005).	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Average data on Chinese iron ore deposits (16.4 % of world production) suggest that in many cases iron ore is associated with slightly elevated concentrations of uranium and/or thorium.	high
Indicator 4: Mine Type		
Medium EHP	Surface mining, underground mining	medium
Indicator 5: Use of auxiliary substances		
Medium EHP	Floatation, magnetic separation	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	Iron is the product from iron ore, therefore, the assessment for iron corresponds to the assessment for iron ore.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	Iron is the product from iron ore, therefore, the assessment for iron corresponds to the assessment for iron ore.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
High EHP	Iron is the product from iron ore, therefore, the assessment for iron corresponds to the assessment for iron ore.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 61.84.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 4,786 million t/a results from the $CRD_{specific}$ of 4.1 t/t and the global annual production of 1,160,000,000 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 26,796 PJ/a result from the $CED_{specific}$ of 23,100 MJ-eq/t and the global annual production of 1,160,000,000 t/a. CED_{global} refers to the product pig iron (Nuss/Eckelman 2014).	high
Indicator 12: Position of mining sites in the arctic region		
Medium	Iron is the product from iron ore, therefore, the assessment for iron corresponds to the assessment for iron ore.	medium

4.25 Iron Ore


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
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3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 1%
- Mined as main product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Iron ore
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.25.1 General Information

Introduction and characteristics

There is a variety of different iron ores that are mined. Minerals with a high concentration of iron are e.g. hematite, magnetite, limonite, goethite and siderite (European Commission 2017a).

Applications

See Iron (Chapter 4.24.1.).

Recycling

See Iron (Chapter 4.24.1.).

Substitution

Iron ore cannot be substituted in the production of iron other than by recycling scrap iron.

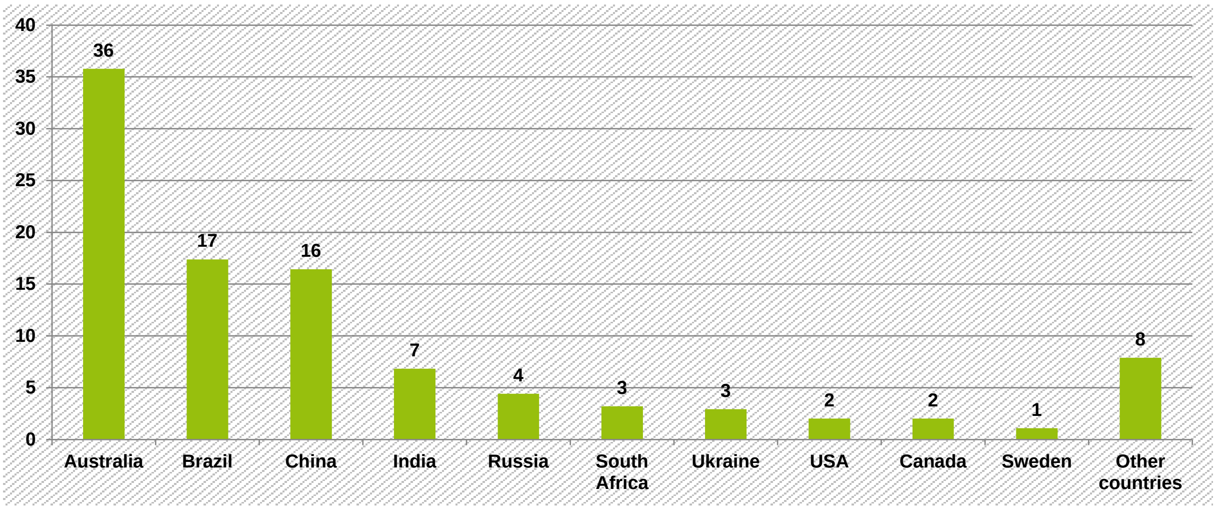
Main product, co-product or by-product

Iron ore is a main product.

Primary production

Total global production: 2,283,000.000 tonnes in 2015 (USGS 2017).

Percentage of iron ore mines mined in 2015 (%) (USGS 2017)



Information on Deposits

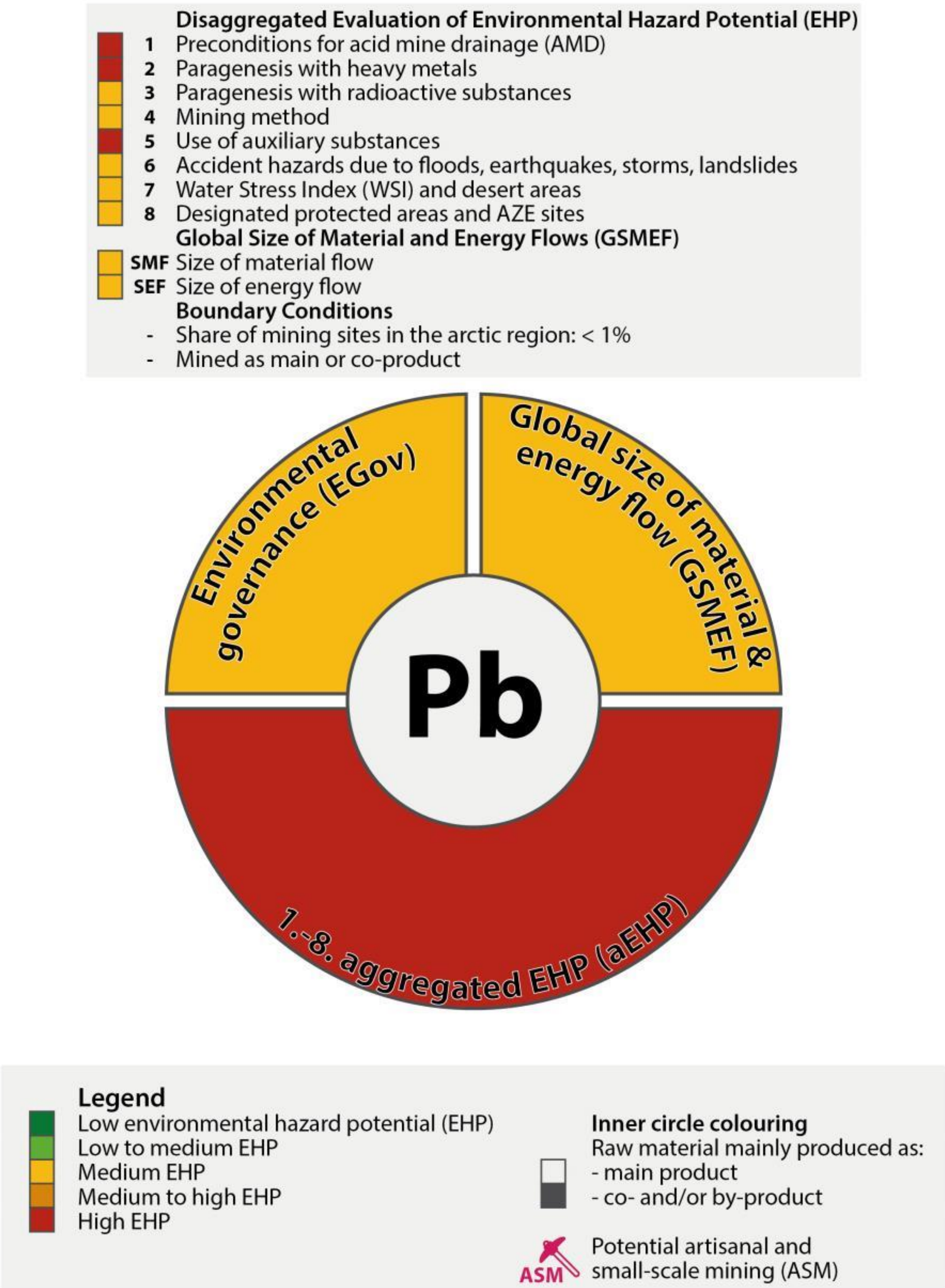
Iron is a siderophilic element. As a mining raw material, it occurs as ilmenite, magnetite, hematite as oxide, as limonite as hydroxide, in siderite as carbonate, and as magnetic gravel (sulphide). Deposits can include almost all different types of genes. Of particular economic importance are the banded iron formations, which are referred to as marine sedimentary reduction deposits. For smelting, oxides, hydroxides and carbonates are preferred.

4.25.2 Profile Iron Ore

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Medium EHP	Occasionally sulphidic ores are processed (magnetic gravel, pyrite etc.).	high
Indicator 2: Paragenesis with heavy metals		

Environmental hazard potential	Explanation	Data quality
Medium EHP	Iron itself is not a heavy metal, but according to Reuterrad it is often associated with heavy metals such as lead, zinc, chromium, copper and arsenic in deposits (Reuter et al. 2005).	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Average data on Chinese iron ore deposits (46.6 % of world production) suggest that in many cases iron ore is associated with slightly elevated concentrations of uranium and/or thorium.	high
Indicator 4: Mine Type		
Medium EHP	Surface mining, underground mining	medium
Indicator 5: Use of auxiliary substances		
Medium EHP	Floatation, magnetic separation	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for iron ore range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 44 % low, 30 % medium, 26 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for iron ore range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 54 % low, 2 % medium, 44 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
High EHP	The results for iron ore range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 88 % low, 10 % medium, 2 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 61.84.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 2,297 million t/a results from the $CRD_{specific}$ of 1 t/t and the global annual production of 2,283,000,000 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 144 PJ/a results from the $CED_{specific}$ of 63 MJ-eq/t and the global annual production of 2,283,000,000 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for iron range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium EHP.	medium

4.26 Lead


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 1%
- Mined as main or co-product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Pb
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.26.1 General Information

Introduction and characteristics

Lead is a soft, malleable, darkish grey metal with the atomic number 82. Its concentration in the Earth continental upper crust is relatively low (compared to the other base metals; 17 ppm). Lead usually occurs in ore with zinc, silver and copper and is extracted together with these metals. The most important lead mineral is lead glance (PbS), with a Pb-comcentration of 86.6 %. (European Commission 2017a) Lead is toxic and is classified as likely to be carcinogenic (see for example Itter/Papel 2013).

Applications

The major application for lead is lead-acid batteries (automotive, motive and stationary batteries) which accounted for about 85 %. 6 % of the global lead consumption is used for lead compounds as stabilisers in PVC, but this has been voluntarily phased out in the EU since 2015. Other applivations are rolled and extruded products (e.g. lead sheets,), ammunition, soldering alloys and cable sheatings. (European Commission 2017a)

Recycling

Today, more refined lead is produced than mined through recycling. In 2010-2014, EU secondary lead production remained relatively constant with an average production of about 75 % of total refined lead production. Most of the secondary lead comes from scrap lead-acid batteries, lead pipe, sheet and cable sheathing. (European Commission 2017a)

Substitution

Lithium-ion batteries are increasingly replacing lead-acid batteries (currently almost 10 % of the market). Other schemes are nickel-metal hydride (NiMH) and nickel-cadmium (NiCd) batteries (limited use in the EU due to the Cd content in some electrical appliances). Lead based PVC stabilisers can be replaced by calcium based stabilisers, titanium dioxide, organic and inorganic pigments, zinc phosphate primers etc. Lead sheets can be replaced by sheets of galvanised steel, aluminium, copper and non-metallic materials. Lead-free cables can be made from an aluminium polyethylene strip (AluPE), a high density polyethylene (HDPE) sheath and a polyamide (PA) cover. There are numerous Sn-based alloys that replace leaded solders. The manufacture and exceptional use of lead solder is regulated in the EU (RoHS 2017). (European Commission 2017a)

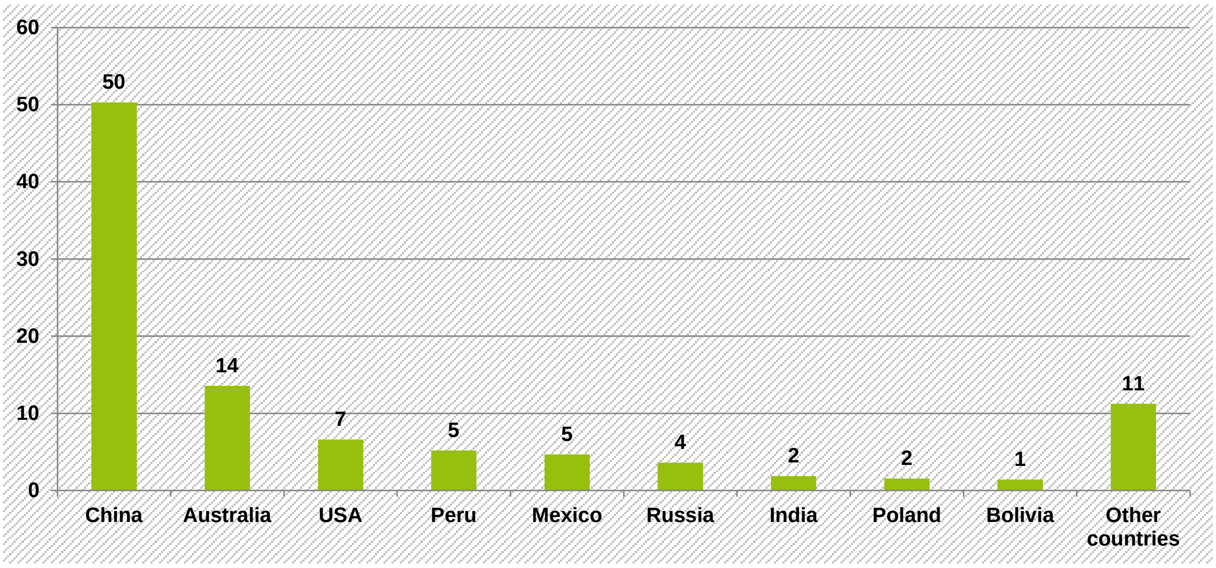
Main product, co-product or by-product

Lead is a main product (European Commission 2017a).

Primary production

Total global production: 5,368,632 tonnes in 2014 (BGS 2016).

Percentage of lead mines mined in 2014 (%) (BGS 2016)



Information on Deposits

Lead is a chalcophilic element. It is found in nature in plutonic and subvucanian hydrothermal deposits (mostly Gangerz deposits), as well as in submarine exhalative synsedimentary deposits (Black smoker, type Rammelsberg). Galena (PbS) as well as the sulfosalts bournonite and boulangerite are economically important as ore minerals. They are accompanied by other sulphide minerals (pyrite, arsenic gravel, copper minerals etc.), very often closely associated with zinc mineralizations (mainly zinc blende) and often rich in silver. (Paul Ramdohr, Hugo Strunz: Klockmann's Textbook of Mineralogy 1978)

4.26.2 Profile Lead

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	According to the Goldschmidt classification, lead is a chalcophilic element and is generally sulfidic.	high
Indicator 2: Paragenesis with heavy metals		
High EHP	Lead is a heavy metal.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Average data on Chinese lead-zinc deposits (52,8 % of world lead production) suggest that in many cases lead is associated with slightly elevated concentrations of uranium and/or thorium.	high
Indicator 4: Mine Type		
Medium EHP	Surface mining, underground mining	medium
Indicator 5: Use of auxiliary substances		
High EHP	Flotation, roasting	low
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for lead range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 36 % low, 35 % medium, 29 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for lead range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results	medium

Environmental hazard potential	Explanation	Data quality
	for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 65 % low, 4 % medium, 31 % high EHP.	
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for lead range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 91 % low, 6 % medium, 3 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 57.80.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 53 million t/a results from the $CRD_{specific}$ of 9.8 t/t and the global annual production of 5,368,632 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 110 PJ/a results from the $CED_{specific}$ of 20,540 MJ-eq/t and the global annual production of 5,368,632 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
	The results for lead range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99.8 % low, 0.2 % medium EHP.	medium

4.27 Limestone

4.27.1 General Information

Introduction and characteristics

Limestone belongs to the carbonate rock and consists mainly of calcite ($CaCO_3$). Industrial limestones are high-quality limestones with high chemical purity (usually more than 97 % $CaCO_3$), which account for only a small part of total limestone production. The largest part is non-industrial limestone, which is mainly used in the construction industry. (European Commission 2017a)

Applications

Calcium carbonate is used e.g. in paper making, plastics manufacturing, paints, coatings and adhesives, container glass, flue gas treatment and many others. Lime is used as a flux in steel production in electric arc furnaces, in flue gas treatment, in concrete production, in soil stabilization, in mortars and in the production of precipitated calcium carbonate (PCC). (European Commission 2017a)

Recycling

Calcium carbonate and lime are usually not obtained from waste, but many of the end-of-life products in which they are used are recycled. This includes the recycling of paper, plastics and glass. Energy recovery from these products also leads to reuse, as calcium carbonate is diverted into the incineration waste often used in construction applications. Lime (used as a flux in the steelmaking process) and impurities form a slag that is used in the construction industry. Calcium carbonate and lime are also used in flue gas treatment where FGD gypsum is used for gypsum board (European Commission 2017a).

Substitution

The substitutes for calcium carbonate in paper production include kaolin, talc and titanium dioxide. Other fluxes for iron and steel production are aluminium oxide, fluorspar and silica. Alumina trihydrate (ATH), talc, silicon dioxide, feldspar, kaolin, spheroidal clay and dolomite can be used in concrete production. In plastics and rubbers substitutes are talc, kaolin, wollastonite, mica, silicon dioxide and aluminium oxide hydrate. Alumina, bentonite, silicon dioxide and others could be used in flue gas scrubbing (European Commission 2017a).

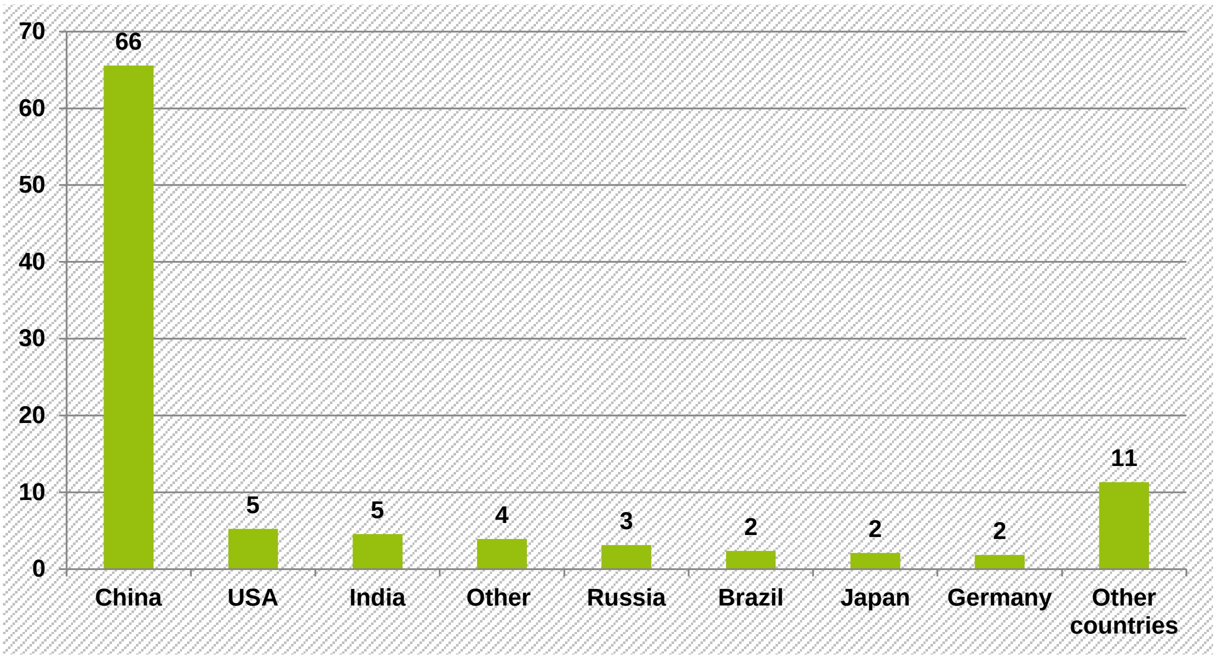
Main product, co-product or by-product

Limestone is a main product (European Commission 2017a).

Primary production

Total global production: 350,770 tonnes in 2015 (USGS 2017).

Percentage of limestone mines mined in 2015 (%) (USGS 2017)



Information on Deposits

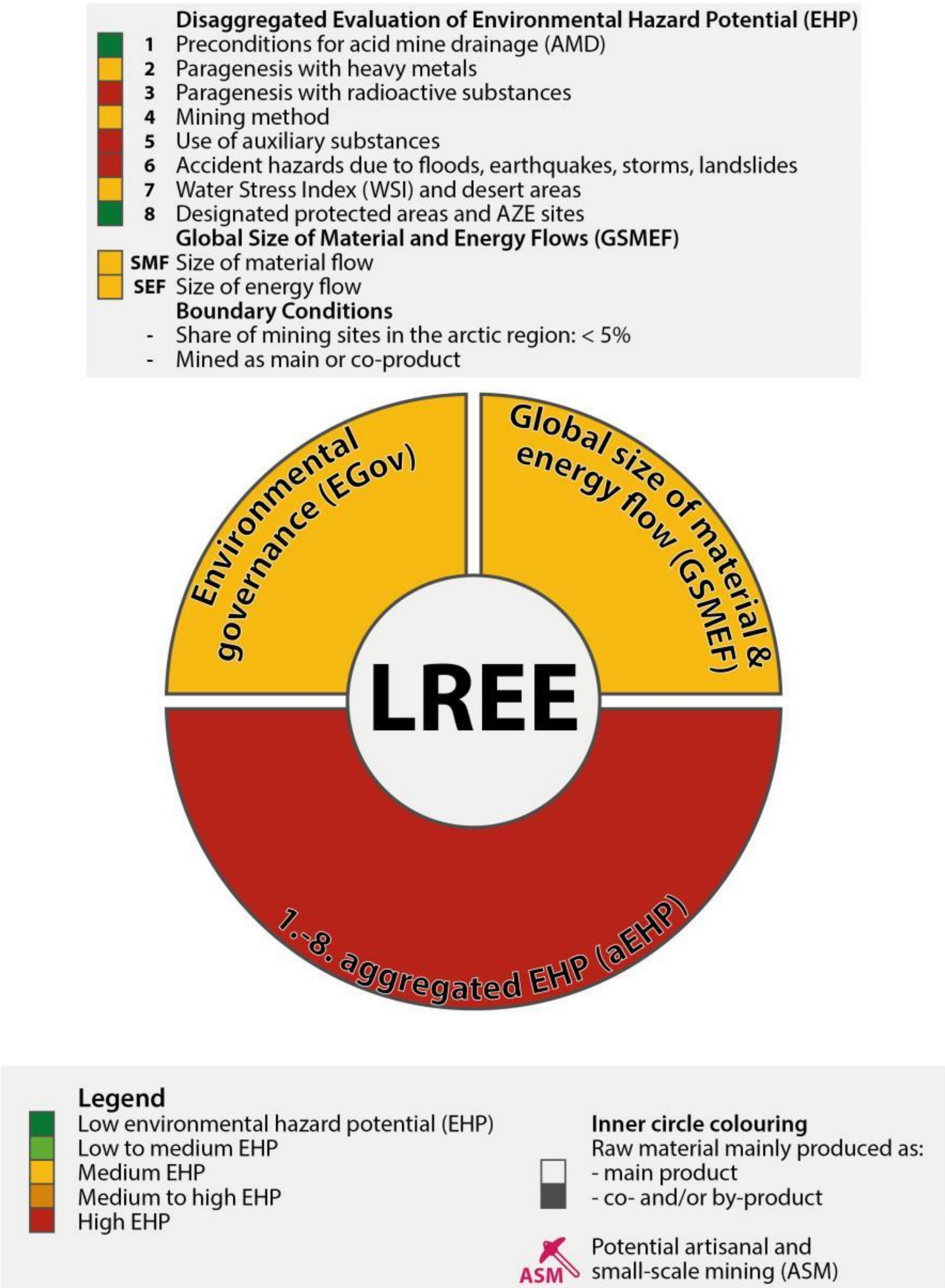
Calcium is a lithophilic element. Limestone is a rock composed of calcite, calcium carbonate, $CaCO_3$. It can be found in deposits of a wide range of formation conditions, pneumatolytic, hydrothermal, but especially inorganic and biochemical marine sedimentary deposits, as well as in evaporites. Economically important for the extraction of limestone are the marine sedimentary recoveries. Limes partly occur together with dolomite, gypsum, anhydrite and clays, claystones.

4.27.2 Profile Limestone

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		

Environmental hazard potential	Explanation	Data quality
Low EHP	Inert material without sulfidic companions due to the biogenic-sedimentary formation conditions of economically used limestone deposits.	medium
Indicator 2: Paragenesis with heavy metals		
Low EHP	Limestone is an abiotic non-metallic raw material from marine sedimentary formation with predominantly very low concentrations of heavy metals.	high
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Compared to magmatic rocks, limestone usually has low concentrations of radioactive substances. Although some radioactive substances are contained in sedimentary constituents (e.g. clay minerals), the total concentrations are generally low.	high
Indicator 4: Mine Type		
Medium EHP	Surface mining	high
Indicator 5: Use of auxiliary substances		
Medium EHP	Calcination	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
N/A	Information not available due to data restrictions	N/A
Indicator 7: Water Stress Index and desert areas		
N/A	Information not available due to data restrictions	N/A
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
N/A	Information not available due to data restrictions	N/A
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 54.49.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 0.4 million t/a results from the $CRD_{specific}$ of 1 t/t and the global annual production of 350,770 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 0.01 PJ/a results from the $CED_{specific}$ of 24 MJ-eq/t and the global annual production of 350,770 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
N/A	Information not available due to data restrictions	N/A

4.28 Light rare earth elements (LREE)



4.28.1 General Information

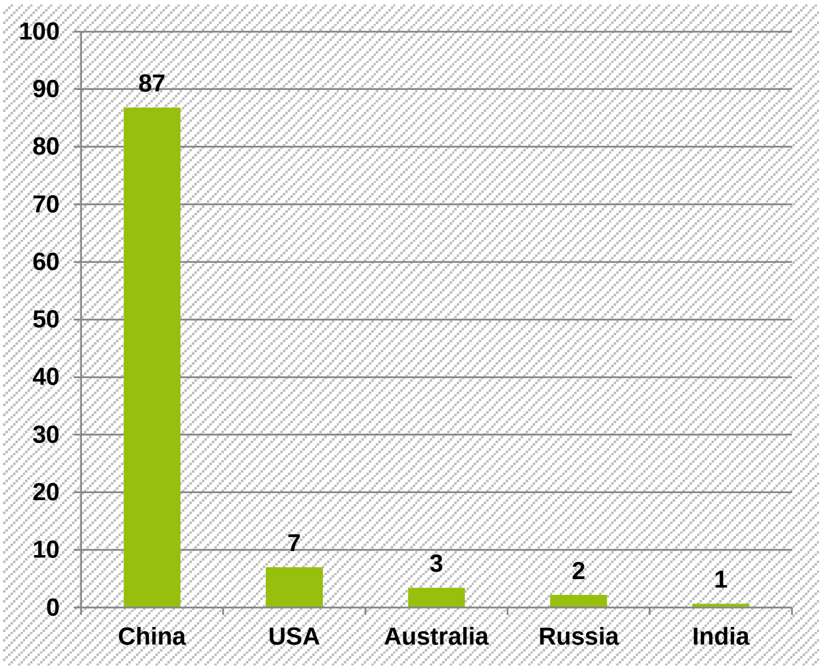
Introduction and characteristics till Main product, co-product or by-product

See Rare Earths (Chapter 4.43.1)

Primary production

Total global production 2012: 114,201 tonnes (European Commission 2015b).

Percentage of LREE mines mined in 2012 (%) (European Commission 2015b)



Information on Deposits

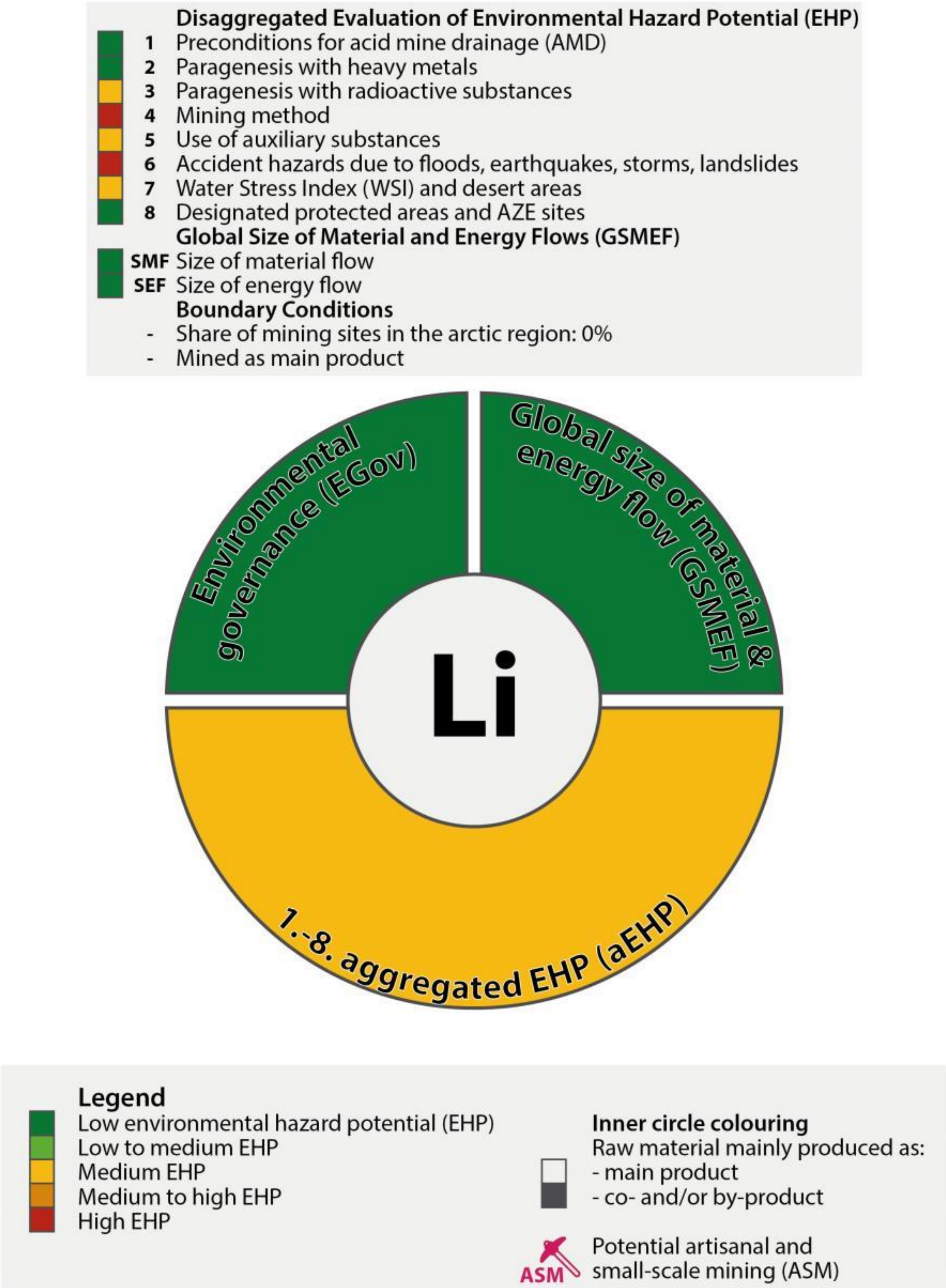
Rare earths (light rare earths: cerium earths and heavy rare earths: ytter earths) are lithophilic elements and occur in pegmatites and carbonatites as silicate minerals and phosphates. The most important ore minerals are monazite ($CePO_4$), xenotim (YPO_4) and bastnäsite ($Ce(F\ CO_3)$). In the primary deposits the contents of plutonium and thorium (e.g. from thorite) have to be considered. The minerals in pegmatitic deposits are often associated with the "black brothers" (black, radioactive and non-magnetic, e.g. euxenite, gadolinite, fergusonite, thortveitite). Due to its resistance to weathering, monazite is often also worth building as placer (together with ilmenite, zircon, rutile, columbite diamond or tin).

4.28.2 Profile Light rare earth elements (LREE)

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Due to the lithophilic properties and the formation conditions of REE, the preconditions for the formation of acid solutions or for autooxidation are low.	low
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Due to the deposit's genesis, only low heavy metal contents are to be expected.	medium
Indicator 3: Paragenesis with radioactive substances		

Environmental hazard potential	Explanation	Data quality
High EHP	Rare earths are usually associated with high concentrations of U and Th. This is confirmed by data from Chinese deposits (86.4 % of world production).	high
Indicator 4: Mine Type		
Medium EHP	Open pit mining, rarely underground mining	high
Indicator 5: Use of auxiliary substances		
Low EHP	Flotation, physical-chemical separation processes Roasting, carbonate precipitation, acid leaching, solvent extraction, in-situ leaching	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	The results for LREE range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 7 % low, 42 % medium, 51 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for LREE range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 76 % low, 11 % medium, 13 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for LREE range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 0 % medium, 1 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 53.12.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 31 million t/a results from the $CRD_{specific}$ of 572 t/t and the global annual production of 114,201 t/a.	low
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 87 PJ/a results from the $CED_{specific}$ of 764,338 MJ-eq/t and the global annual production of 114,201 t/a.	low
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for LREE range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium EHP.	medium

4.29 Lithium


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: 0%
- Mined as main product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Li
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.29.1 General Information

Introduction and characteristics

Lithium is a soft, silvery white alkali metal with the atomic number 3. It is the lightest metal and has the lowest density of all solid elements. It is almost half as dense as water. In elemental form the metal is highly reactive with water and oxygen (JRC 2018, European Commission 2017a).

In the extraction of lithium from salt lakes in South America, the very high demand for water, the associated lowering of the groundwater level or the salination of fresh water is increasingly criticised (see, for example, Deutschlandfunk 2019). There are contradictory statements regarding the actual water requirement of lithium extraction from salt water. In the meantime, improvements in the processes with the return of the purified brine or the extraction of drinking water from the treated "residual water" of lithium extraction are being discussed (see e.g. Handelsblatt 2019).

Applications

The combination of a very good electrical conductivity and the highest electrochemical potential of all metals make Lithium perfect for battery applications. Moreover its low weight leads to an excellent energy to weight ratio. Lithium and its compounds have a low thermal expansion and lead to a reduction of melting points in glass manufacturing. Accordingly the main uses of lithium are in glass & ceramics and batteries, but also other applications play a role e.g. lubricating greases (JRC 2018, European Commission 2017a).

Recycling

Applications with dissipative end-uses such as lubricating greases are not available for recycling. The only waste flow with a potential for lithium recycling are end of life li-ion batteries. The recycling of spent batteries with the recovery of lithium is technically feasible but has not been applied in the past due to cost effectiveness. So far only small amounts of lithium come from secondary sources. With the increasing role of electric vehicles and larger numbers coming to the end of life lithium recycling from spent batteries might become more important (JRC 2018).

Substitution

Lithium in ceramics and glass manufacturing can be replaced by other fluxes at the cost of performance. Lithium can be replaced as anode material in battery applications by a variety of other metals. However, li-ion batteries are currently the only technically feasible option for electric vehicles. Although various substitutes are available in different applications there is little incentive to do so since both low price and stability of supply are ensured. (European Commission 2017a)

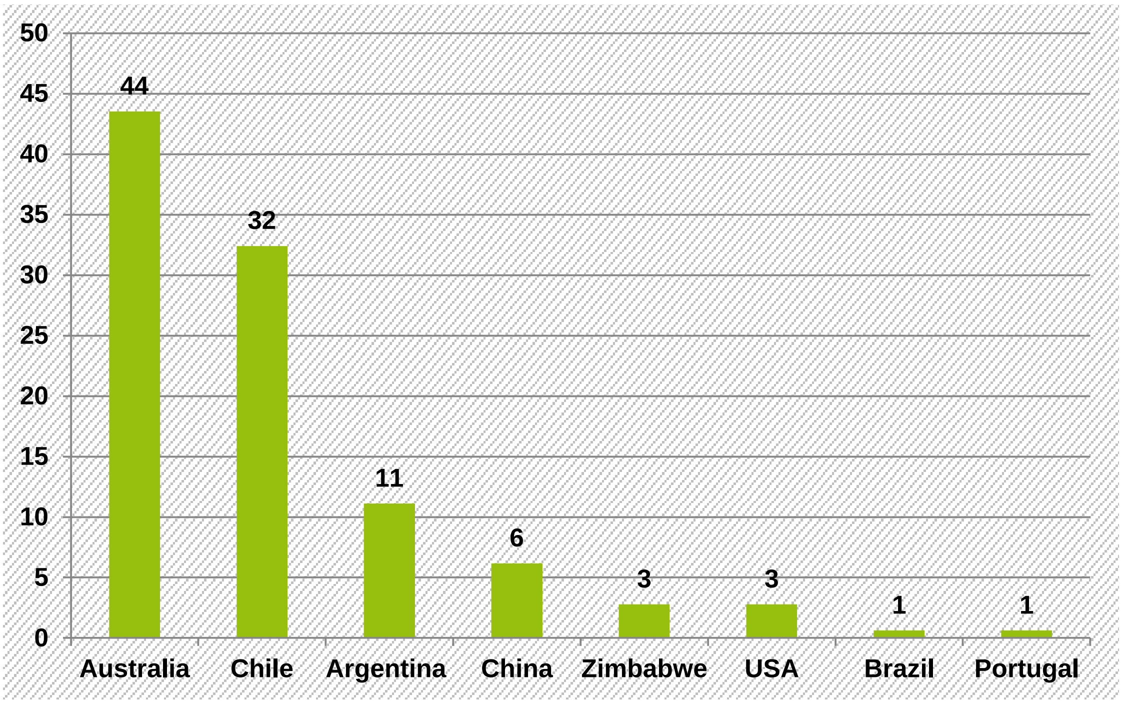
Main product, co-product or by-product

Lithium is a main product (European Commission 2017a).

Primary production

Total global production 2014/15: 32,400 tonnes (USGS 2017, for USA: BGS 2016)

Percentage of lithium mines mined in 20 (%) (USGS 2017, for USA: BGS 2016)



Information on Deposits

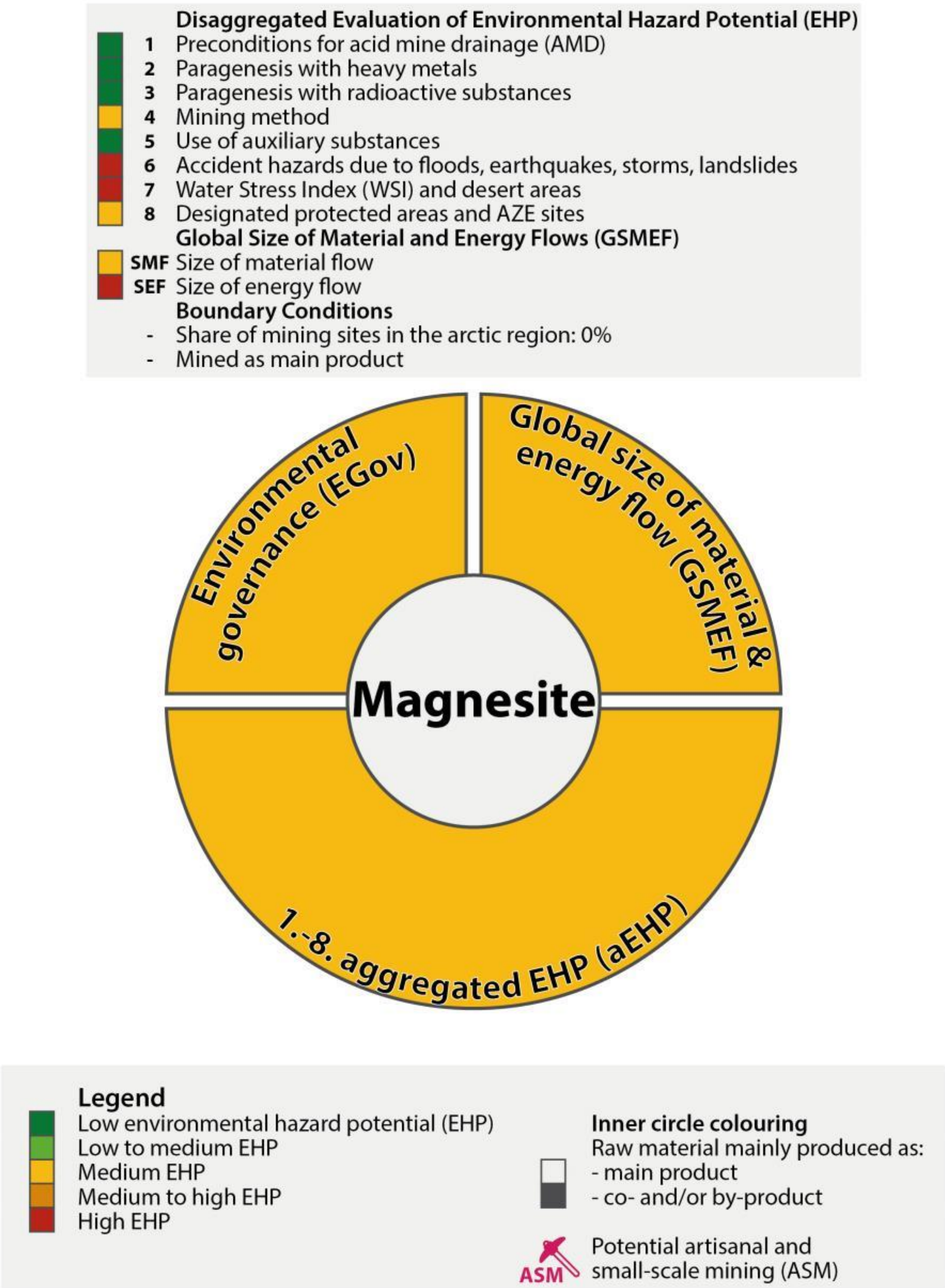
Lithium is a lithophilic element and is mined from two very different raw materials: from silicate lithium minerals ambygonite and spodumene from pegmatites and tin forestite and lepidolite from pneumatolytic deposits (greisen). The second economically significant sources are lithium chlorite and carbonate-rich salts in evaporitic deposits in arid regions (salars in the South American Andes). The extraction from solid rock and brine is currently taking place at a more or less balanced ratio (Schmidt 2017).

4.29.2 Profile Lithium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Both the components of silicate and evaporitic lithium deposits are chemically inert materials that do not tend to autooxidize.	medium
Indicator 2: Paragenesis with heavy metals		
Low EHP	Lithium deposits of either evaporitic or silicate origin. Both types of deposits are predominantly free of heavy metals. Exceptions are deposits of some silicate lithium minerals which can occur in association with tungsten minerals, beryl and other metallic compounds. This type of deposit accounts for only a relatively small proportion of world production.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Lithium from salars can be assumed to have predominantly low concentrations of U and Th. In the case of silicate lithium deposits, it cannot be ruled out that accompanying minerals containing U and Th may be present due to the pegmatitic pneumatolytic formation conditions.	low
Indicator 4: Mine Type		
High EHP	Brine extraction at salt lakes (high EHP) and solid rock mining at silicate minerals (medium EHP) in a ratio of approximately 1:1. Together, this results in the classification high EHP.	high

Environmental hazard potential	Explanation	Data quality
Indicator 5: Use of auxiliary substances		
Medium EHP	Condensation of solutions During extraction from salt lakes, the lithium-containing brine is pumped into evaporation basins in which the lithium is concentrated with the aid of solar energy. Depending on the chemical composition of the brine, different processes can be used. In several steps, the caustic solution is concentrated by evaporation and the precipitation of unwanted components to a content of about 6 % lithium chloride, then the end product lithium carbonate is formed with the addition of sodium carbonate (Evans 2014). When extracted from silicates (spodumene etc.), the ore is usually mined and crushed and ground in open-cast mines and then heated to 1,150°C in a furnace. Sulphuric acid is then used to form lithium sulphate, which is concentrated and, with the addition of sodium carbonate, forms lithium carbonate, which is the end product. (Evans 2014)	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	The results for lithium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 5 % low, 53 % medium, 42 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for lithium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 57 % low, 1 % medium, 42 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for lithium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 98 % low, 2 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 64.61.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 0.4 million t/a results from the $CRD_{specific}$ of 13 t/t and the global annual production of 32,400 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 4.1 PJ/a results from the $CED_{specific}$ of 125,000 MJ-eq/t and the global annual production of 32,400 t/a.	low
Indicator 12: Position of mining sites in the arctic region		
Low	The results for lithium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP.	medium

4.30 Magnesite



4.30.1 General Information

Introduction and characteristics

Magnesite is the common name for the mineral magnesium carbonate (MgCO3). In the EU, magnesite is mainly used for processing magnesia, which is refined into three commercial grades: Calcined lye magnesite (CCM), dead-burned magnesite (DBM) and fused magnesia (FM). (European Commission 2017a)

Applications

Magnesia is used for steel making, in agriculture, paper industry, cement making, ceramics and glass making. (European Commission 2017a)

Recycling

Magnesia is only poorly recovered from post-consumer waste. The input quota for end-of-life recycling is calculated at 2 %. The recycling of refractory materials is possible in the steel and construction industries. However, due to the low consumption of refractories and the amount of primary magnesia, there are few incentives to recycle used refractories. (European Commission 2017a)

Substitution

No material exists that could replace magnesia without serious loss of end performance or increase of cost. In agriculture and industrial applications there is no substitute for CCM. (European Commission 2017a)

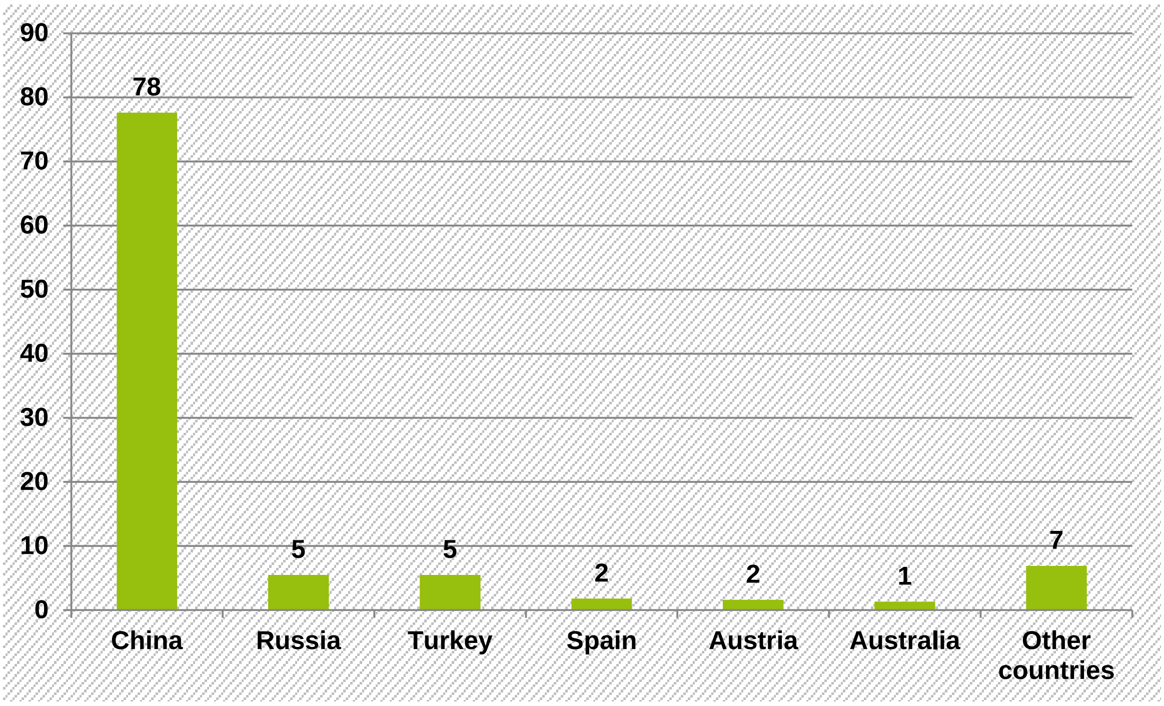
Main product, co-product or by-product

Magnesite is a main product (European Commission 2017a).

Primary production

Total global production 2014: 47,689,394 tonnes (BGS 2016).

Percentage of magnesite mines mined in 2014 (%) (BGS 2016)



Information on Deposits

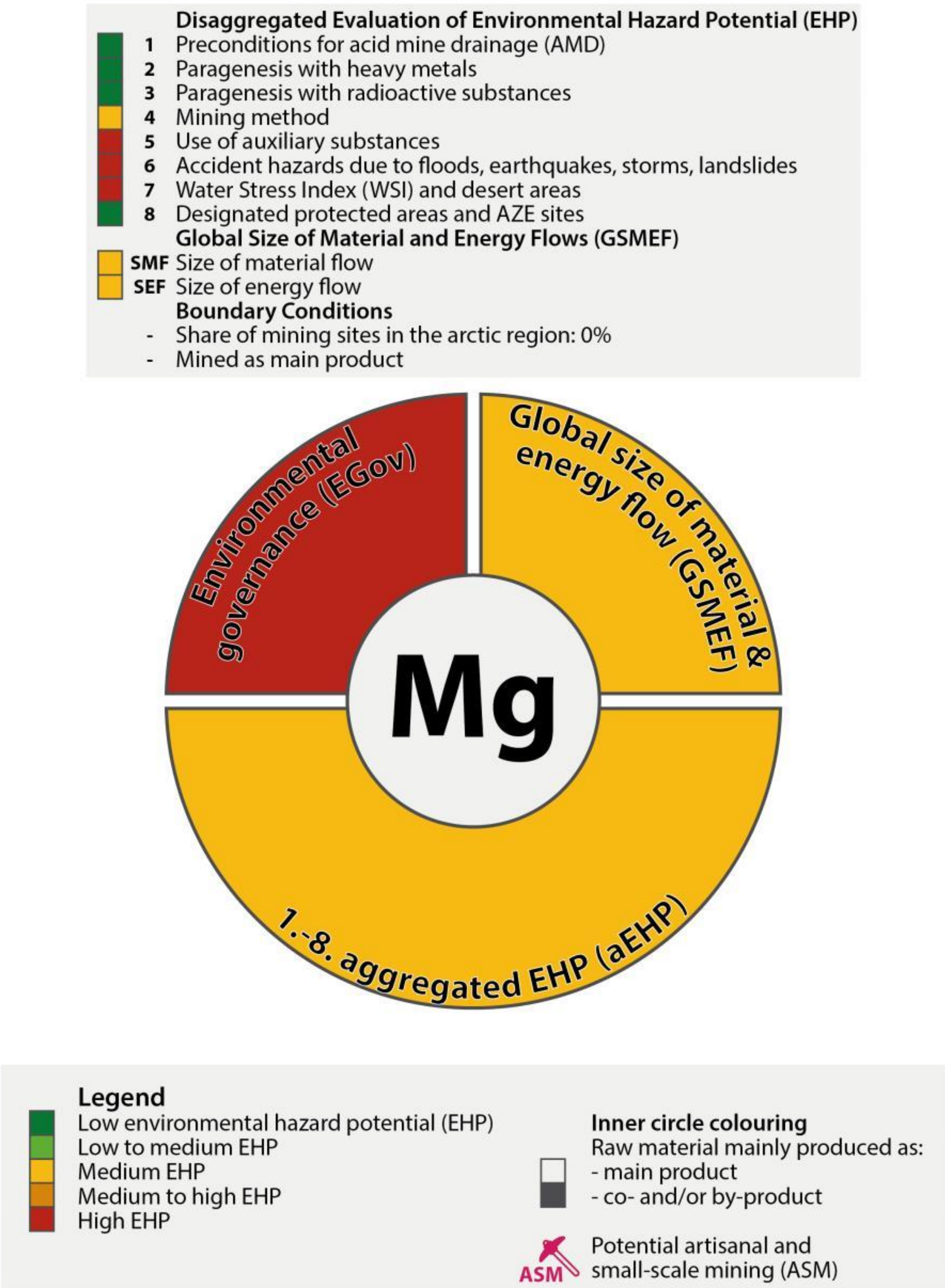
Magnesium is a lithiphilic element, bound in various minerals, to be found in occurrences of almost all conditions of formation and formed as an economically recoverable mineral as carbonate, magnesite, $Mg[CO]_3$. This is the starting product both for high refractory products and for the production of metallic magnesium. Magnesite is found in hydrothermal deposits of plutonic and sub-volcanic origin.

4.30.2 Profile Magnesite

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Magnesite is usually oxidic.	high
Indicator 2: Paragenesis with heavy metals		
Low EHP	Magnesite is mined from deep-thermal deposits, which are usually largely free of minerals with elements with very large atomic radius.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Magnesite is mined from deep-thermal deposits, which are usually largely free of minerals with elements with very large atomic radii (U and Th).	medium
Indicator 4: Mine Type		
Medium EHP	Mining almost always in solid rock open-cast mining	medium
Indicator 5: Use of auxiliary substances		
Low EHP	Processing is usually carried out without the use of chemical auxiliaries by crushing, classifying and calcination.	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	The results for magnesite range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 5 % low, 46 % medium, 49 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for magnesite range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 12 % low, 4 % medium, 84 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for magnesite range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 0 % medium, 1 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 53.62.	high
Indicator 10: Cumulated raw material demand of global production CRDglobal		
Medium	CRDglobal of 100 million t/a results from the CRDspecific of 2.1 t/t and the global annual production of 47,689,394 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 187 PJ/a results from the $CED_{specific}$ of 3,927 MJ-eq/t and the global annual production of 47,689,394 t/a.	high
Indicator 12: Position of mining sites in the arctic region		

Low	The results for magnesite range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP.	medium

4.31 Magnesium



4.31.1 General Information

Introduction and characteristics

Magnesium is the eighth most abundant element in the earth's crust. It is a metal that occurs in nature not in its elemental form, but in various forms in minerals (dolomite, magnesite and carnallite) as well as in seawater and brine. Magnesium is sold in the form of pure metal or as a casting alloy. (European Commission 2017b)

Applications

The major application for magnesium are alloys in the automotive industry (58 %) to lower the overall weight. 12 % is used as desulphurisation agent in steel-making. Further fields of application are packaging, construction equipment and medical or sports applications. (European Commission 2017b)

Recycling

At EU level, the magnesium recycling capacity is about 75,000 tonnes per year (mainly for new scrap). The EoL recycling input rate for the EU is estimated at 9 %. A large share of magnesium is used in the EU as an alloying element in the production of aluminium alloys, so most of the magnesium scrap consumed is recycled as part of the aluminium stream. (European Commission 2017b)

Substitution

Possible substitutes in casting and aluminium alloys are composites such as carbon fibre reinforced plastics as well as steel and titanium alloys. In transport applications, reinforced plastics, steel or titanium can be used instead of magnesium-containing aluminium alloys. In the construction sector, steel, plastics and wood are possible substitutes. Steel, glass and plastics can be used for packaging. The steel desulphurisation process allows the use of several reagents such as lime (carbon oxide, CaO), calcium carbide (CaC_2) and magnesium (Mg). (European Commission 2017b)

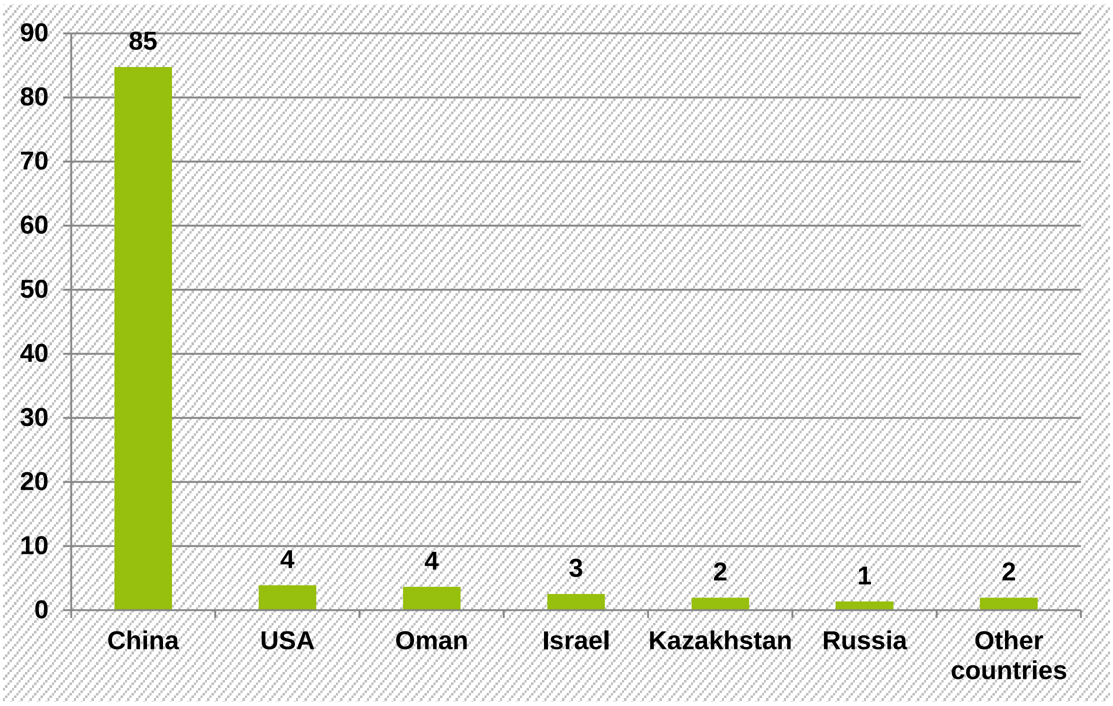
Main product, co-product or by-product

Magnesium is a main product (European Commission 2017b).

Primary production

Total global production 2014: 1,031,227 tonnes (BGS 2016).

Percentage of magnesium mines mined in 2014 (%) (BGS 2016)



Information on Deposits

Metallic magnesium is extracted from two very different sources: mineral magnesium carbonates (magnesite, dolomite, etc.) or magnesium silicates (e.g. olivine as a by-product of asbestos extraction), and seawater.

4.31.2 Profile Magnesium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Magnesium is usually present as oxidic lithophilic elements.	high
Indicator 2: Paragenesis with heavy metals		
Low EHP	A large part of the mining is carried out from sedimentary rocks of marine formation with predominantly very low concentrations of heavy metals.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Mining magnesium ores are mainly extracted from marine sedimentary deposits. It is assumed that these deposits generally have a low concentration of radioactive substances due to their formation. Alternative deposits (e.g. deep-thermal magnesite deposits) also have low concentrations of radioactive substances (see magnesite).	medium
Indicator 4: Mine Type		
Medium EHP	Extraction of ores / minerals containing magnesium for magnesium production mainly in open pit mining. Carnallite is an exception here, but is less relevant in terms of quantity.	medium
Indicator 5: Use of auxiliary substances		
High EHP	During processing, leaching is carried out with HCl or $CaCl_2$.	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	The results for magnesium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment.	medium

Environmental hazard potential	Explanation	Data quality
	The results of the GIS assessment are: 2 % low, 49 % medium, 49 % high EHP.	
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for magnesium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 5 % low, 0 % medium, 95 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for magnesium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 0,5 % medium, 0,5 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 52.60.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 5.2 million t/a results from the $CRD_{specific}$ of 5.1 t/t and the global annual production of 1,031,227 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 19 PJ/a results from the $CED_{specific}$ of 18,800 MJ-eq/t and the global annual production of 1,031,227 t/a.	low
Indicator 12: Position of mining sites in the arctic region		
Low	The results for magnesium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP.	medium

4.32 Manganese

Disaggregated Evaluation of Environmental Hazard Potential (EHP)

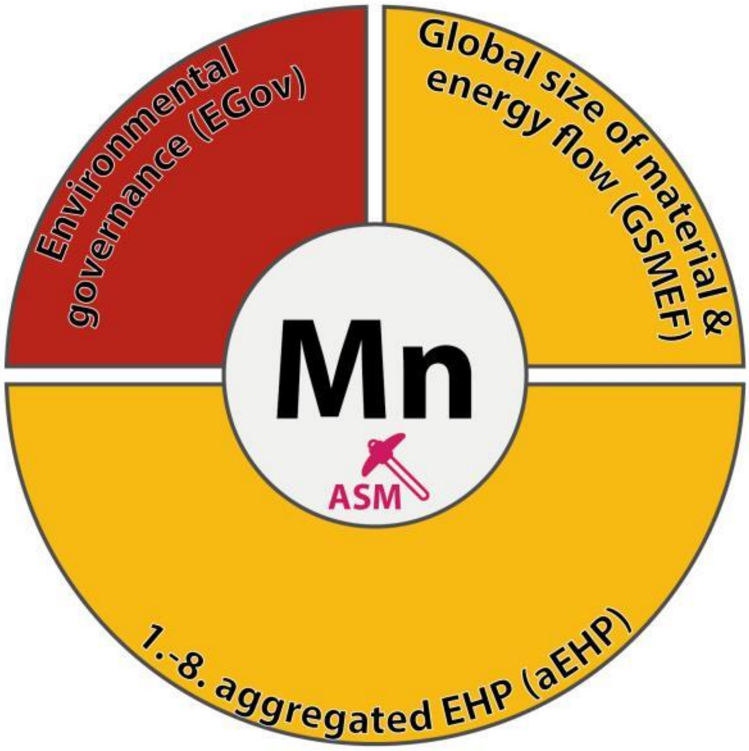
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites

Global Size of Material and Energy Flows (GSMEF)

SMF Size of material flow
SEF Size of energy flow

Boundary Conditions

- Share of mining sites in the arctic region: 0%
- Mined as main product



Legend

Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP

Inner circle colouring

Raw material mainly produced as:
- main product
- co- and/or by-product

ASM Potential artisanal and small-scale mining (ASM)

4.32.1 General Information

Introduction and characteristics

Manganese is a paramagnetic, relatively hard but brittle metal. It is the 12th most common element in the upper crust of the earth. The main ore mineral of manganese is pyrolusite (MnO_2), although brownite (a Mn silicate), psilomelan (a Mn oxide) and rhodochrosite ($MnCO_3$) may be locally important. (European Commission 2017a)

Applications

Around 87 % of manganese is used in steelmaking as a desulphurising and reducing agent and to improve the mechanical properties of steel. Manganese is also used in the production of non-steel alloys (6 %), which are mainly used in the production of aluminium cans and food packaging. The most important non-metallurgical use of manganese is the manufacture of dry batteries. (European Commission 2017a)

Recycling

The end-of-life recycling of manganese (mainly as a component of ferrous and non-ferrous scrap) is estimated at more than 50 %. However, the amount of manganese actually recovered from scrap is negligible, estimated at around 12 % by the ad hoc working group on the definition of critical raw materials. Manganese can also be obtained from slag from steel production. (European Commission 2017a)

Substitution

There are currently no suitable substitutes for manganese in its major applications. (European Commission 2017a)

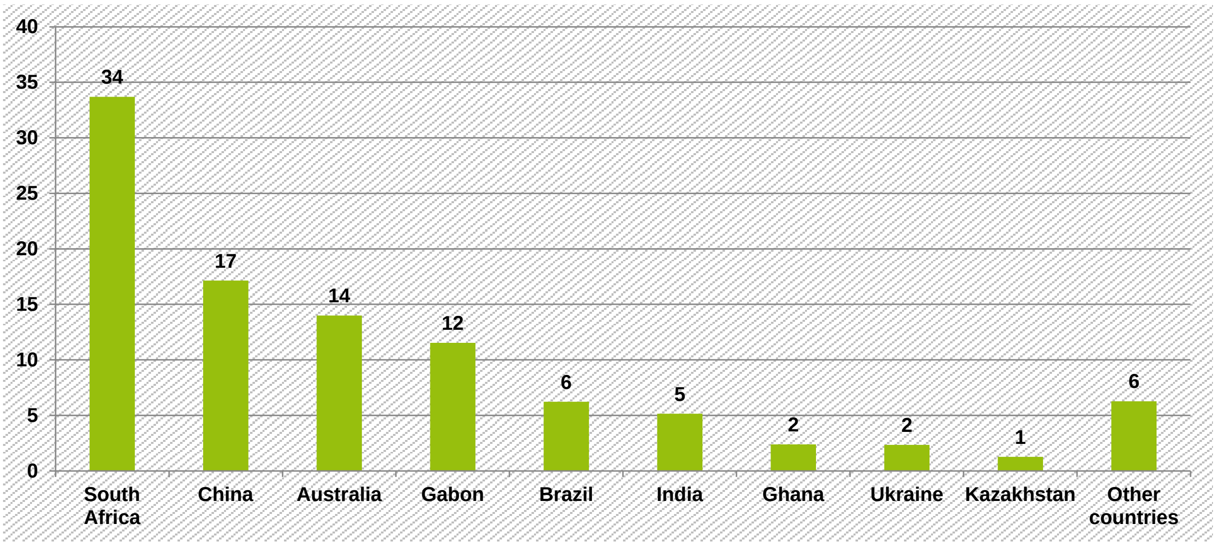
Main product, co-product or by-product

Manganese is a main product (European Commission 2017a).

Primary production

Total global production 2015: 17,507,000 tonnes (USGS 2017).

Percentage of manganese mines mined in 2015 (%) (USGS 2017)



ASM relevance

The global share of manganese production from ASM is estimated by BGR (2007) at around 11 %, GEUS (2007) gives a number of 20 %.

Important manganese producing countries with prominent ASM production are South Africa, China, Gabon, Brazil, India and Ghana. 80 % of manganese is produced in countries with ASM.

Information on Deposits

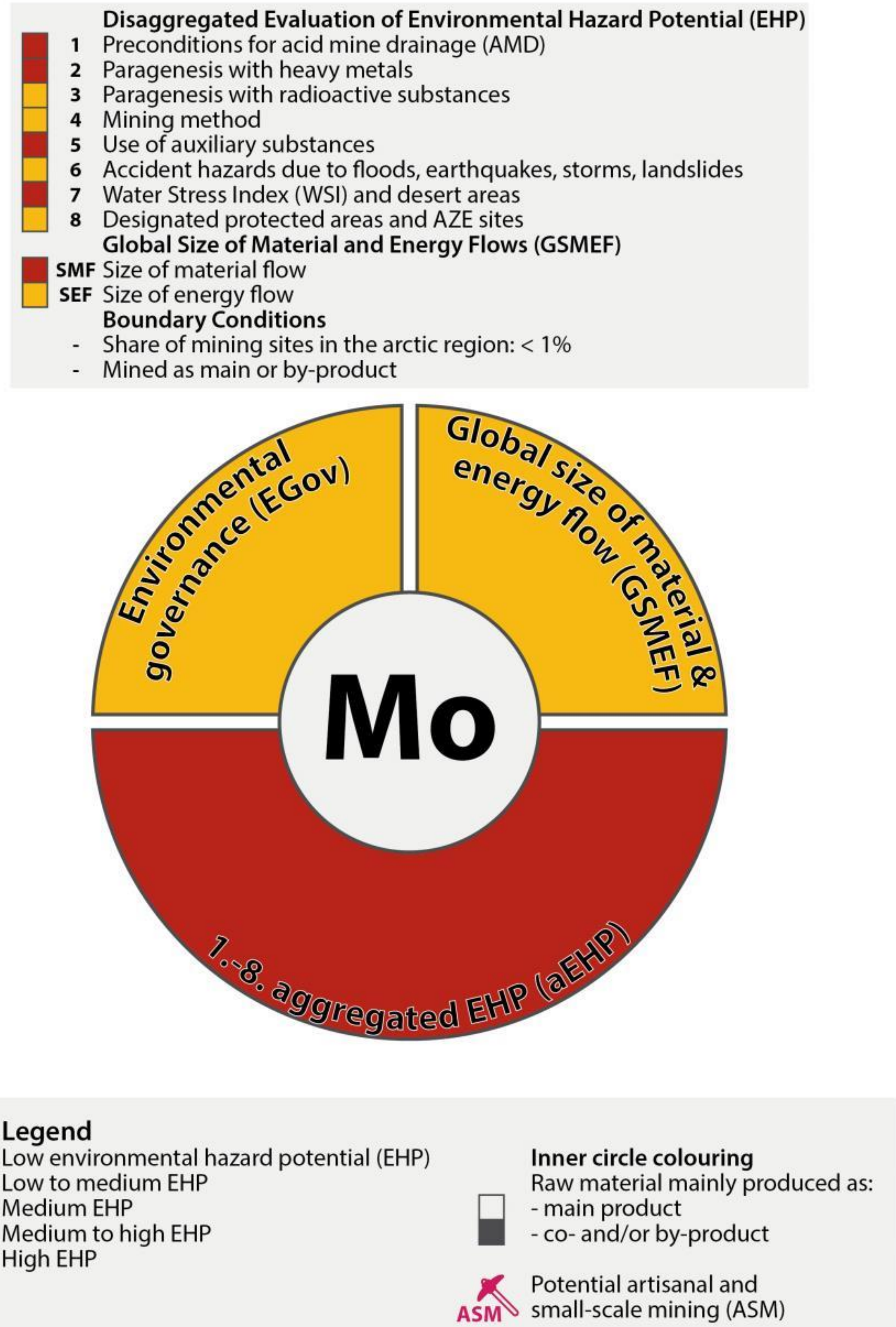
Manganese is a lithophilic element and is contained in many minerals. It is economically recoverable in the form of the two oxides pyrolusite and psilomelan. The former occurs in plutonic and sub-volcanic hydrothermal deposits as well as in inorganic marine sedimentary deposits (e.g. as manganese nodules). Finally both oxides in weathering deposits on the mainland. A distinction has to be made between the two forms of trade: pure oxides as the starting product for metallic manganese (battery production) and iron ores for the production of ferromanganese (steel refiners).

4.32.2 Profile Manganese

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Parageneses are low sulfide or sulfide free.	mittel
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Manganese itself is not a heavy metal, but is mostly extracted from deposits under the association of heavy metals.	high
Indicator 3: Paragenesis with radioactive substances		
High EHP	Data from Egyptian manganese deposits show on average high concentrations of uranium and thorium. However, as only a relatively small part of world production takes place in Egypt, the significance of these data is limited.	low
Indicator 4: Mine Type		
Medium EHP	Surface mining, underground mining	medium
Indicator 5: Use of auxiliary substances		
Low EHP	Sword washing, hand picking	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for manganese range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 73 % low, 13 % medium, 14 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for manganese range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 51 % low, 2 % medium, 47 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
High EHP	The results for manganese range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 85 % low, 12 % medium, 3 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		

Environmental hazard potential	Explanation	Data quality
High	From the EPI and the production share of the individual countries results an EGov-Score of 51.21. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 144 million t/a results from the $CRD_{specific}$ of 8.2 t/t and the global annual production of 17,507,000 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 415 PJ/a results from the $CED_{specific}$ of 23,700 MJ-eq/t and the global annual production of 17,507,000 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Low	The results for maganese range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP.	medium

4.33 Molybdenum



4.33.1 General Information

Introduction and characteristics

Molybdenum is a silver-white, very hard transition metal with the atomic number 42. It has the highest melting point of all pure elements. Molybdenum is most abundant in the earth's crust as mineral molybdenite (MoS_2), which is the main source of molybdenum. (European Commission 2017a)

Applications

Due to its properties, molybdenum can be used in a wide range of applications. It is an important alloy element in stainless steel, other aloyey steel and iron, high performance nickel-based alloys and as molybdenum metal and alloys in e.g. high temperature heating elements, rotating X-ray anodes, sprayed coatings on automotive piston rings. It is also used in catalysts, pigments, corrosion inhibitors, smoke suppressants, lubricants and micronutrients for agriculture as well as an essential trace nutrient element for plant, animal and human life. (European Commission 2017a)

Recycling

Although molybdenum is not recovered from steel scrap, a large percentage of it is reused due to the high recycling of molybdenum-containing steel alloys. For this purpose, molybdenum-containing scrap is collected separately in order to reuse molybdenum. The amount of molybdenum, from new and old steel and other scrap, is estimated at up to 30 % of the apparent supply of molybdenum. (European Commission 2017a)

Substitution

Among others, tungsten, nickel, titanium, cobalt, niobium and chromium can be used as susbtitute for molybdenum as alloying element. PGM or even glass products could be used for industrial corrosion resistance and high temperature environments. In high-temperature applications, molybdenum (with an associated reduction in temperature resistance of about 600°C) can be replaced by iron, nickel and cobalt-based superalloys, ceramics and other high-melting metals (tungsten, tantalum and niobium). (European Commission 2017a)

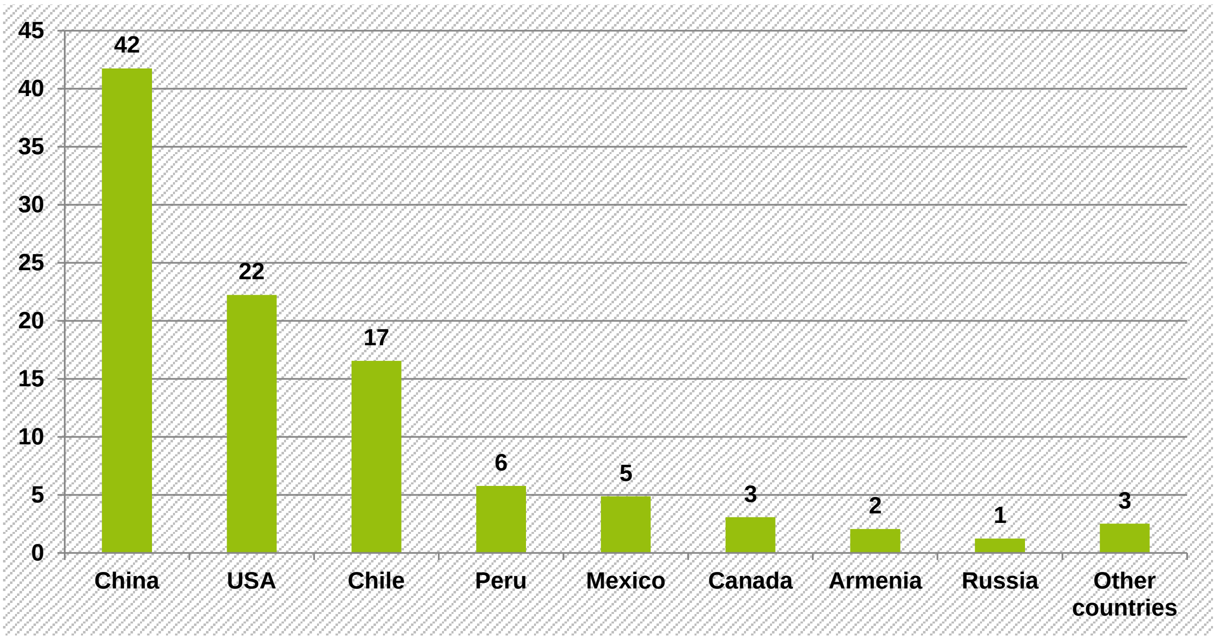
Main product, co-product or by-product

Molybdenum is mostly being mined as a main product, but can be a by-product of copper (European Commission 2017a)

Primary production

Total global production 2014: 294,725 tonnes (BGS 2016).

Percentage of molybdenum mines mined in 2014 (%) (BGS 2016)



Information on Deposits

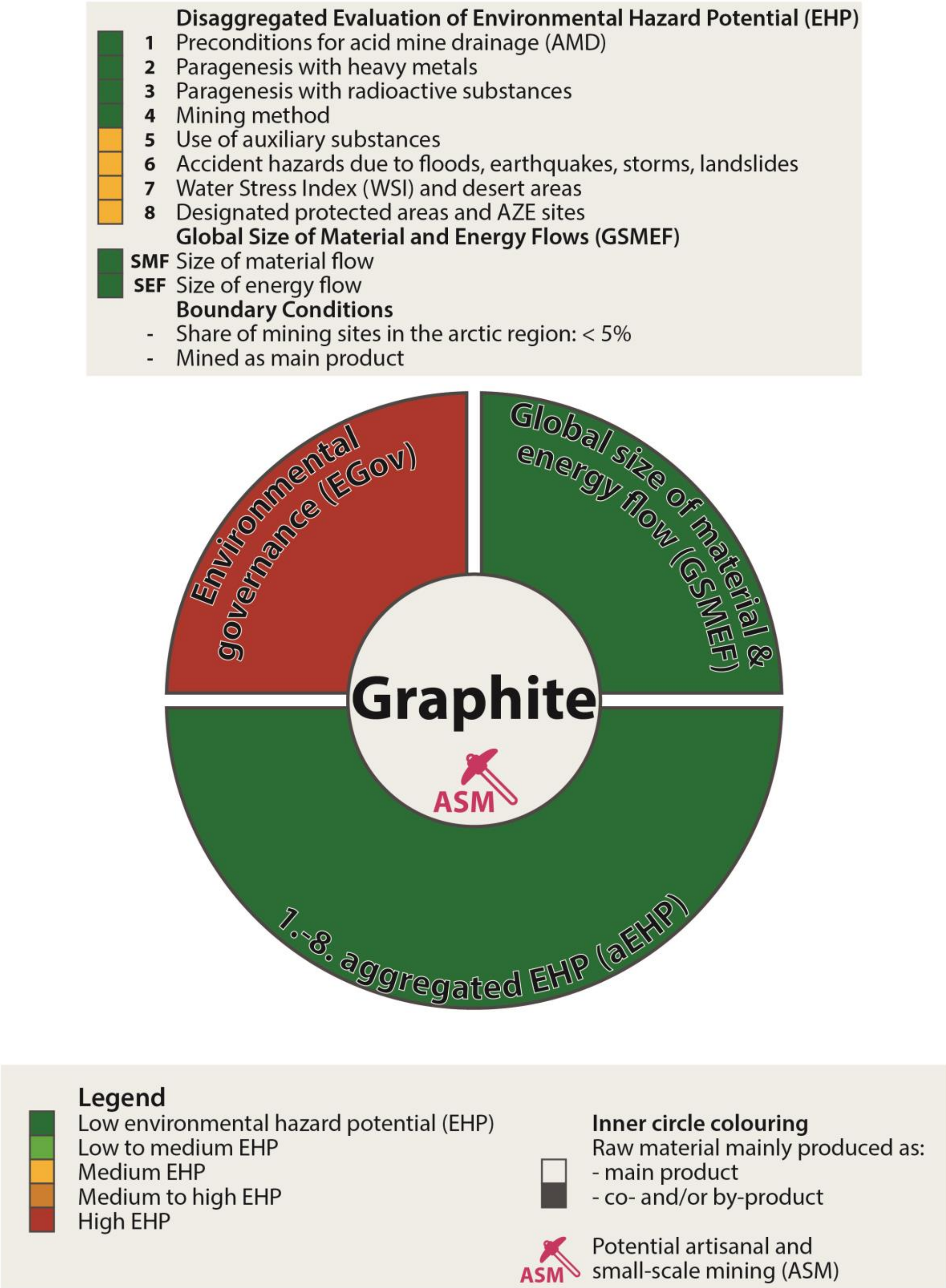
Molybdenum is a siderophilic element. Ore minerals of economic importance are molybdenite (molybdenum sulphide) and wulfenite (lead molybdate). Paragenetically, tin calcite, bismuth minerals, pyrite, copper pyrites, fluorspar, beryl, topaz and tungsten minerals can be expected. These parage genes are found in pneumatolytic, deep thermal and sub-volcanic hydrothermal deposits.

4.33.2 Profile Molybdenum

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Both the pure molybdenum ores and the ores from which molybdenum is extracted as a by-product are paragenetically associated with sulphide minerals, which have a high potential for acid formation.	high
Indicator 2: Paragenesis with heavy metals		
High EHP	46 % of the molybdenum mined is a by-product of copper ores. Other deposits include wulfenite (lead molybdate).	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	No specific data are available. In accordance with the procedure described in the method document, an evaluation is carried out with a medium EHP. This assessment is supported by general statements by Valkovic (2000).	medium
Indicator 4: Mine Type		
Medium EHP	30 % from ores, 70 % as by-product of copper production	low
Indicator 5: Use of auxiliary substances		
High EHP	Gravimetry, flotation, calcination	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for molybdenum range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment.	medium

Environmental hazard potential	Explanation	Data quality
	The results of the GIS assessment are: 30 % low, 30 % medium, 40 % high EHP.	
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for molybdenum range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 42 % low, 7 % medium, 51 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for molybdenum range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 98 % low, 0 % medium, 2 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 58.72.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 292 million t/a results from the $CRD_{specific}$ of 989 t/t and the global annual production of 294,725 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 34 PJ/a results from the $CED_{specific}$ of 117,000 MJ-eq/t and the global annual production of 294,725 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for molybdenum range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99.5 % low, 0.5 % medium EHP.	medium

4.34 Natural graphite



4.34.1 General Information

Introduction and characteristics

Natural graphite (chemical symbol C) is a soft, grey-black mineral with both metallic and non-metallic properties. It is a good thermal and electrical conductor, has high thermal resistance and lubricity, is corrosion resistant, chemically inert and non-toxic. (European Commission 2017b)

Applications

The largest markets for natural graphite are refractories for steel making (52 %) and foundries (14 %). It is also used for anode material in lithium-ion batteries, for lubricants, friction products, to raise the carbon content (recarburising) of steel, in pencils, in expandable and foil graphite applications and other applications. (European Commission 2017b)

Recycling

A very large amount of material containing natural graphite is lost during use and therefore cannot be recycled. The recycling of post-consumer products is dampened by oversupply and low prices. (European Commission 2017b)

Substitution

There is no substitute (also not synthetic graphite) for natural graphite for refractory. For other applications synthetic graphit or other carbon products such as high carbon waste and calcined petroleum coke are used as substitutes. In lubricants molybdenum disulphide can substitute graphite too. (European Commission 2017b)

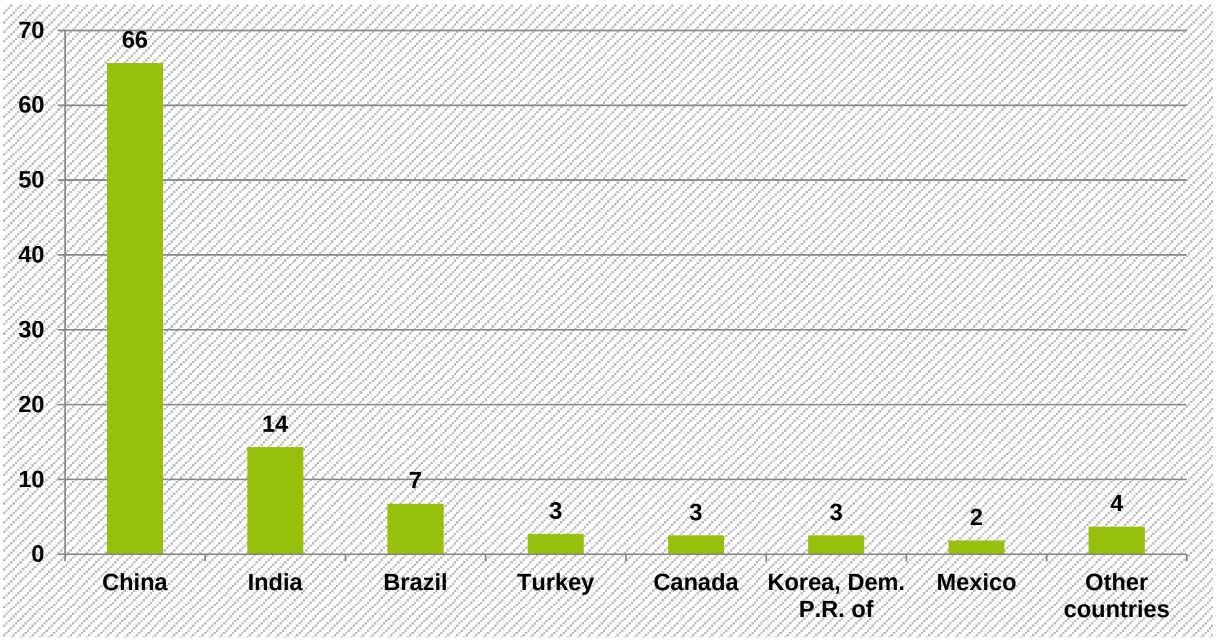
Main product, co-product or by-product

Natural graphite is a main product (European Commission 2017b).

Primary production

Total global production: 1,188,000 tonnes in 2017 (USGS 2017).

Percentage of natural graphite mines mined in 2017 (%) (USGS 2017)



ASM relevance

Due to geological conditions of the deposits the exploitation of graphite is mostly done on a small, but mechanized scale. GEUS (2007) estimated 90 % of the global prevenient from small producers.

Graphite mining is related to a low environmental hazard potential due to inert chemistry of the product and its accessories and absence of toxic heavy metals. Hardrock mining, predominantly underground, mostly even in ASM in a mechanized or semi-mechanized form.

Important graphite producing countries with prominent ASM production are China, India, Brazil and Mexico. 92 % of graphite is produced in countries with ASM.

Information on Deposits

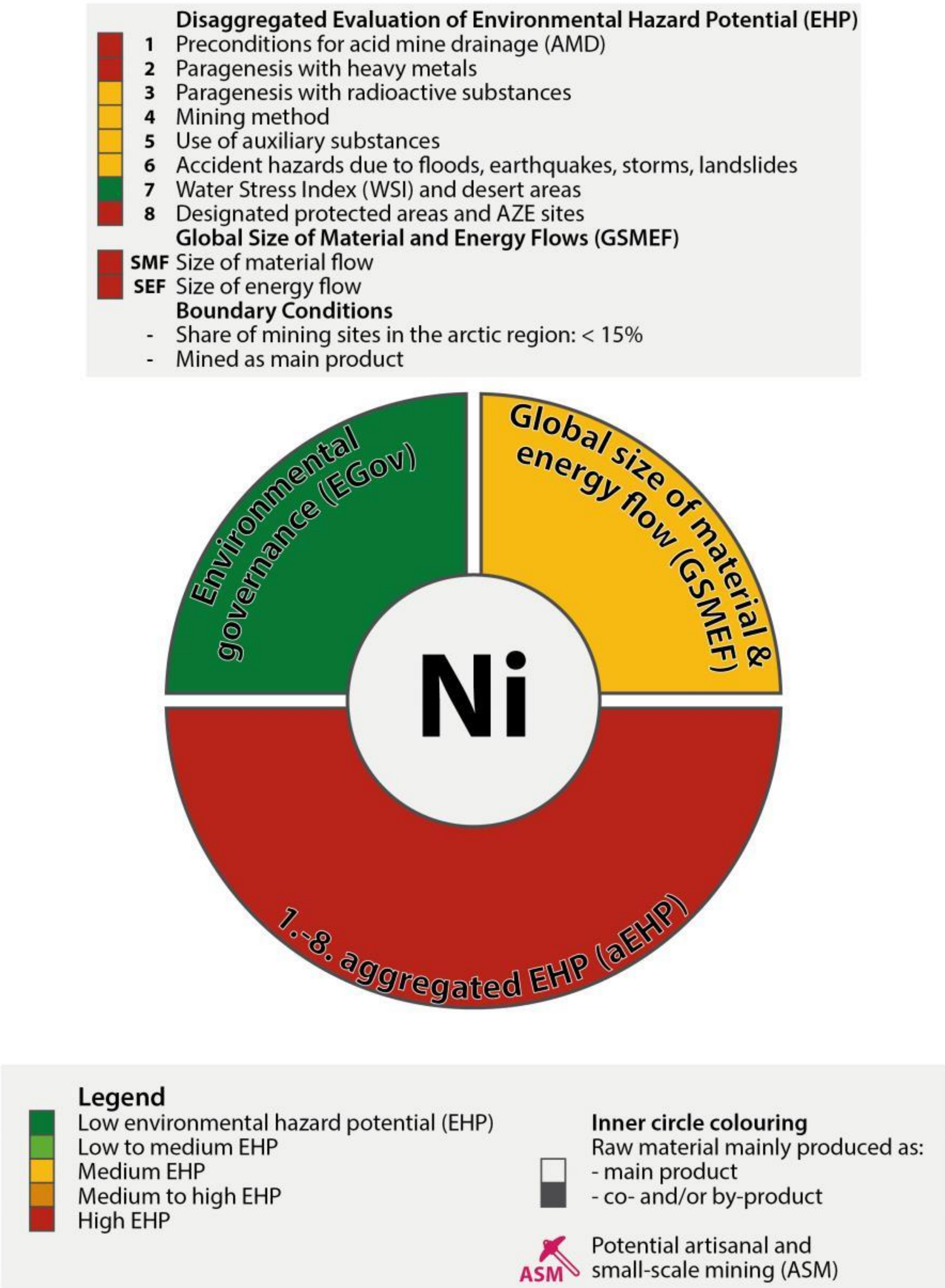
Carbon is a siderophilic element and occurs in nature as carbon, diamond and graphite. Graphite is formed in weakly basic silicate crystallizations and, economically more significant, in contact metasomatic displacements by pegmatite ducts. Here it is mainly associated with silicate minerals.

4.34.2 Profile Natural Graphite

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	As a rule, graphite is not sulfidic.	high
Indicator 2: Paragenesis with heavy metals		
Low EHP	Deposits mainly in formations with silicate mineral aggregations that contain only very small amounts of heavy metals.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Graphite is usually not associated with radioactive substances.	low
Indicator 4: Mine Type		
Low EHP	As a rule, graphite is extracted in underground mining, as the deposits are usually corridor deposits that require selective extraction.	high
Indicator 5: Use of auxiliary substances		
Medium EHP	"For processing, graphite is usually floated using chemical auxiliaries. Flotation, magnetic separation, electrostatic processes (Johnstone (1954): 197)".	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for graphite range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 51 % low, 20.5 % medium, 28.5 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for graphite range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 61 % low, 1 % medium, 38 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for graphite range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results	medium

Environmental hazard potential	Explanation	Data quality
	for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 97.5 % low, 0.5 % medium, 2 % high EHP.	
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 49.53. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 1.3 million t/a results from the $CRD_{specific}$ of 1.1 t/t and the global annual production of 1,188,000 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 0.5 PJ/a results from the $CED_{specific}$ of 437 MJ-eq/t and the global annual production of 1,188,000 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for natural graphite range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium EHP.	medium

4.35 Nickel


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 15%
- Mined as main product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Ni
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.35.1 General Information

Introduction and characteristics

Nickel is a shiny white metal. In nature it mostly occurs in a combined form, mainly as isotopes of mass numbers 58 (68 %) and 60 (26 %). The presence of nickel in the earth's crust is mediocre at 47 parts per million frequency of the upper crust. Sulphide ores are currently the main source of the mined nickel. Nickel alloys are characterized by strength, toughness and corrosion resistance over a wide temperature range. (European Commission 2017a)

Metallic and inorganic nickel as dust is carcinogenic (Daunderer 2006).

Applications

Nickel is used in stainless steel (accounts for 65 % of nickel first-use), in other steel alloys, other non-ferrous alloys (e.g. in coins, superalloys for power generation or aerospace), for plating (in e.g. medical equipment, construction materials and cosmetic applications), in foundry and in a wide range of chemical production (batteries, reforming hydrocarbons and production of fertilisers, pesticides and fungicides). (European Commission 2017a)

Recycling

The recycling input rate of nickel is 34 %. The economic value of nickel metal provides a significant incentive for recycling. The recycling efficiency is estimated at around 68 %. Recycling takes place indirectly in stainless steel production through the use of nickel-containing alloys, waste from primary nickel producers and other nickel-containing waste. (European Commission 2017a)

Substitution

For nickel used in metal products such as plates, pipes, beams, etc., other steel alloys with titanium, chromium or cobalt can be used. The substitution of nickel-metal hydride (NiMH) batteries is limited. Lithium ion batteries could be an alternative, but are basically different products with different technical requirements. (European Commission 2017a)

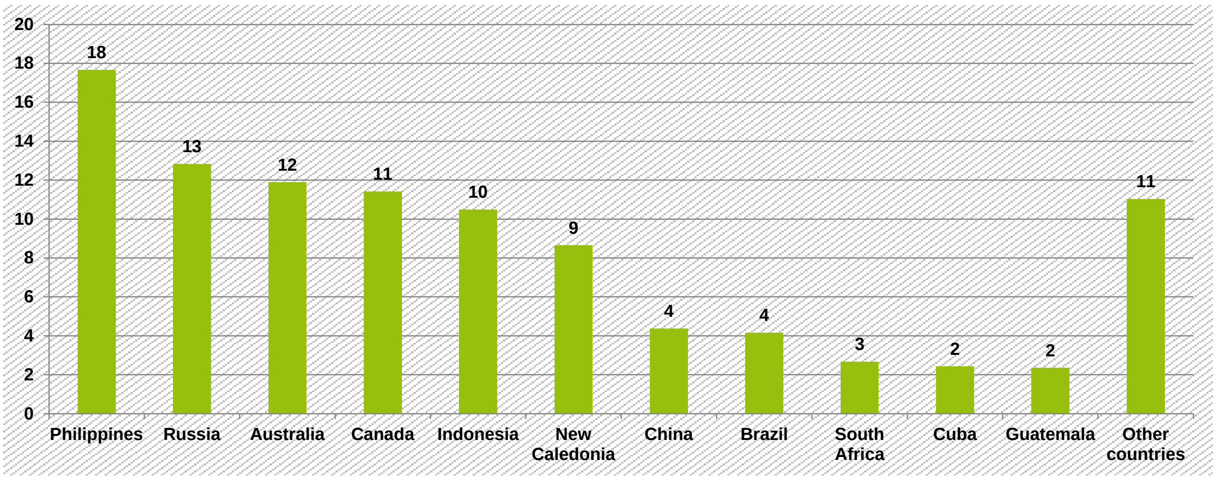
Main product, co-product or by-product

Nickel is a main product (European Commission 2017a).

Primary production

Total global production 2014: 2,056,641 tonnes (BGS 2016).

Percentage of nickel mines mined in 2014 (%) (BGS 2016)



Information on Deposits

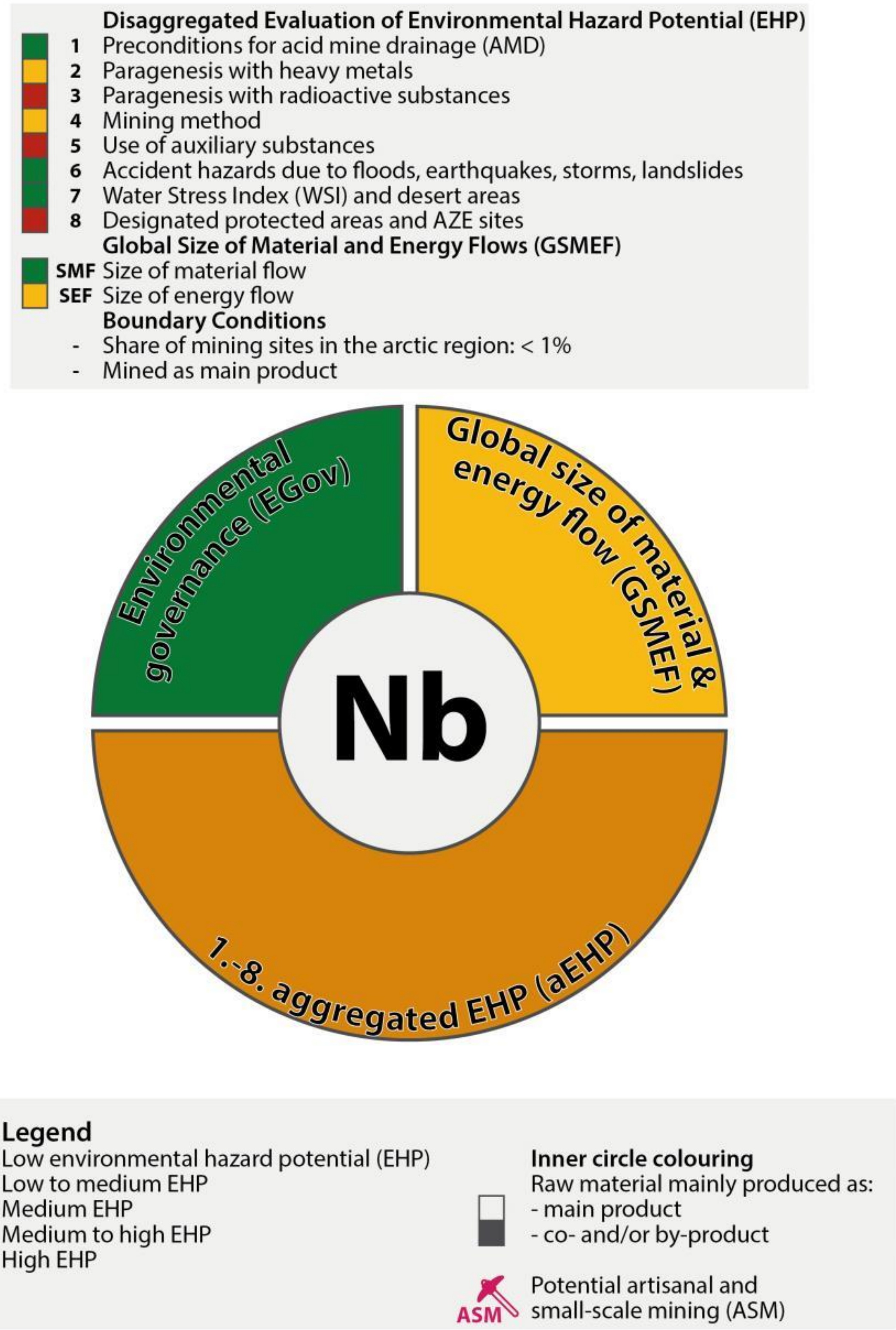
Nickel is a siderophilic element. The most important economic deposits are the liquid magmatic segregations, the plutonic hydrothermal strata in the cobalt-nickel-silver-bismuth-uranium group and the terrestrial weathering deposits. Pentlandite ($(Ni,Fe)_9S_8$), nickel-containing magnetic gravel (Pyrrhotin, Fe_7S_8), pyrite, chalcopyrite, the PGM minerals Sperrylith and Stibiopalladinite and cobalt-rich minerals are predominant as value minerals in the first mentioned nickel magnetic gravel deposits. Here and in the hydrothermal deposits also red nickel gravel (Nickelin, NiAs). In the weathering deposits nickel silicates, e.g. garnierite next to cobalt minerals.

4.35.2 Profile Nickel

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Nickel and cobalt ores are in most cases present in the form of sulphidic iron-nickel-cobalt minerals (e.g. nickel magnetic gravel).	high
Indicator 2: Paragenesis with heavy metals		
High EHP	The element nickel itself has toxic properties and is defined as a heavy metal in this method description.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	No specific data are available. In accordance with the procedure described in the method document, an evaluation is carried out with a medium EHP. This assessment is supported by general statements by Valkovic (2000).	medium
Indicator 4: Mine Type		
Medium EHP	Surface mining, underground mining	medium
Indicator 5: Use of auxiliary substances		
Medium EHP	Flotation, roasting, magnetic separation	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for nickel range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 57 % low, 12 % medium, 31 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Low EHP	The results for nickel range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 88 % low, 1 % medium, 11 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
High EHP	The results for nickel range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 86 % low, 7 % medium, 8 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 60.60.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 274 million t/a results from the $CRD_{specific}$ of 133 t/t and the global annual production of 2,056,641 t/a.	high

Environmental hazard potential	Explanation	Data quality
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 228 PJ/a results from the $CED_{specific}$ of 111,000 MJ-eq/t and the global annual production of 2,056,641 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
High	The results for nickel range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 90 % low, 10 % medium EHP.	medium

4.36 Niobium


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 1%
- Mined as main product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Nb
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.36.1 General Information

Introduction and characteristics

Niobium is a grey, relatively hard, paramagnetic, refractory transition metal. It is very resistant to chemical attack and behaves like a superconductor at very low temperatures. Niobium occurs in the upper earth crust with a frequency of 12 ppm. It does not occur in nature as a free metal, but mainly in minerals such as columbitol and pyrochlore. (European Commission 2017b)

Applications

About 86 % of niobium (in the form of ferroniobium) is used in the manufacture of HSLA steels (used for example to reduce weight in vehicles). Other applications for HSLA steel include pipelines, hulls and railway tracks. Further uses for niobium are in super alloys (8 %) e.g. in the nuclear or space industry and in chemical applications (6 %). (European Commission 2017b)

Recycling

The end-of-life recycling rate for niobium, especially as a component of scrap iron, is more than 50 %. However, functional recycling is negligible. (European Commission 2017b)

Substitution

Metals such as vanadium, molybdenum, tantalum and titanium can replace niobium in the production of HSLA steel and superalloys. However, any substitution would be accompanied by a reduction in price and/or performance. In general, there are few economic or technical incentives to replace niobium in its main applications. (European Commission 2017b)

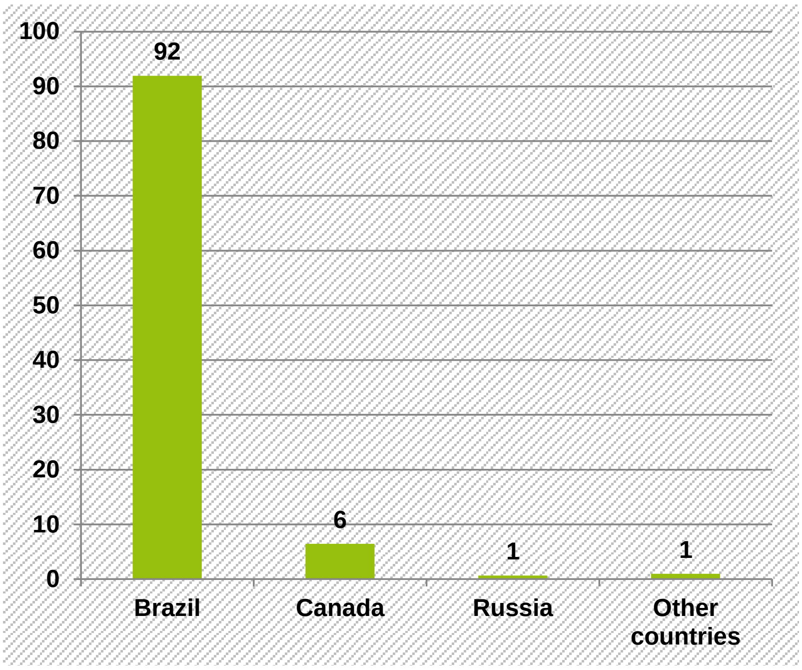
Main product, co-product or by-product

Niobium is a main product (European Commission 2017b).

Primary production

Total global production 2014: 87,006 tonnes (Reichl et al. 2016).

Percentage of niobium mines mined in 2014 (%) (Reichl et al. 2016)



Information on Deposits

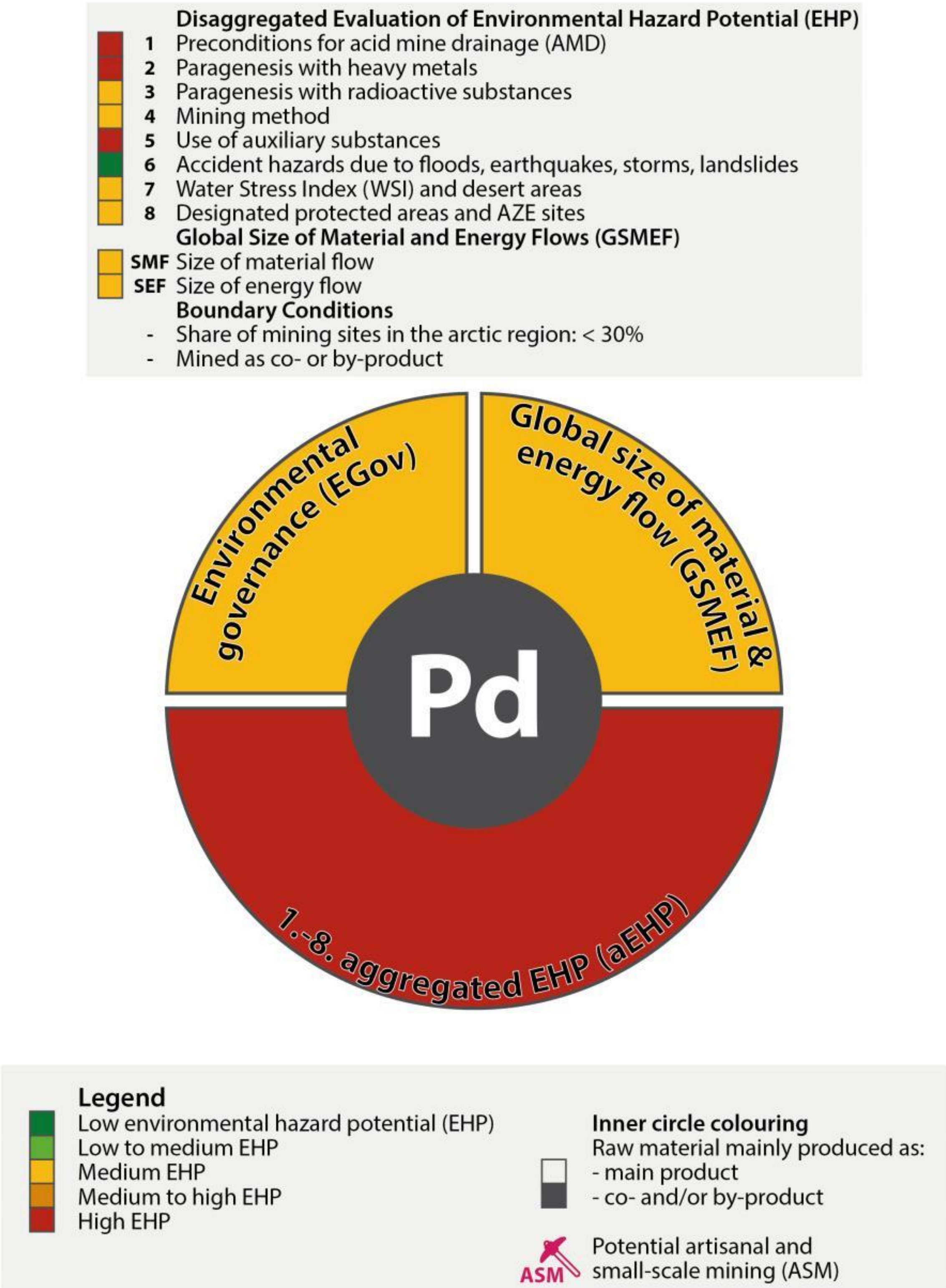
Niobium is lithophilic. It has its economic importance in niobium-tantalum deposits of pegmatitic and pneumatolytic genesis, as well as in carbonatites. The ore minerals are columbite and pyrochlore. They often have thorium contents. Otherwise, columbitol is often found in parageneses with tin calcite, tungsten and other pegmatite minerals.

4.36.2 Profile Niobium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Niobium is found in sulphide-free deposits; correspondingly, the acid formation potential is low.	high
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Niobium is extracted from deposits that may contain heavy metals as companions.	medium
Indicator 3: Paragenesis with radioactive substances		
High EHP	Niobium is usually associated with high concentrations of U and/or Th. This is confirmed by data from Chinese deposits (<2 % of world production).	medium
Indicator 4: Mine Type		
Medium EHP	surface mining	high
Indicator 5: Use of auxiliary substances		
High EHP	Flotation (pre-flotation and cleaning flotation with addition of silicofluorides)	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for niobium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 70 % low, 8 % medium, 2 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Low EHP	The results for niobium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 91 % low, 0 % medium, 9 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
High EHP	The results for niobium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 95 % low, 0 % medium, 5 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 61.24.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 1.2 million t/a results from the $CRD_{specific}$ of 14 t/t and the global annual production of 87,006 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 15 PJ/a results from the $CED_{specific}$ of 172,000 MJ-eq/t and the global annual production of 87,006 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for niobium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results	medium

Environmental hazard potential	Explanation	Data quality
	for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99.8 % low, 0.2 % medium EHP.	

4.37 Palladium



4.37.1 General Information

Introduction and characteristics

Palladium (Pd) is one of the six chemical elements known as platinum group metals (PGM). These metals are very rare in the earth's crust with abundances in the range of 1-5 parts per billion (ppb). The palladium content in the upper crust is 0.52 ppb. PGM are found together in nature and are often associated with nickel and copper ores. (European Commission 2017b)

Applications

The largest share of use is in automotive catalytic converters (72 % global, 92 % in Europe). The rest is mainly used in electronics, in the chemical and dental industries as well as in jewellery. (European Commission 2017b)

Recycling

Due to its high value, palladium recycling is attractive and technologies have been developed that enable highly effective recovery of palladium from a variety of waste streams (especially automotive catalysts and WEEE). The recycling rate depends in particular on the palladium price and on factors affecting the collection efficiency of end-of-life products. In 2013, 38 % of palladium came from secondary materials, of which 75 % came from automotive catalysts and 17 % from electrical scrap. (European Commission 2017b)

Substitution

For palladium, the potential substitutes are other PGM, gold or base metals, although these may lead to price or performance degradation. Since PGMs are by-products, the replacement of palladium with platinum is likely to be limited in the event of a supply disruption. (European Commission 2017b)

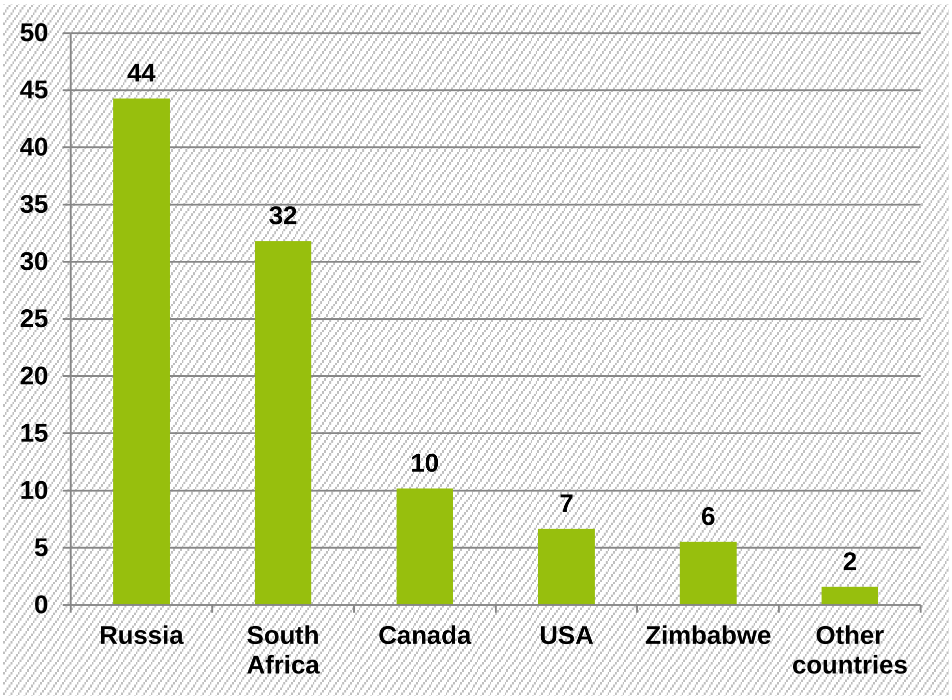
Main product, co-product or by-product

Palladium is a co-product with other PGMs and can be a by-product of nickel and copper mining (European Commission 2017b)

Primary production

Total global production 2014: 184 tonnes (BGS 2016).

Percentage of palladium mines mined in 2014 (%) (BGS 2016)



Information on Deposits

Palladium is siderophilic. It occurs in the ore minerals stibiopalladinite and solid palladium. They are found in nickel magnetic gravel deposits of the liquid magmatic segregations (Norilsk). Subordinate but of little economic importance to alluvial deposits.

4.37.2 Profile Palladium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Deposits are in nickel magnetic gravel deposits which have high sulphide contents and bring with them a corresponding acid formation potential.	medium
Indicator 2: Paragenesis with heavy metals		
High EHP	Extraction from nickel-magnetic gravel deposits and thus closely associated with the heavy metal nickel.	medium
Indicator 3: Paragenesis with radioactive substances		
medium EHP	No specific data are available. In accordance with the procedure described in the method document, an evaluation with medium EHP is carried out.	low
Indicator 4: Mine Type		
medium EHP	underground mining, open pit solid rock mining, dredging	high
Indicator 5: Use of auxiliary substances		
High EHP	Flotation to marketable PGM concentrate, later roasting, leaching, electrolysis	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for palladium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 89 % low, 4 % medium, 7 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		

Environmental hazard potential	Explanation	Data quality
Medium EHP	The results for palladium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 67 % low, 1 % medium, 32 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for palladium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 95 % low, 4 % medium, 1 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 57.97.	high
Indicator 10: Cumulated raw material demand of global production CRDglobal		
Medium	CRDglobal of 6.8 million t/a results from the CRDspecific of 36,937 t/t and the global annual production of 184 t/a.	high
Indicator 11: Cumulated energy demand of global production CEDglobal		
Medium	CEDglobal of 13 PJ/a results from the CEDspecific of 72,700,000 MJ-eq/t and the global annual production of 184 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
High	The results for palladium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 72 % low, 28 % medium EHP.	medium

4.38 Perlite

4.38.1 General Information

Introduction and characteristics

Perlite is a generic term for naturally occurring siliceous rock. Due to its high water content, it expands or foams when heated and forms a light granular aggregate. It has low density and porous texture (in its expanded form), low thermal conductivity, high sound absorption and high chemical stability. (European Commission 2017a)

Applications

Perlite is used in building construction products (59 %), in filter aid applications (24 %), as a horticultural aggregate (11 %) and in fillers (6 %). (European Commission 2017a)

Recycling

Perlite is generally not obtained from waste. However, construction and demolition waste is largely recycled throughout the EU. The recycling of mineral waste in the EU can be estimated at 42 % based on Eurostat data. Due to the poor literature on perlite recycling, it is not possible to estimate the overall recycling rate. (European Commission 2017a)

Substitution

Substitutes for perlite can be (in various applications) expanded clay, vermiculite and pumice stone. As lightweight aggregates diatomaceous earth, expanded shale, fly ash, slag and glass can be used. In filler applications slag, slate and numerous other industrial minerals can also be used in filler applications. Rockwool, stone wool, coco-coir, sawdust, peat moss and rice hulls can also be used as substitutes in some applications (e.g. in horticulture and filter aids). (European Commission 2017a)

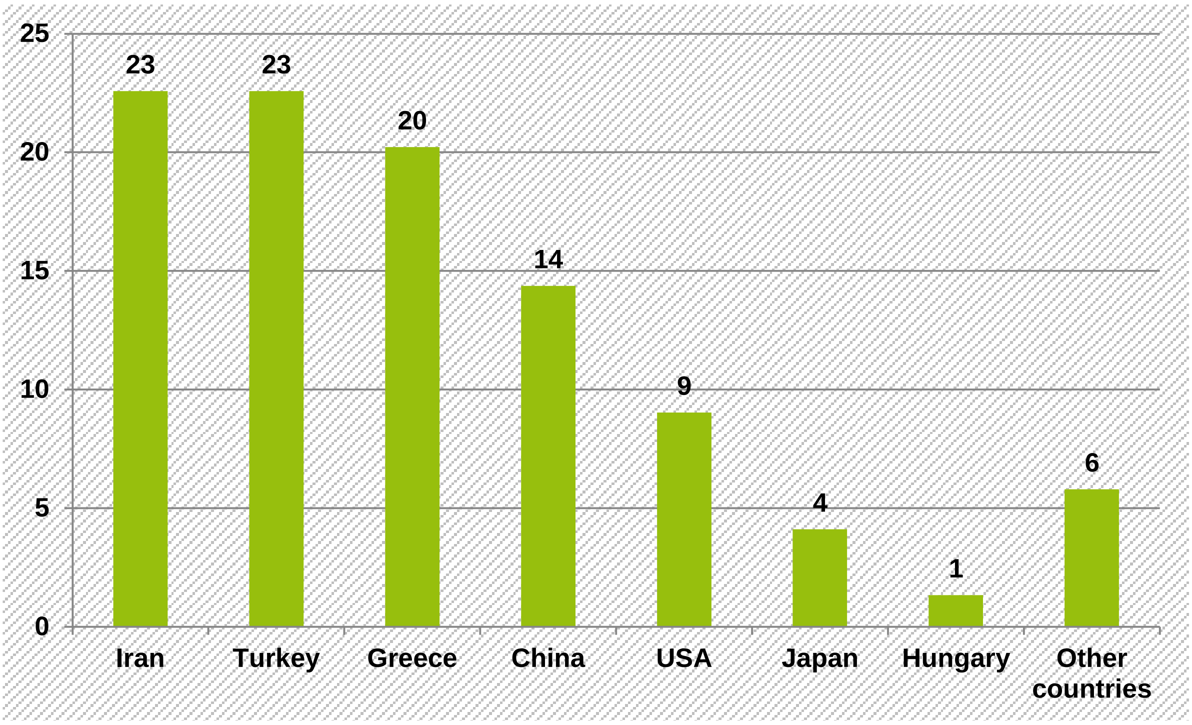
Main product, co-product or by-product

Perlite is a main product (European Commission 2017a).

Primary production

Total global production 2014: 4,872,448 tonnes (BGS 2016).

Percentage of perlite mines mined in 2014 (%) (BGS 2016)



Information on Deposits

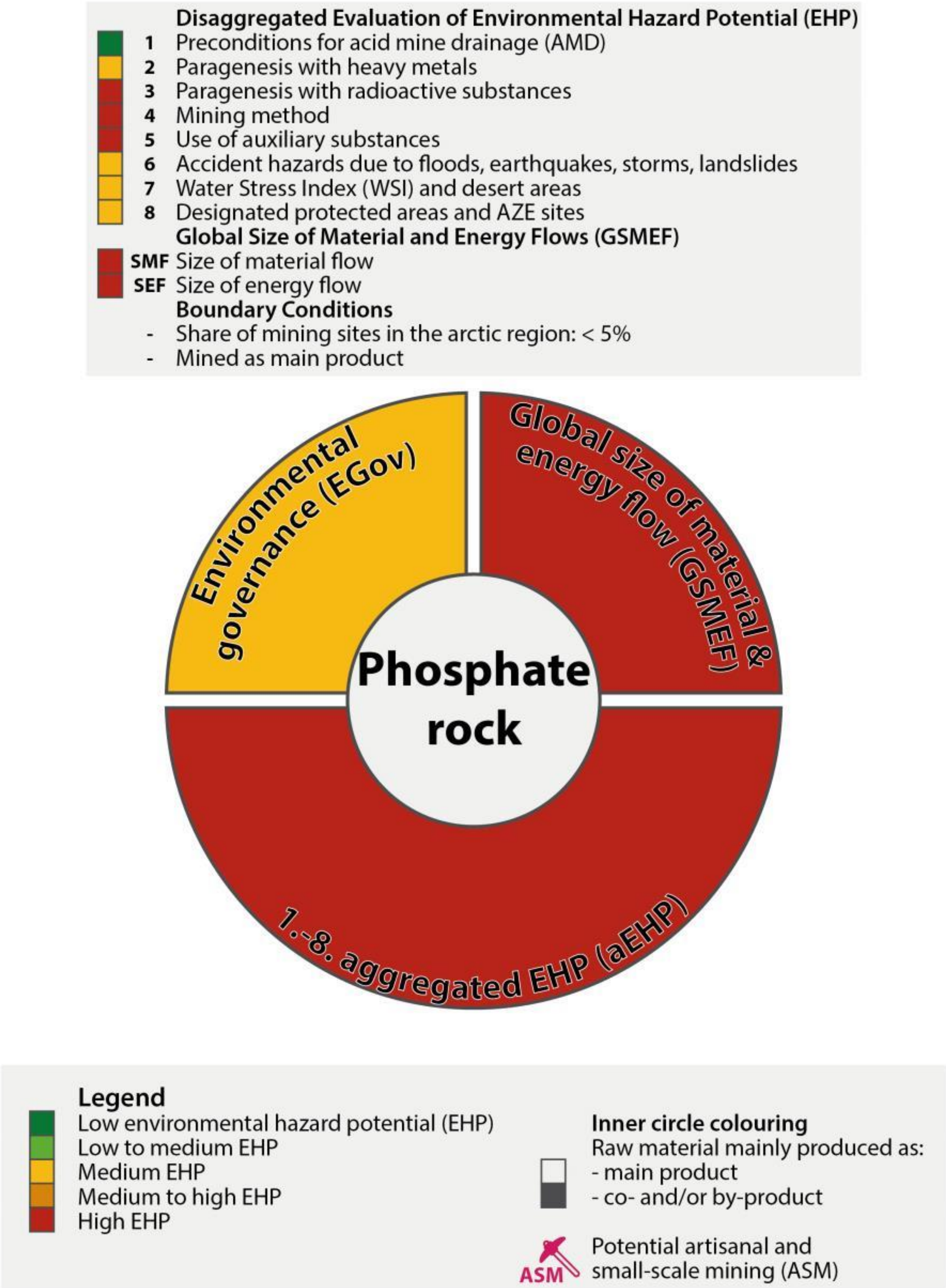
Perlite is a weathering rock of volcanic glasses and is characterized by its expandability.

4.38.2 Profile Perlite

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Inert material from weathering processes	medium
Indicator 2: Paragenesis with heavy metals		
Low EHP	As a weathering product of vulcanites usually free of significant heavy metal concentrations.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Perlite may be associated with radioactive elements due to its volcanic glass formation conditions. Perlite from some Turkish deposits is not suitable as a building material for residential buildings due to its radioactive associations.	medium
Indicator 4: Mine Type		
Medium EHP	surface mining	medium
Indicator 5: Use of auxiliary substances		

Environmental hazard potential	Explanation	Data quality
Low EHP	hot-cold dissolving process	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
N/A	Information not available due to data restrictions	N/A
Indicator 7: Water Stress Index and desert areas		
N/A	Information not available due to data restrictions	N/A
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
N/A	Information not available due to data restrictions	N/A
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 61.20.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 7.1 million t/a results from the $CRD_{specific}$ of 1.5 t/t and the global annual production of 4,872,448 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 69 PJ/a results from the $CED_{specific}$ of 14,169 MJ-eq/t and the global annual production of 4,872,448 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
N/A	Information not available due to data restrictions	N/A
Consolidation of the individual results		

4.39 Phosphate rock



4.39.1 General Information

Introduction and characteristics

Phosphate rock refers to commercially exploitable phosphate minerals and is the main source of phosphorous in the earth's crust. Together with oxygon, hydrogen, potassium, nitrogen and carbon it is a main building block of life. Phosphorus plays a vital role in all bio based economic processes (European Commission 2017b).

Applications

The vast majority (95 %) of phosphate is used in agriculture, where it used as fertilizer and in animal feed. Pure phosphorous is partially obtained from phosphate rock and used in the production of chemcials e.g. flame retardants, oil additives, industrial water treatment, emulsifying agents (European Commission 2017b).

Recycling

Phosphate rock itself is not recyclable and therefore the end of life recycling input rate could be considered to be 0 % (European Commission 2017b).

Substitution

Phosphate rock can be replaced in fertilizers by secondary sources of phosphate such as biogenic waste flows e.g. food and vegetal waste, manure and sewage sludge substitutes the use of mineral phosphate fertilizers (European Commission 2017b). Phosphorus as an essential nutrient for living beings cannot be replaced (BGR 2013).

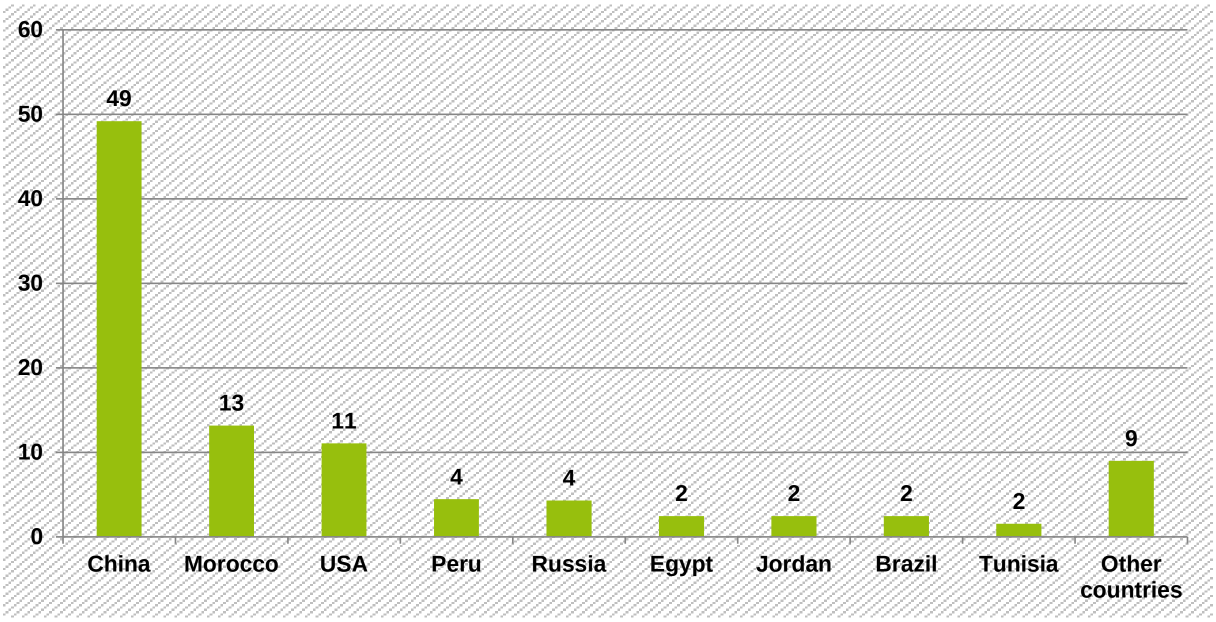
Main product, co-product or by-product

Phosphate rock is a main product (European Commission 2017b).

Primary production

Total global production 2014: 244,915,816 tonnes (BGS 2016).

Percentage of phosphate rock mines mined in 2014 (%) (BGS 2016)



Information on Deposits

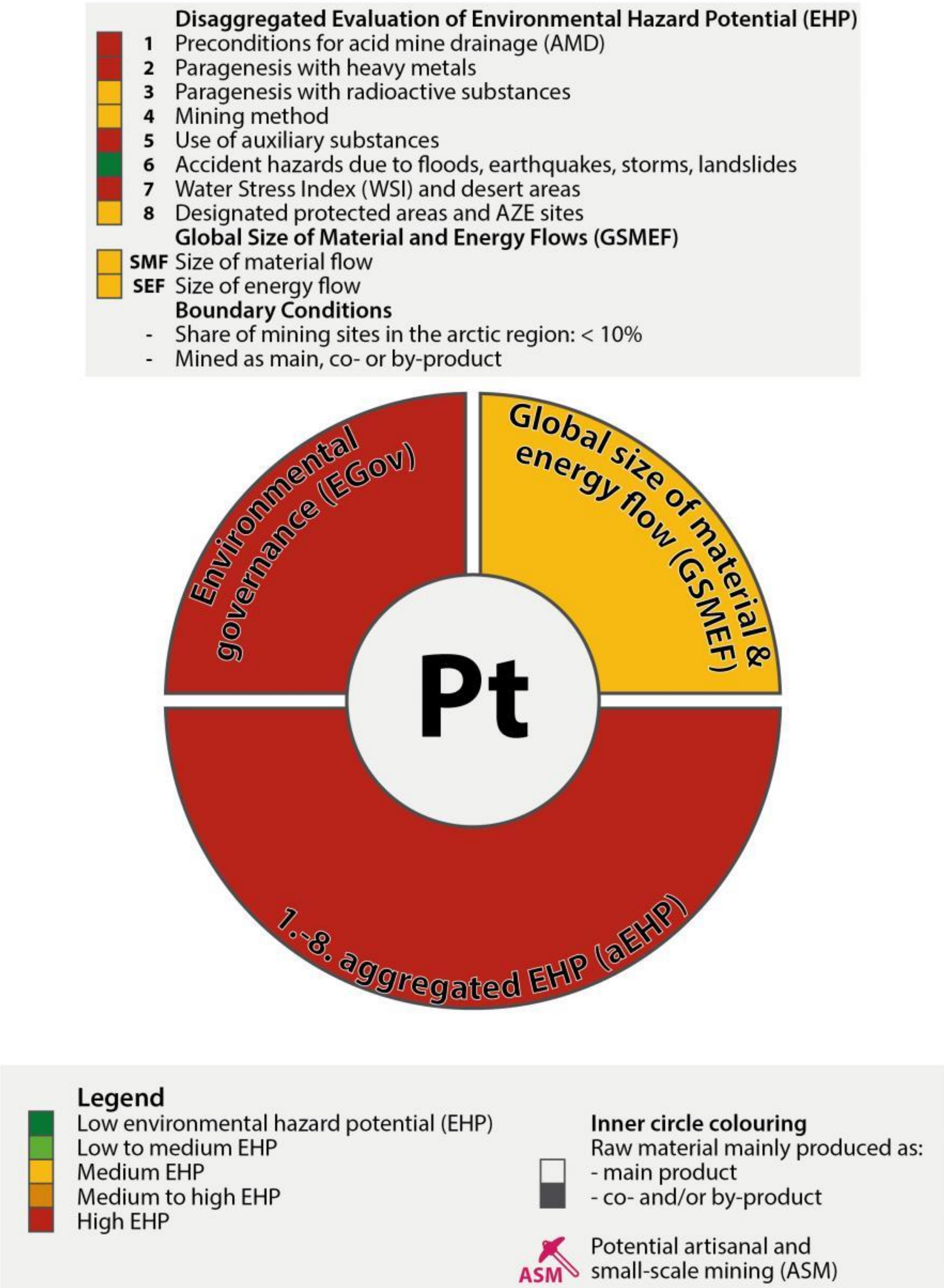
Phosphorus is a siderophilic element. Economically important phosphates are apatite and phosphorite, the former from basic silicate crystallization, the latter marine sedimentary in a reducing environment and as terrestrial weathering deposits.

4.39.2 Profile Phosphate rock

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Phosphates are extracted economically from weathering deposits and biogenic sediments, which are inert in terms of acidification potential.	medium
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Phosphate deposits often have elevated cadmium concentrations in the range of 0.15 to 507 mg/kg. Concentrations are thus generally above critical thresholds for the use of the substance for agricultural production in accordance with the Federal Soil Protection Act, but below concentration thresholds to fulfil the criteria as hazardous waste in Commission Decision 2000/532/EC of 3 May 2000.	high
Indicator 3: Paragenesis with radioactive substances		
High EHP	Sedimentary phosphate (e.g. Saharan and Florida phosphate) is usually associated with considerable concentrations of Uranium.	high
Indicator 4: Mine Type		
High EHP	surface mining	high
Indicator 5: Use of auxiliary substances		
High EHP	Digestion with acids, if necessary flotation for separation of impurities, drying	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for phosphates range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 42 % low, 26 % medium, 32 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for phosphates range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment The results of the GIS assessment are: 52 % low, 3 % medium, 45 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for phosphates range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment The results of the GIS assessment are: 86 % low, 13 % medium, 1 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 57.24.	high

Environmental hazard potential	Explanation	Data quality
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 4,484 million t/a results from the $CRD_{specific}$ of 18 t/t and the global annual production of 244,915,816 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 970 PJ/a results from the $CED_{specific}$ of 3,962 MJ-eq/t and the global annual production of 244,915,816 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for phosphate rock range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 98 % low, 2 % medium EHP.	medium

4.40 Platinum



4.40.1 General Information

Introduction and characteristics

Platinum is one of six elements belonging to the group of Platinum Group Metals with the atomic number 78. It is a silvery-white precious metal that is highly unreactive (European Commission 2017b).

Applications

The major application for platinum is automotive catalysts, where the metal is the principal component in the catalytic converter. Unburnt HC and CO are oxidized to water and carbon dioxide in platinum-rich autocatalysts. The second most important application of platinum is in jewellery. Another significant use is the employment in platinum-based catalysts in the chemical industry (JRC 2018).

Recycling

The high value of platinum makes it very attractive for recycling. There are very effective recovery processes established to recover platinum from a variety of waste streams. Up to 95 % of platinum from PGM containing scrap can be recovered with current technology. The majority of recycled platinum originates from spent automotive catalysts but also from jewellery and electronic. The average end of life recycling rate is between 60 and 70 %. The end of life recycling input rate is 11 % input rate is (European Commission 2017b, JRC 2018).

Substitution

The combination of high price and possible supply disruptions lead to a high interest in substituting platinum. The main options for the substitution of platinum in its main applications are other PGMs or base metals at the cost of performance or higher prices. Accordingly, the potential to substitute platinum is limited (European Commission 2017b).

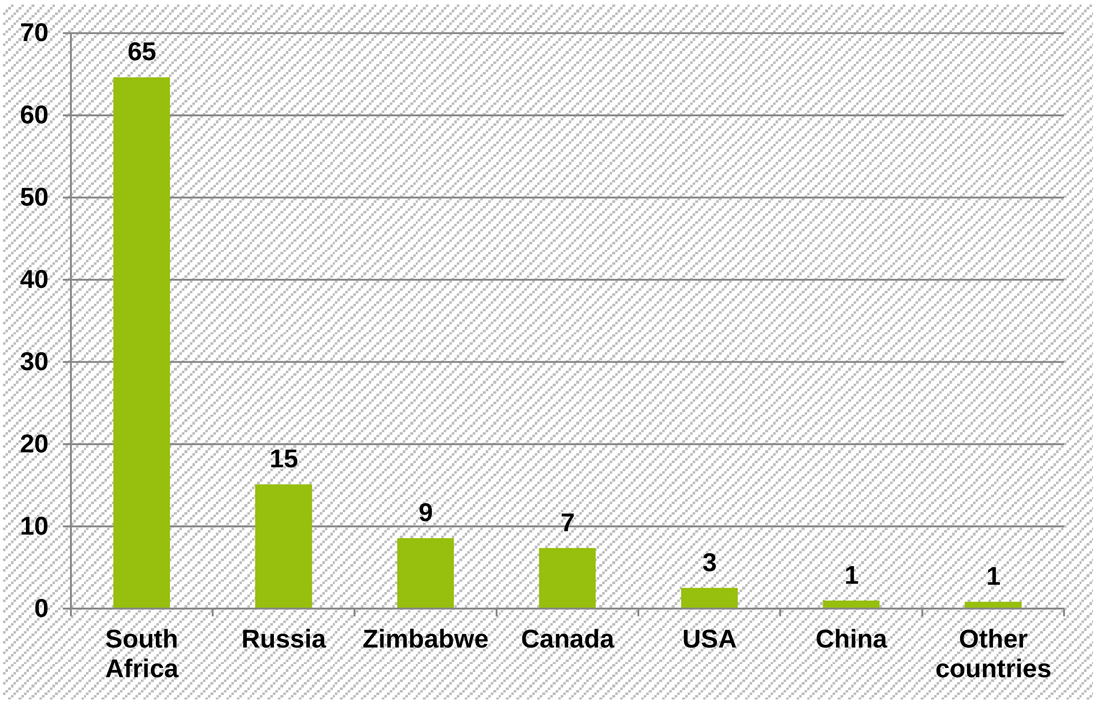
Main product, co-product or by-product

Platinum is a main product or co-product with other PGMs and also a by-product of nickel and copper production (European Commission 2017b)

Primary production

Total global production 2014: 145 tonnes (BGS 2016).

Percentage of platinum mines mined in 2014 (%) (BGS 2016)



Information on Deposits

Platinum is a siderophilic element. In primary deposits platinum is always enriched in ultrabasic and basic rocks; ultrabasic in sulfide-free dunite massifs, basic in sulfide-bearing norite and Gebbro intrusions in nickel magnetic gravel deposits and in addition, economically less important, in soap deposits. Mineralogically, the element is present in solid form and as an intermetallic compound with other PGMs.

4.40.2 Profile Platinum

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Deposits in the economically important nickel magnetic gravel deposits have high sulphide contents, which bring with them a corresponding acid formation potential.	low
Indicator 2: Paragenesis with heavy metals		
High EHP	Extraction from nickel-magnetic gravel deposits and thus closely associated with the heavy metal nickel.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	No specific data are available. In accordance with the procedure described in the method document, an evaluation with medium EHP is carried out.	low
Indicator 4: Mine Type		
Medium EHP	underground mining, open pit solid rock mining, dredging	high
Indicator 5: Use of auxiliary substances		
High EHP	Flotation to marketable PGM concentrate, later roasting, leaching, electrolysis	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for platinum range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment.	medium

Environmental hazard potential	Explanation	Data quality
	The results of the GIS assessment are: 85 % low, 3 % medium, 12 % high EHP.	
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for platinum range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 36 % low, 0 % medium, 64 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for platinum range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 98 % low, 2 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
High EHP	From the EPI and the production share of the individual countries results an EGov-Score of 50.50.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium EHP	CRD_{global} of 19 million t/a results from the $CRD_{specific}$ of 128,779 t/t and the global annual production of 145 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium EHP	CED_{global} of 35 PJ/a results from the $CED_{specific}$ of 243,000,000 MJ-eq/t and the global annual production of 145 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
High EHP	The results for platinum range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 92 % low, 8 % medium EHP.	medium

4.41 Platinum group metals

4.41.1 General Information

Introduction and characteristics

PGMs or Platinum Group Metals consist of six elements ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir) and platinum (Pt). The metals are very rare in the earth's crust with a range between 1 to 5 ppb. Commercially Platinum and Palladium are the most important PGMs (European Commission 2017b).

Applications

The main applications derive from the commercially most important PGMs platinum and palladium, namely catalysts in automotive and chemical industries. Since PGMs describe a group of elements the application of each individual element is specific to its properties (European Commission 2017b). Information on platinum, palladium and rhodium can be found in the corresponding chapters.

Recycling

The high intrinsic value of PGMs makes them very attractive for recycling. There are very effective recovery processes established to recover platinum, palladium and rhodium globally -

in 2014 almost 30 % of their supply was covered by secondary material (European Commission 2017b).

Substitution

The main substitute for a PGM is another element from the group resulting in no effective and economic alternatives at the moment (European Commission 2017b).

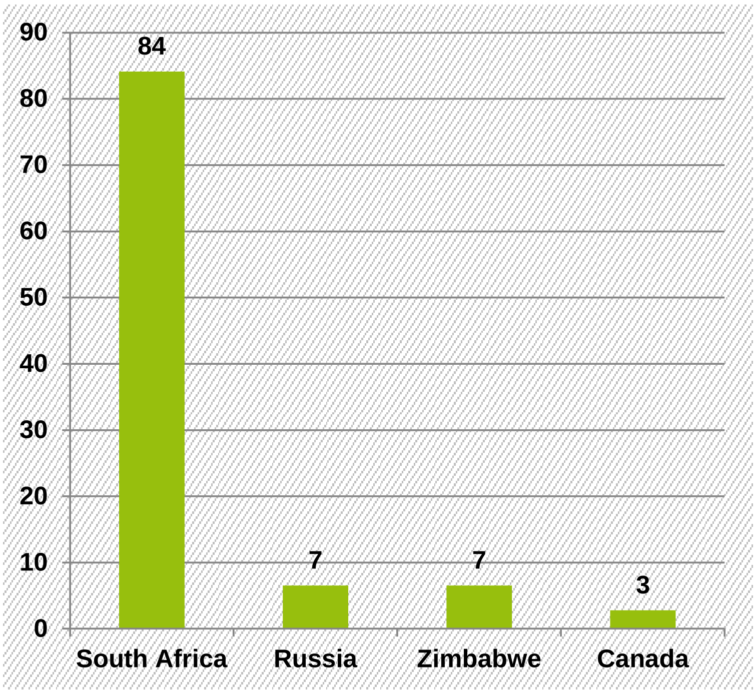
Main product, co-product or by-product

PGMs are a main product or a by-product of nickel mining (European Commission 2017b)

Primary production

Total global production in 2014 was 372 tonnes, excluding platinum and palladium 43 tonnes (BGS 2016).

Percentage of platinum group metals mines mined in 2014 (%) (BGS 2016)



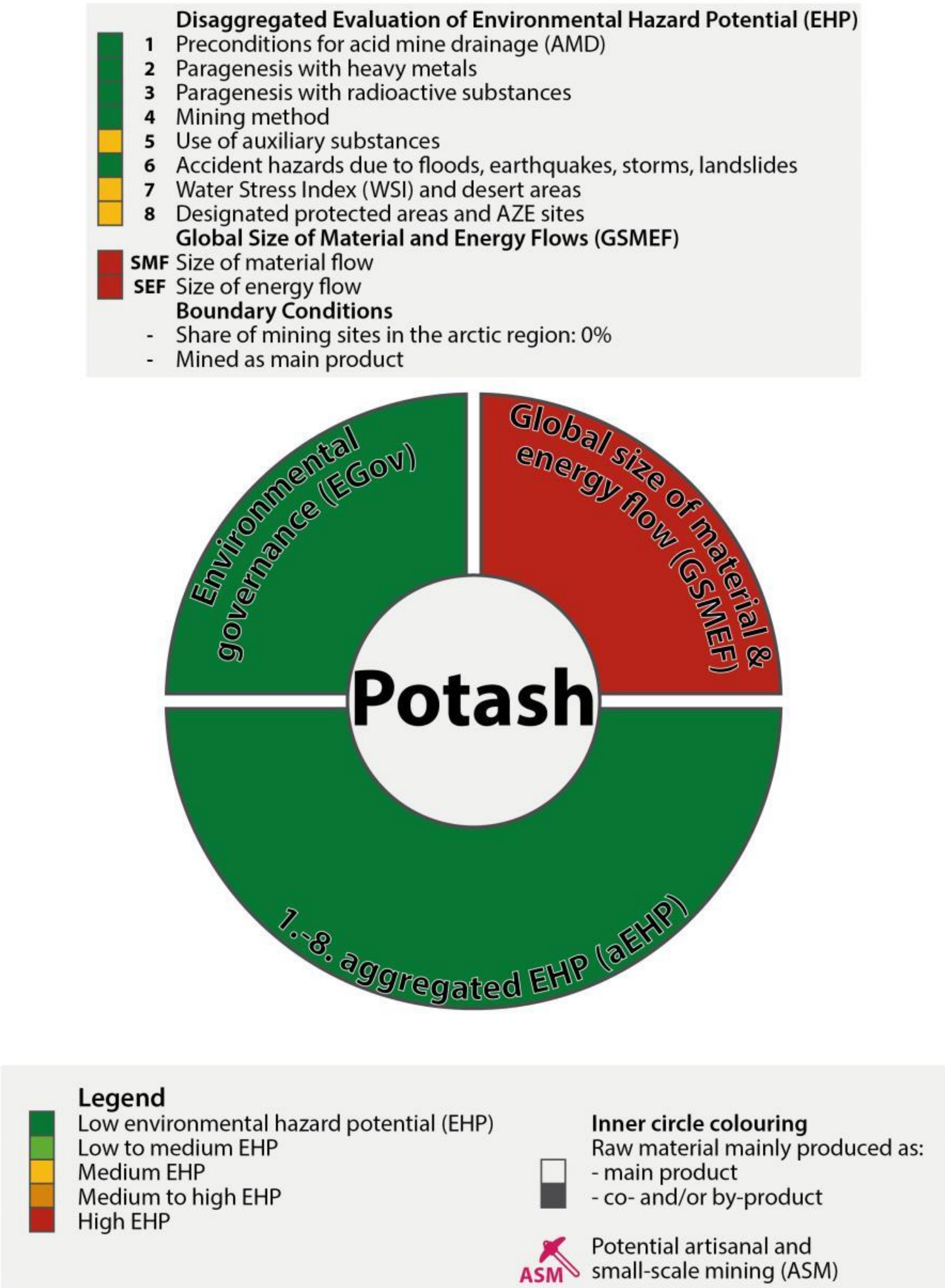
Information on Deposits

Platinum and the other PGM are siderophilic elements. In primary deposits, PGM are almost always enriched in ultrabasic and alkaline rocks. A distinction is made between PGM dominant deposits and nickel-copper dominant deposits. The former include the thin reefs of ultrabasic rocks, chromite-rich reef structures, PGM-rich contact zones and dunit-pipes as found in the Bushveld Complex and Merensky reef. PGM in nickel-copper deposits are associated with meteorite impacts (Sudbury), basic in sulfide-bearing norite and gabbro intrusions in nickel-magnetic gravel deposits (Norilsk) and in comatite structures (magnesium-rich intrusives). In addition, economically less important in soap deposits. Other deposit types such as PGM-rich laterites, hydrothermal remobilizations, porphyries, copper slates and carbonatites occur. Mineralogically the PGM are present in solid form and as intermetallic compounds, as sulfides, bismuthinides, arsenides, antimonides and tellurides.

4.41.2 Profile Platinum group metals

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Deposits in the economically important nickel magnetic gravel deposits have high sulphide contents, which bring with them a corresponding acid formation potential.	low
Indicator 2: Paragenesis with heavy metals		
High EHP	Extraction from nickel-magnetic gravel deposits and thus closely associated with the heavy metal nickel.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	No specific data are available. In accordance with the procedure described in the method document, an evaluation with medium EHP is carried out.	low
Indicator 4: Mine Type		
Medium EHP	Underground mining, hard rock open pit mining, dredging	high
Indicator 5: Use of auxiliary substances		
High EHP	Flotation to marketable PGM concentrate, later roasting, leaching, electrolysis	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
N/A	Information not available due to data restrictions	N/A
Indicator 7: Water Stress Index and desert areas		
N/A	Information not available due to data restrictions	N/A
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
N/A	Information not available due to data restrictions	N/A
Indicator 9: Environmental governance in major production countries (EPI)		
-	has not been rated	-
Indicator 10: Cumulated raw material demand of global production CRDglobal		
-	has not been rated	-
Indicator 11: Cumulated energy demand of global production CEDglobal		
-	has not been rated	-
Indicator 12: Position of mining sites in the arctic region		
N/A	Information not available due to data restrictions	N/A

4.42 Potash


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: 0%
- Mined as main product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Potash
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.42.1 General Information

Introduction and characteristics

Potash is a term describing a range of potassium bearing minerals and refined products. Only water-soluble minerals are of commercial significance, the most important being sylvine. (British Geological Survey 2011). Potassium plays an essential role in the growth and metabolism of animals, plants and humans (European Commission 2017a).

In potash mining, the backfilling of tailings is rather rare. Normally, overburden dumps remain, which contribute to the salinisation of soil and water in the surrounding area. The measuring instructions are not including an indicator that asses the salinity of tailings. Therefore, the low EHP can only be regarded as valid when regarding the assessed indicators. If the environmental hazard potential of the salt content in the residues were taken into account, the aEHP for potash could possibly be higher.

Applications

As a consequence of potassium's essentiality as a macro-nutrient for plants, the global end-use of potash is dominated by fertilizers accounting for 92 % of demand in 2014. The only other relevant field of application is chemical manufacturing, where potash is used to produce potassium bearing chemicals. The end-use of the chemicals is very diverse and includes e.g. bleaching agents, explosives, medicine, ceramics etc. (European Commission 2017a).

Recycling

Due to the water-solubility of potash, the material becomes dispersed and irrecoverable. This results in an End-of-life recycling input rate of 0 % (European Commission 2017a).

Substitution

Being one of three essential macro-nutrients for plants, substitution is not effective (phosphorous and nitrogen being the other two). Replacing potash as a source of potassium with e.g. manure or glauconite is possible but due to lower potassium contents and higher costs not cost-effective (European Commission 2017a).

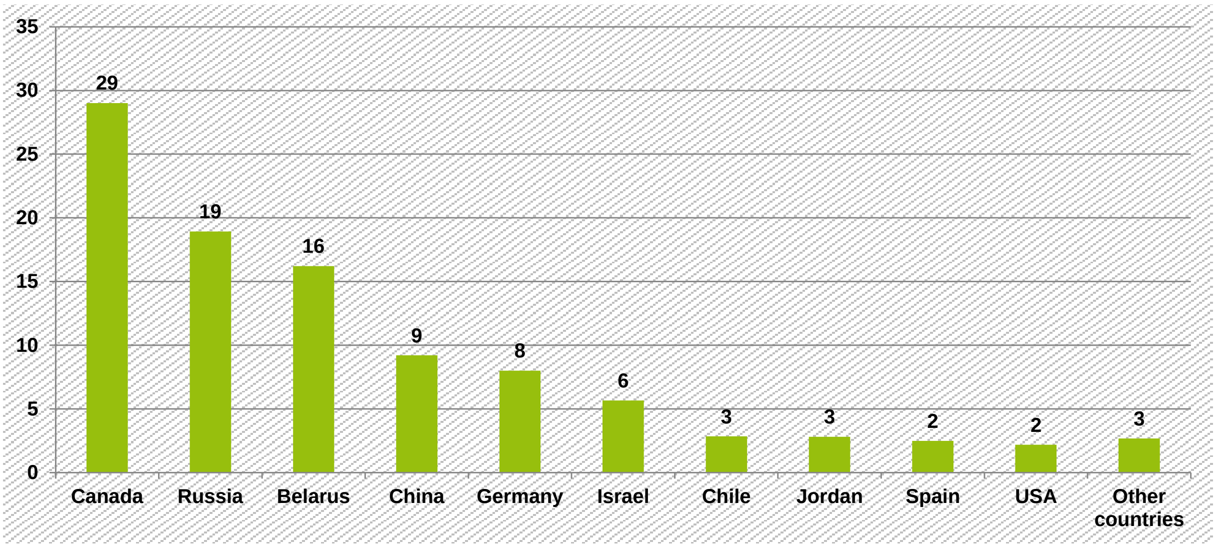
Main product, co-product or by-product

Potash is a main product (European Commission 2017a).

Primary production

Total global production: 39,100,071 tonnes in 2014 (BGS 2016)

Percentage of potash mines mined in 2014 (%) (BGS 2016)



Information on Deposits

Potassium is a lithophilic element and as a frequent element in the earth's crust is incorporated in a large number of minerals. The potassium salts carnallite ($KMgCl_3$-$6H_2O$), sylvin (KCl) and kainite ($KMg[Cl|SO_4]$ - 3 H_2O) are of economic importance. These are evaporation products from the evaporation of sea water and are found in salt domes or salt deposits. They are usually associated with rock salt (halite, NaCl), other salts (chlorides, sulphates and carbonates of light alkali and alkaline earth metals), as well as with gypsum/anhydrite. In addition, potash salts from arid weathering zones are economically significant.

4.42.2 Profile Potash

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Inert material without sulfidic companion due to evaporitic educational conditions.	medium
Indicator 2: Paragenesis with heavy metals		
Low EHP	Mainly extracted from salt domes with mostly low concentration of heavy metals.	high
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Due to the frequency of potassium in the human body and the environment, radioactivity due to K40 decay is considerably less harmful to health and the environment than that of U and Th, which is reflected in the largely unregulated extraction and marketing of potassium for radiation protection purposes.	medium
Indicator 4: Mine Type		
Low EHP	Underground mining	high
Indicator 5: Use of auxiliary substances		
Medium EHP	Hot-cold dissolving process, electrostatic treatment, flotation	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for potash range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 71 % low, 15 % medium, 14 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		

Environmental hazard potential	Explanation	Data quality
Medium EHP	The results for potash range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 68 % low, 0 % medium, 32 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for potash range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 94 % low, 4 % medium, 2 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 67.53.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 302 million t/a results from the $CRD_{specific}$ of 7.7 t/t and the global annual production of 39,100,071 t/a	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 209 PJ/a results from the $CED_{specific}$ of 5,345 MJ-eq/t and the global annual production of 39,100,071 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Low	The results for potash range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP.	medium

4.43 Rare Earths

4.43.1 General Information

Introduction and characteristics

Rare earth elements describe a group of 15 to 17 elements which depends on the inclusion of scandium and yttrium. The other elements have the atomic number 57 to 71 and are comprised of lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu). The rare earths can be divided into two groups, the Light Rare Earth Elements (LREE) (4.28) and Heavy Rare Earth Elements (HREE) (4.22). All rare earth elements are silvery-white to grey metals that show high reactiveness in combination with water and oxygen (European Commission 2017b).

Applications

REE have a wide variety of applications which depend on the individual element considered. Globally catalysts are one of the main uses, in particular containing cerium and lanthanum. The other main application is magnets where praseodymium, neodymium, dysprosium and samarium are used. Other important applications include e.g. metallurgy, polishing and glass (European Commission 2017b).

Recycling

The recycling rate of rare earth elements is very low, the required processes to recover them are energy intensive and complex since the REEs are often incorporated as small components in complex products (European Commission 2017b).

Substitution

In the majority of its applications rare earths elements can only by substituted at the cost of performance. There are however many R&D projects working on the topic (European Commission 2017b).

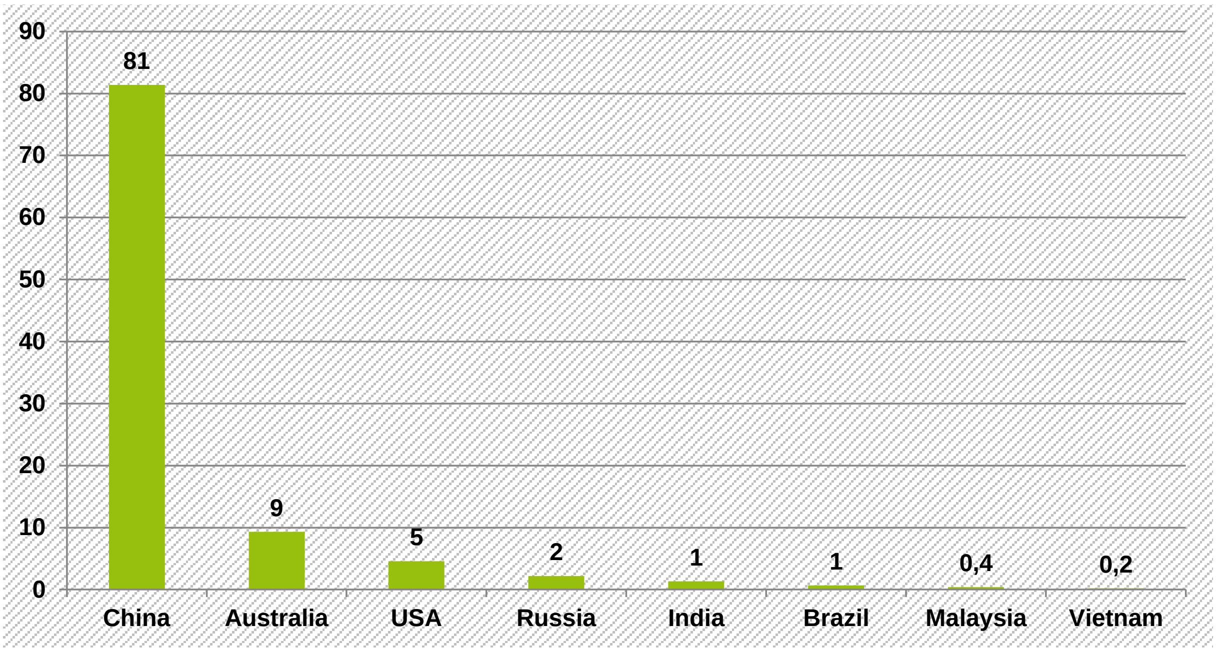
Main product, co-product or by-product

Rare Earths are mostly a main product or a co-product of iron ore extraction and others (European Commission 2017b)

Primary production

Total global production: 129,030 tonnes in 2015 (USGS 2016). The sum of LREE and LREE differs slightly from this, at 131,102 tonnes, as a different source was used for these two. The correlation between the two sources is very good!

Percentage of REE mines mined in 2015 (%) (BGS 2016)



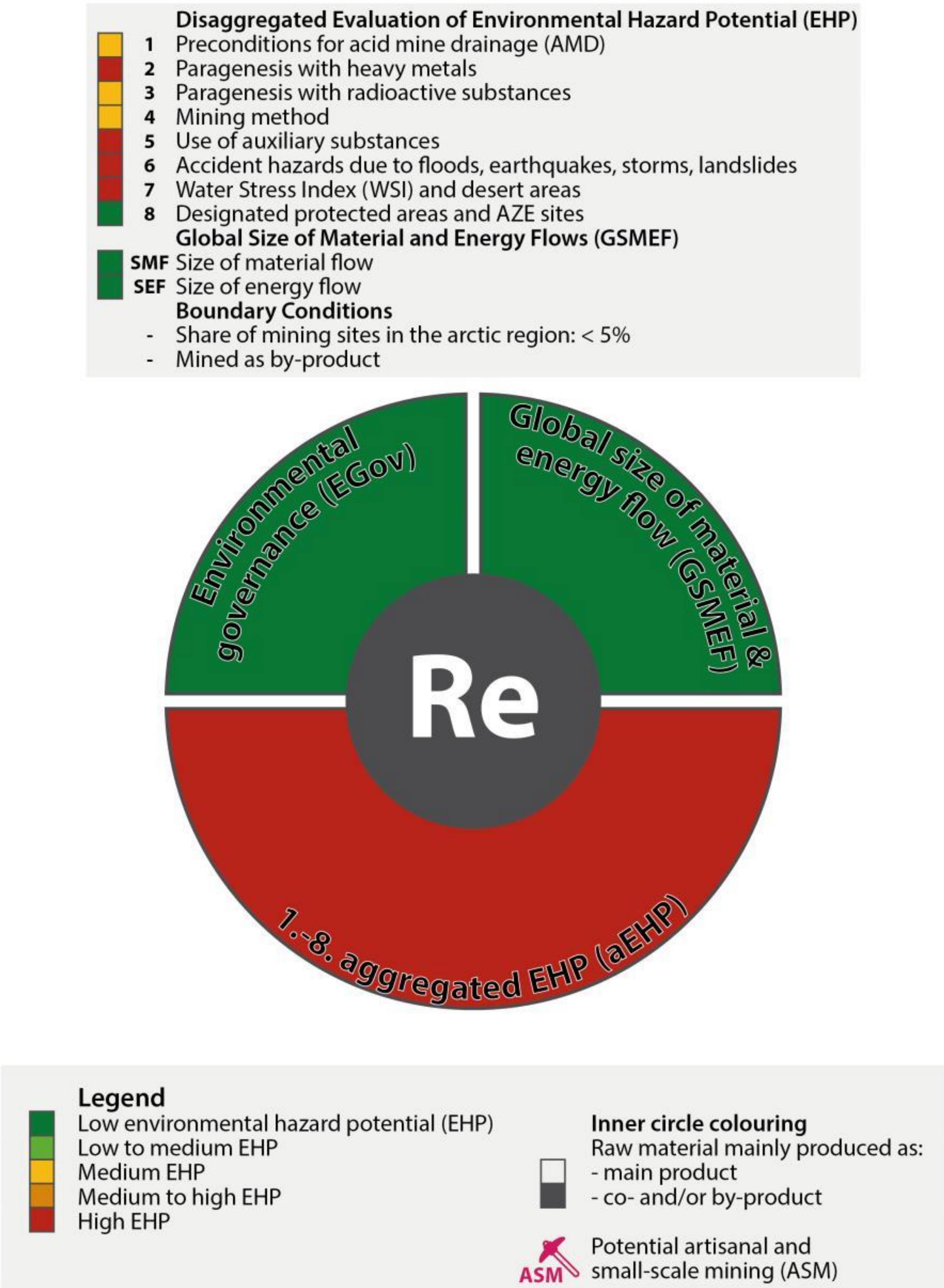
Information on Deposits

Rare earths (light rare earths: cerium earths and heavy rare earths: ytter earths) are lithophilic elements. The REE occur in primary deposits in pegmatites and carbonatites, as well as in alkali magmatites, subordinated also in hydrothermal deposits mineralogically as carbonates, silicate minerals and phosphates. Further important deposit types are secondary genesis, namely marine soaps, lateritic weathering deposits and enrichments by ion exchange. The most important ore minerals are monazite ($CePO_4$), xenotim (YPO_4) and bastnäsite ($Ce(F\ CO_3)$). In the primary deposits the contents of plutonium and thorium (e.g. from thorite) have to be considered. The minerals in pegmatitic deposits are often associated with the "black brothers" (black, radioactive and non-magnetic, e.g. gadolinite, fergusonite, thortveite). Due to its resistance to weathering, monazite is often also worth building as placer (together with ilmenite, zircon, rutile, columbite diamond or tin).

4.43.2 Profile Rare Earths

Environmental hazard potential	**Explanation**	**Data quality**
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Due to the lithophilic properties and the formation conditions of SE, the prerequisites for the formation of acid waters or for autooxidation are low.	low
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Due to the deposit's genesis, only low heavy metal contents are to be expected.	medium
Indicator 3: Paragenesis with radioactive substances		
High EHP	Rare earths are usually associated with high concentrations of U and Th. This is confirmed by data from Chinese deposits (86.4 % of world production).	high
Indicator 4: Mine Type		
Medium EHP	Open pit mining, rarely underground mining.	high
Indicator 5: Use of auxiliary substances		
High EHP	Flotation, physical-chemical separation processes Roasting, carbo-nate precipitation, acid leaching, solvent extraction, in-situ leaching.	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
N/A	Information not available due to data restrictions	N/A
Indicator 7: Water Stress Index and desert areas		
N/A	Information not available due to data restrictions	N/A
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
N/A	Information not available due to data restrictions	N/A
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 53.96.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 31 million t/a results from the $CRD_{specific}$ of 238 t/t and the global annual production of 129,030 t/a.	low
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 5.8 PJ/a results from the $CED_{specific}$ of 44,853 MJ-eq/t and the global annual production of 129,030 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
N/A	Information not available due to data restrictions	N/A

4.44 Rhenium


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 5%
- Mined as by-product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Re
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.44.1 General Information

Introduction and characteristics

Rhenium is a ductile, dense and highly corrosion-resistant metal of greyish white colour with extremely high melting and boiling points. With a concentration of 0.2 ppb in the upper continental crust it is one of the rarest elements (European Commission 2017a).

Applications

There are two major end-uses for rhenium – superalloys used in aerospace applications and petro-chemical catalysts. Other applications play a minor role (European Commission 2017a).

Recycling

The end-of-life recycling input rate of rhenium is very high with more than 50 %. Most of the recycling material comes from within the upstream supply chain and is used in the catalysts or superalloys production loop (European Commission 2017a).

Substitution

Following a price spike in 2008 there has been a lot of interest to substitute rhenium. One approach is the reduction of rhenium to aerospace superalloys to the most critical parts. Also rhenium free super-allyos can be used where ceramic matrix composites replace the metal. Although rhenium quantities can be reduced, it is difficult to eliminate it due to its advantages in performance (European Commission 2017a).

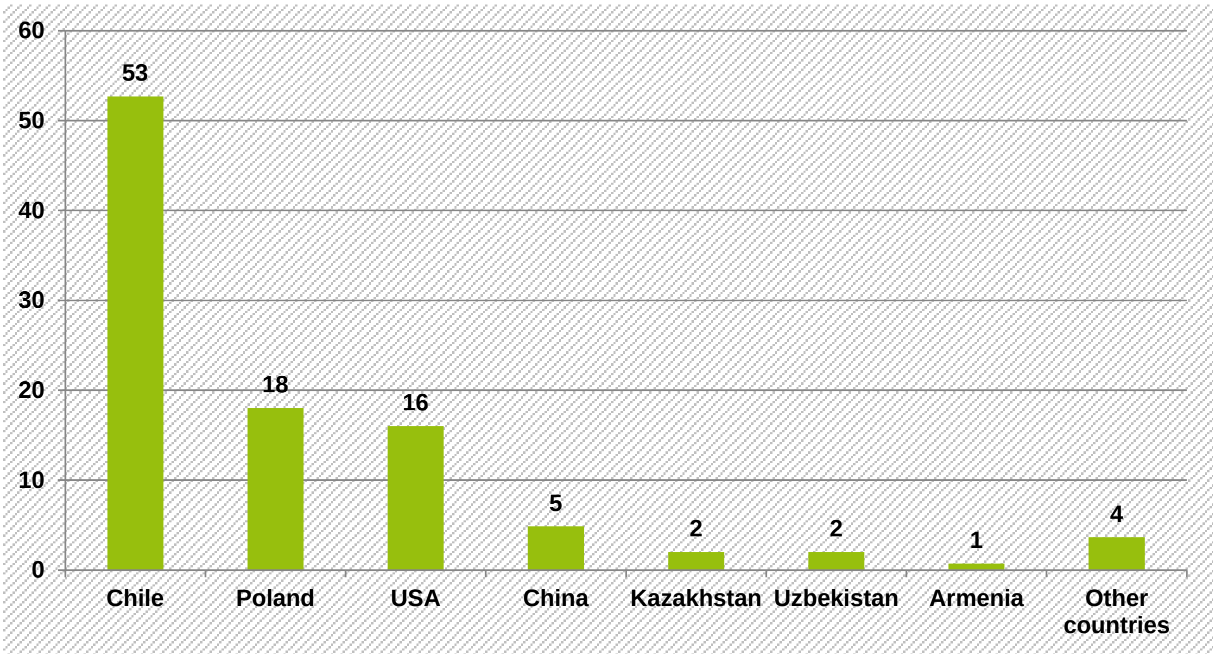
Main product, co-product or by-product

Rhenium is by product of molybdenum and copper sulphide ores (European Commission 2017a).

Primary production

Total global production 2015: 49 tonnes (USGS 2017).

Percentage of rhenium mines mined in 2014 (%) (USGS 2017)



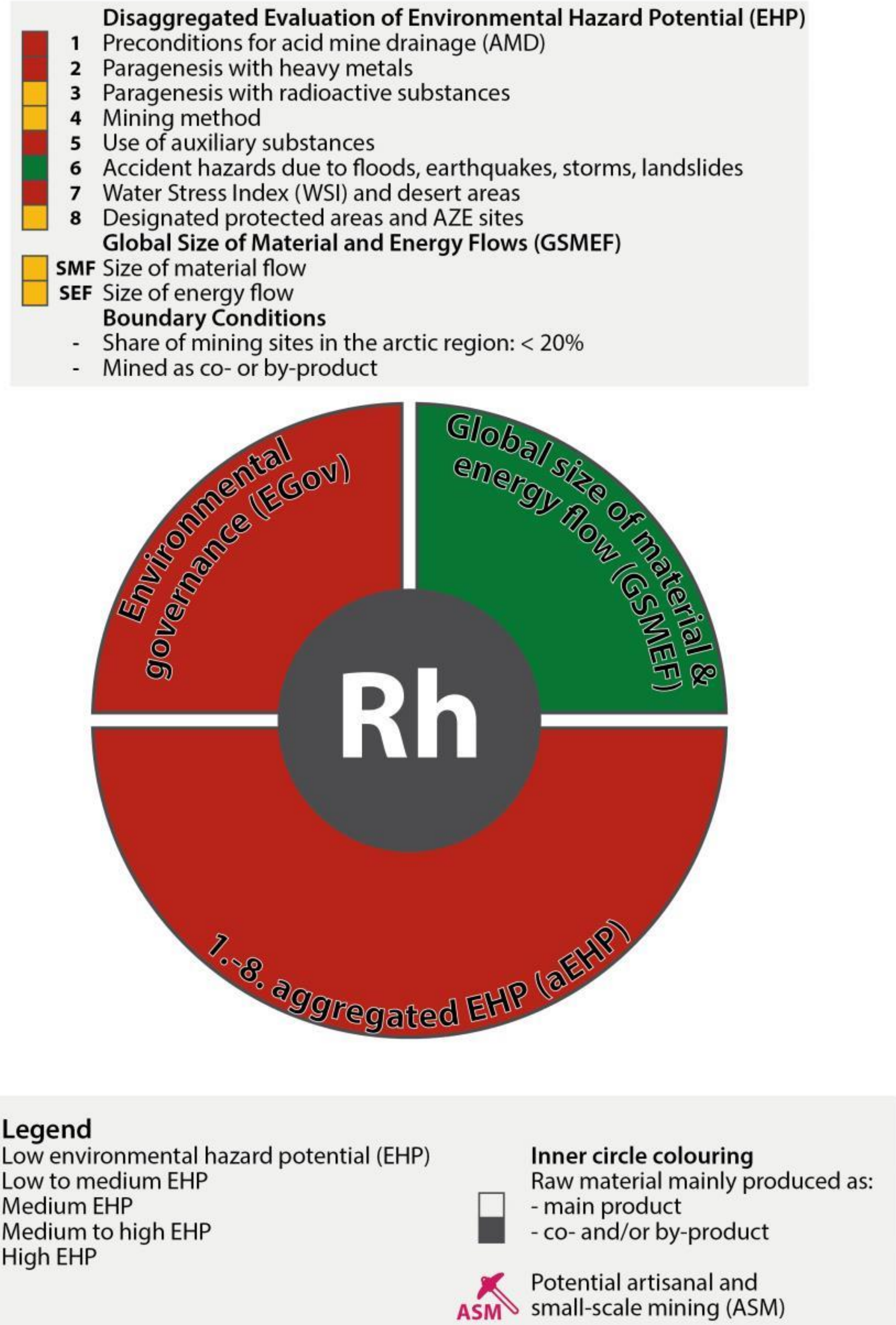
Information on Deposits

Rhenium does not have its own mining production, but is extracted from molybdenum ores as a by-product.

4.44.2 Profile Rhenium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Medium EHP	Due to the extraction as a by-product grouping such as Mo.	medium
Indicator 2: Paragenesis with heavy metals		
High EHP	Rhenium is extracted exclusively as a by-product from molybdenum copper and copper ores. Generally these types of deposits have high concentrations of heavy metals (see corresponding evaluation of Cu and Mo).	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Mined from molybdenum copper and copper ores (see valuations for molybdenum and copper).	medium
Indicator 4: Mine Type		
Medium EHP	Extraction from metallic dusts from molybdenum production	medium
Indicator 5: Use of auxiliary substances		
High EHP	Asbestos filter, electrostatic precipitation	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	The results for rhenium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 30 % low, 10 % medium, 60 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for rhenium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 27 % low, 0 % medium, 73 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for rhenium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 60.39.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 0.5 million t/a results from the $CRD_{specific}$ of 9,617 t/t and the global annual production of 49 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 0.4 PJ/a results from the $CED_{specific}$ of 9,040,000 MJ-eq/t and the global annual production of 49 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
High	The results for rhenium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 98 % low, 2 % medium EHP.	medium

4.45 Rhodium


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 20%
- Mined as co- or by-product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Rh
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.45.1 General Information

Introduction and characteristics

Rhodium is one of six elements from the Platinum-Group Metals (PGM). It is a silvery-white metal with great reflective properties and high corrosion resistance. Due to its hardness it is perfectly suited to be alloyed with the softer PGMs. It is has the highest electric conductivity among the PGMs (JRC 2018).

Applications

Rhodium is mainly used in autocatalysts and to a lesser extent in tools used in the manufacturing of glass and in the chemical industry for catalysts (JRC 2018).

Recycling

Similar to the other PGMs rhodium is very attractive for recycling due to its high value. Highly effective recovery of rhodium from an averiety of waste streams is possible e.g. autocatalysts, industrial catalysts and equipment for glass manufacture. The end of life recycling input rate of rhodium is 24 % within the EU (European commission 2017b).

Substitution

Rhodium can be potentially substituted by other PGMs, gold or base metals, although these may have associated price or performance penalties (European commission 2017b).

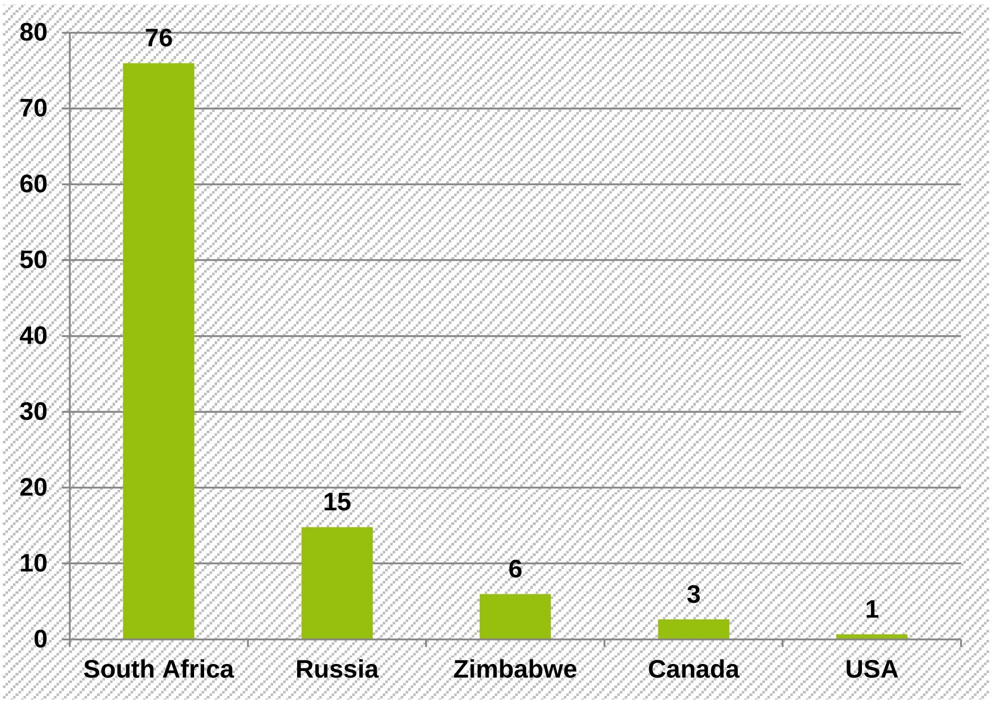
Main product, co-product or by-product

Rhodium is a co-product with other PGMs or a by-product of nickel and copper (European Commission 2017b)

Primary production

Total global production 2014: 19 tonnes (Reichl et al. 2016).

Percentage of rhodium mines mined in 2014 (%) (Reichl et al. 2016)



Information on Deposits

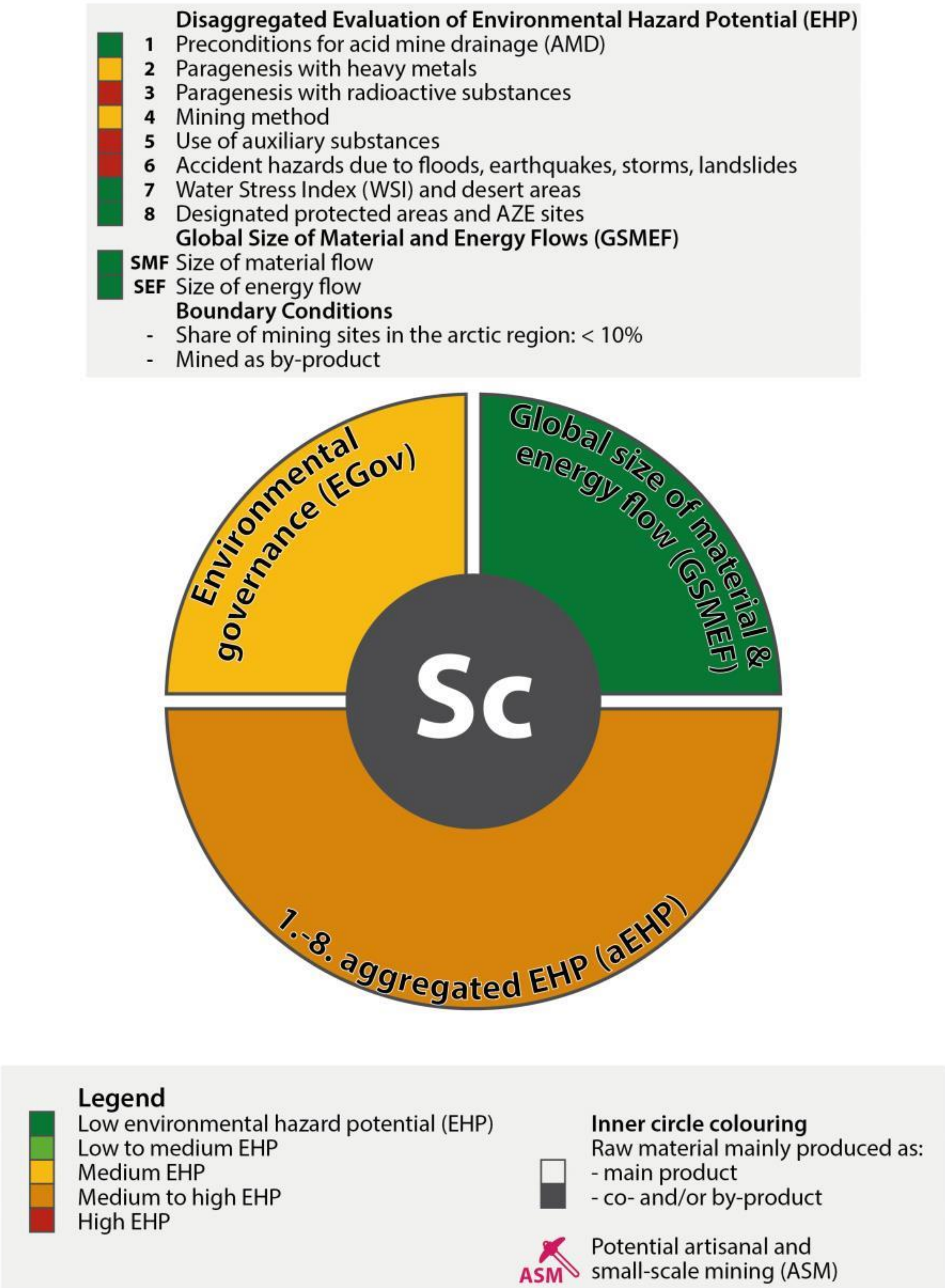
Rhodium belongs to the PGM and has no independent mining production, but, like palladium, is extracted from nickel magnetic gravel deposits by metallurgical means as a by-product.

4.45.2 Profile Rhodium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Metallurgical extraction from ores from deposits in nickel magnetic gravel deposits that have high sulphide contents, which in turn bring with them a corresponding acid formation potential.	low
Indicator 2: Paragenesis with heavy metals		
High EHP	Extraction from nickel-magnetic gravel deposits and thus closely associated with the heavy metal nickel.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	No specific data are available. In accordance with the procedure described in the method document, an evaluation with medium EHP is carried out.	low
Indicator 4: Mine Type		
Medium EHP	Underground mining, hard rock open pit mining, dredging	high
Indicator 5: Use of auxiliary substances		
High EHP	Flotation to marketable PGM concentrate, later roasting, leaching, electrolysis.	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for rhodium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 94 % low, 0 % medium, 6 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for rhodium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 19 % low, 0 % medium, 81 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for rhodium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 97 % low, 3 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 48.36.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 3.2 million t/a results from the $CRD_{specific}$ of 166,122 t/t and the global annual production of 19 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 13 PJ/a results from the $CED_{specific}$ of 683,000,000 MJ-eq/t and the global annual production of 19 t/a.	high
Indicator 12: Position of mining sites in the arctic region		

Environmental hazard potential	Explanation	Data quality
High	The results for rhodium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 84 % low, 16 % medium EHP.	medium

4.46 Scandium



4.46.1 General Information

Introduction and characteristics

Scandium is a silvery-white transition metal, which shares similar characteristics with Rare Earth Elements but is classified separately due to specific geological and industrial properties. It is light weight with a density close to the one of aluminium, but has a high melting point. In nature it does not accumulate in common ores so that, even if it is not a rare element, it generally occurs in low concentrations. While scandium was temporarily classified non-critical, according to the latest classification it again belongs to the critical metals (European Commission 2017b).

Applications

The end-use market for scandium is dominated by Solid Oxide Fuel Cells where it can serve as a stabilizing agent for zirconia instead of yttrium offering improved performance. The average estimated share for this use was 90 %. The remaining is almost exclusively the use in Sc-Al alloys where scandium leads to a significantly improved set of properties, e.g. concerning strength and moulding. While there is a potential for light weighting applications in the aerospace and automotive sectors the main market at present is mostly high-quality sports equipment due to the very high price. Other applications, e.g. in laser technology or lighting account for a share of 1 % (European Commission 2017b).

Recycling

According to European Commission (2017b) there is no recycling circuit for scandium neither from end-of-life products nor from new scrap from manufacturing.

Substitution

Scandium itself represents a substitute for other metals in many cases where it is chosen in order to increase product performance. Consequently alternatives exist for almost all of its uses and the choice depends on the specifications concerning performance, price and availability. In its main application in Solid Oxide Fuel Cells yttrium is the element traditionally used instead of scandium. Substitutes for scandium in alloys achieving comparable resistance and low weight could be titanium and lithium, or a complete substitution of the alloy by carbon fibre materials (European Commission 2017b).

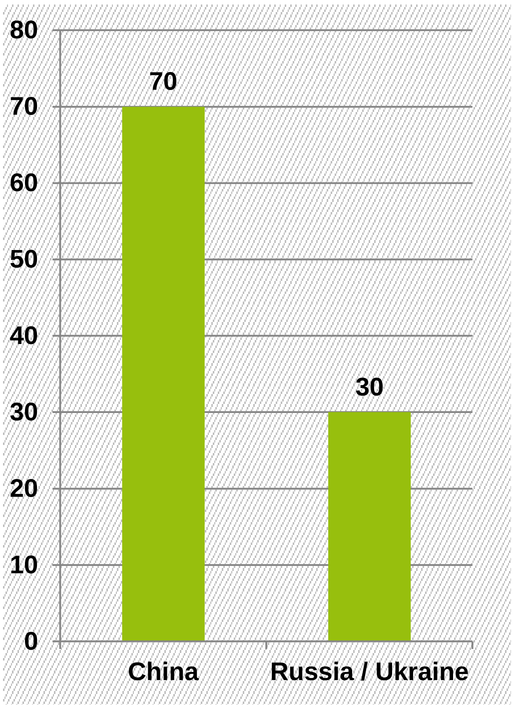
Main product, co-product or by-product

Scandium is a by-product of REEs, uranium and titanium (European Commission 2017b).

Primary production

Total global production 2011: 10 tonnes (European Commission 2015a).

Percentage of scandium, mines mined in 2012 (%) (European Commission 2015a)



Information on Deposits

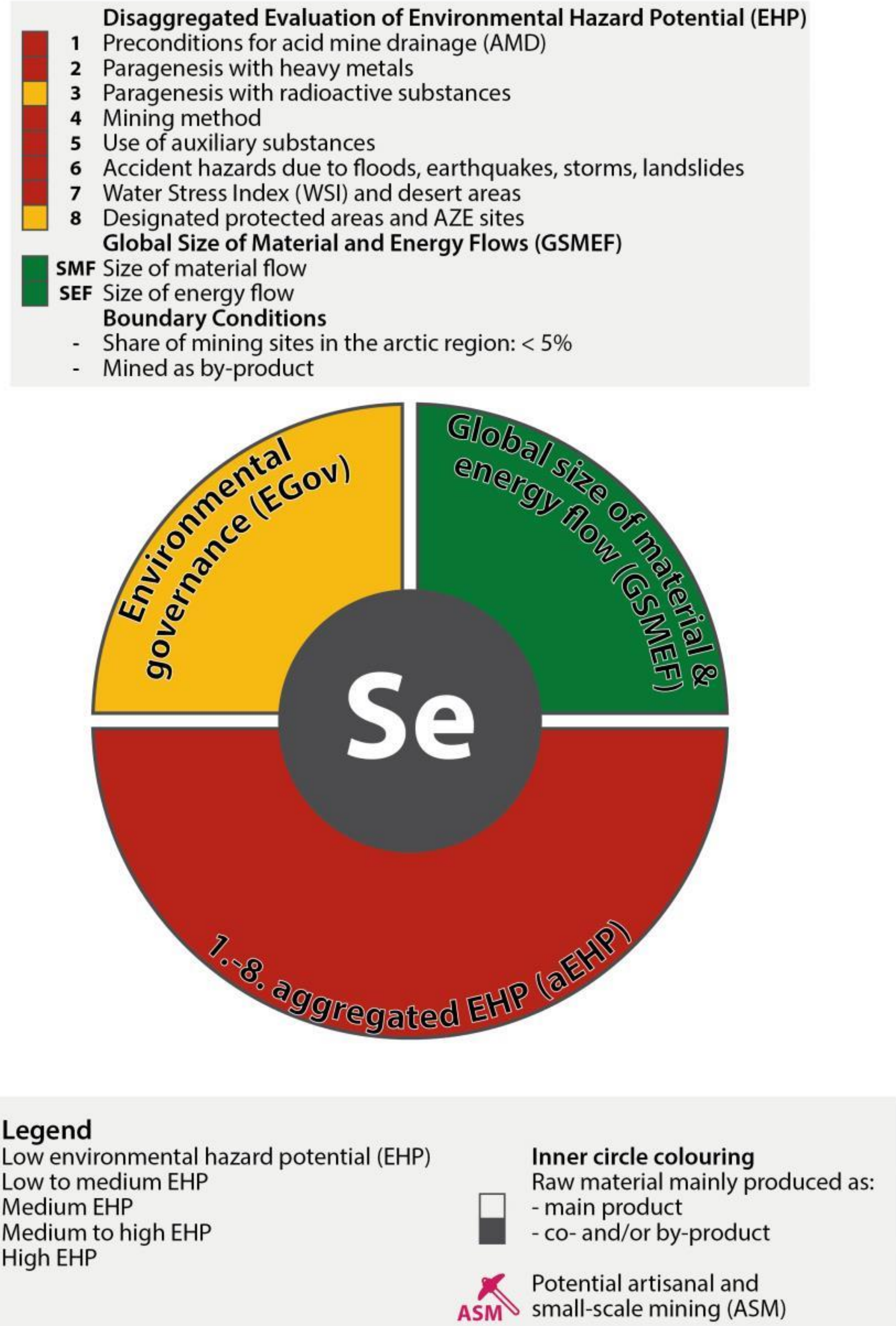
Scandium is lithophilic, a rare earth element and occurs in a few phosphates and silicates as scandium mineral (e.g. Thortveitite). The deposits of scandium are of pegmatic origin.

4.46.2 Profile Scandium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Due to the lithophilic properties and the formation conditions of SE, the prerequisites for the formation of acid waters or for autooxidation are low.	low
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Due to the deposit genesis only low heavy metal contents are to be expected.	medium
Indicator 3: Paragenesis with radioactive substances		
High EHP	Scanium is a rare earth element. These are usually associated with high concentrations of U and Th.	high
Indicator 4: Mine Type		
Medium EHP	Open pit mining, rarely underground mining.	high
Indicator 5: Use of auxiliary substances		
High EHP	Flotation, physical-chemical separation processes Roasting, carbonate precipitation, acid leaching, solvent extraction, in-situ leaching.	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	The results for scandium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 12 % low, 37 % medium, 51 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		

Environmental hazard potential	Explanation	Data quality
Low EHP	The results for scandium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 84 % low, 8 % medium, 8 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for scandium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 54.66.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 0.002 million t/a results from the $CRD_{specific}$ of 238 t/t and the global annual production of 10 t/a.	low
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 1 PJ/a results from the $CED_{specific}$ of 97,200,000 MJ-eq/t and the global annual production of 10 t/a.	hoch
Indicator 12: Position of mining sites in the arctic region		
High	The results for scandium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 94 % low, 6 % medium EHP.	medium

4.47 Selenium



4.47.1 General Information

Introduction and characteristics

Selenium is a trace element for human health which can exist either in grey crystalline form or as a red–black powder. It is photoconductive and photovoltaic with a hardness similar to gypsum and a low melting temperature of 221°C. In the earth´s crust selenium is rare and widely distributed. Thus it is only extracted as a co-product mostly from sulfidic ores where it partially replaces sulfur (European Commission 2017a).

Applications

Global end uses of selenium, by order of relevance, include metallurgy, glass manufacturing, electronics, pigments for plastics, ceramics, glazes and paints, as well as agricultural/biological products and chemical manufacture. In metallurgy selenium is primarily used in the production of electrolytic manganese but also to improve the machinability of other metals. In glass manufacturing it serves as a colouring (red) as well as a decolouring (remove green) agent. The electronics applications include rectifiers and photoreceptors (both declining tendency) and potentially thinfilm photovoltaic cells (copper-indium-gallium-selenide, CIGS) depending on the market penetration of this technology. In agriculture/biological applications the nutritious quality of selenium as a trace element is exploited. In chemical manufacture selenium serves as a catalyst, plating alloy and to improve abrasion resistance of rubbers (European Commission 2017a).

Recycling

The quantities for recycling are very small for selenium and most of the input is 'new scrap' because many of the end uses of selenium are dissipative (e.g. pigments). Electronics are the only current source of 'old scrap', however, quantities from photoreceptors or rectifiers, are small and declining due to substitution. Thinfilm PV cells could become a source depending on the market penetration of CIGS technology (European Commission 2017a). European Commission (2017a) estimates an 'end-of-life recycling input rate' of 1 %.

Substitution

In metallurgy, sulphur dioxide can be used as a substitute for selenium in the electrolytic production of manganese, while bismuth, lead and tellurium are potential substitutes to improve the machinability of alloys. Decolourising of glass can also be achieved by cerium oxide and manganese, while red colour can be provided by gold chloride and copper instead. In electronics substitution is already under-way with organic photoreceptors and silicon-based rectifiers. Also in PV cells silicon is an alternative to selenium. For thinfilm PV cells cadmium telluride could be used instead. However, lead and cadmium, like mercury, which was once a potential substitute for selenium as a pigment, are critical due to toxicity concerns. At reduced performance organic pigments are a potential substitute for selenium. As selenium constitutes a trace element for human beings and animals there is no substitute in the field of nutrition (European Commission 2017a).

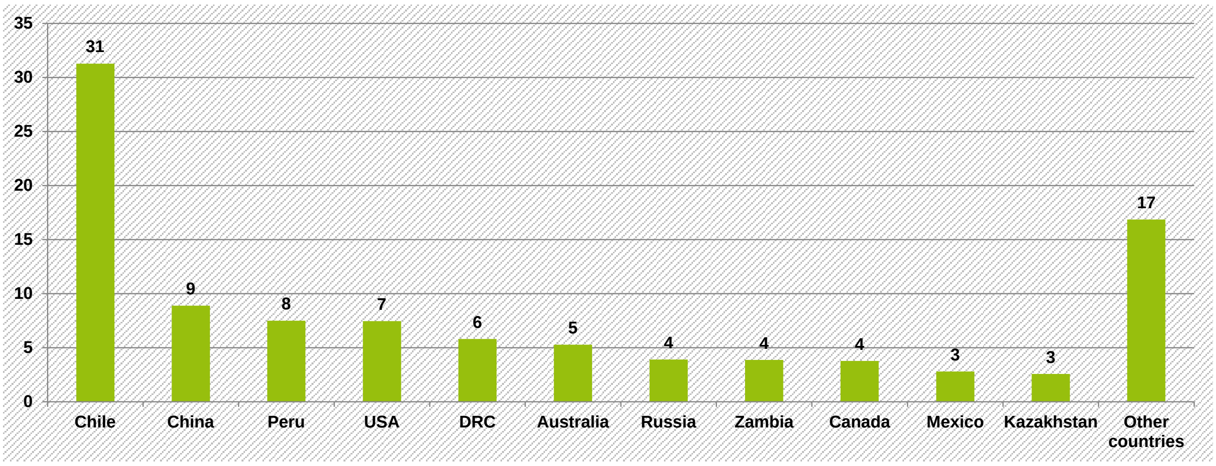
Main product, co-product or by-product

Selenium is a by-product of copper (European Commission 2017a).

Primary production

Total global production 2014: 2,813 tonnes (BGS 2016).

Percentage of selenium mines mined in 2014 (%) (BGS 2016)



Information on Deposits

Selenium is chalkophilic. It occurs in sulphide ores of liquid magmatic segregations, e.g. the nickel magnetic gravel deposits, in hydrothermal veins as lead, silver, gold or copper selenide, as well as in marine sedimentary iron and copper ores.

4.47.2 Profile Selenium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	The extraction from deposits with sulphide mineral parageneses requires a high potential of the residual substances for the formation of acid waters.	medium
Indicator 2: Paragenesis with heavy metals		
High EHP	The element selenium itself has toxic properties and is defined as a heavy metal in this method description.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Is mainly extracted from copper ores (see valuation for copper).	medium
Indicator 4: Mine Type		
High EHP	Extraction from anode sludge from copper production	high
Indicator 5: Use of auxiliary substances		
High EHP	Amalgamation, roasting, digestion with acidity	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	Since selenium is mainly extracted from copper ores the evaluation is the same as for copper. The results for selenium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 33 % low, 14 % medium, 53 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
High EHP	Since selenium is mainly extracted from copper ores the evaluation is the same as for copper. The results for selenium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 42 % low, 1 % medium, 57 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		

Environmental hazard potential	Explanation	Data quality
Medium EHP	Since selenium is mainly extracted from copper ores the evaluation is the same as for copper. The results for selenium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 96 % low, 2 % medium, 2 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 57.95.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 0.01 million t/a results from the $CRD_{specific}$ of 3,8 t/t and the global annual production of 2,813 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 0.2 PJ/a results from the $CED_{specific}$ of 65,500 MJ-eq/t and the global annual production of 2,813 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for selenium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium EHP.	low

4.48 Silica sand

Disaggregated Evaluation of Environmental Hazard Potential (EHP)

1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites

Global Size of Material and Energy Flows (GSMEF)

SMF Size of material flow
SEF Size of energy flow

Boundary Conditions

- Share of mining sites in the arctic region: 0%
- Mined as main product

Legend

Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP

Inner circle colouring

Raw material mainly produced as:
- main product
- co- and/or by-product

ASM Potential artisanal and small-scale mining (ASM)

4.48.1 General Information

Introduction and characteristics

Silica is silicon dioxide (SiO_2). Silica sand is mostly made of quartz, one of the crystalline silica polymorphs and the most common mineral in the earth´s crust. For industrial applications of silica sand a quartz content of at least 95 % is required (European Commission 2017a).

Applications

The major applications for silica sand are in the construction industry, e.g. concrete, surface and road construction, and for glass production. Moreover, due to the high melting point it is used for foundry castings. Other applications are e.g. in ceramics, filtration, paints and polymers (European Commission 2017a). Metallurgical grade silicon and products in the optical and electronics industries require very high-grade quartz as an input which is classified as critical material according to European Commission (2017b).

Recycling

While there is no recycling of silica sand to silica sand, materials containing silica originally from silica sand are widely being recycled. An outstanding example is glass recycling which contributes 95 % to the material input in the glass industry (European Commission 2017a).

Substitution

According to European Commission (2017a) silica sands are not currently substituted due to their superior performance compared to potential substitutes.

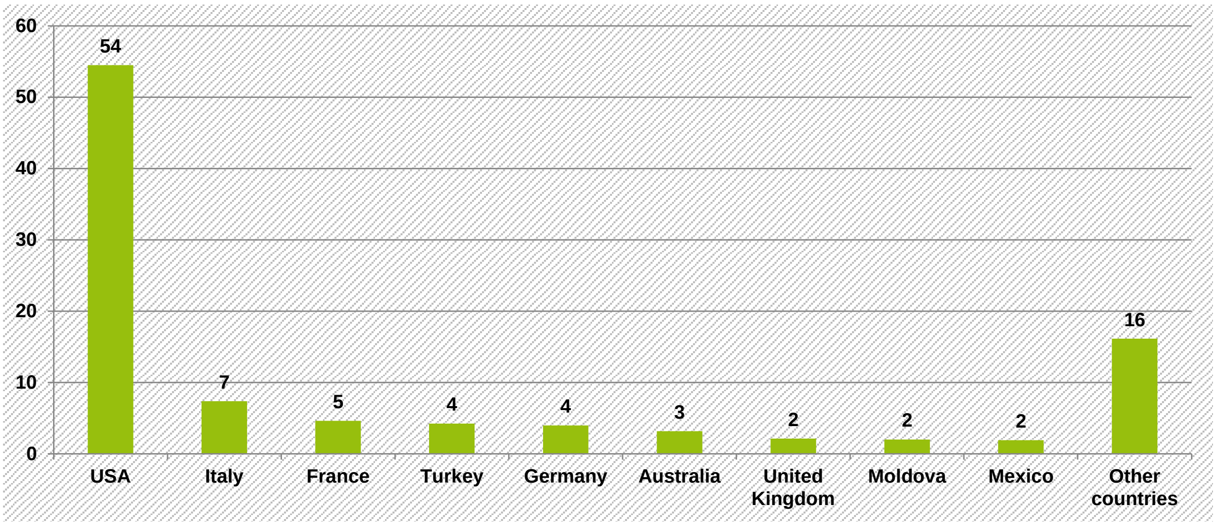
Main product, co-product or by-product

Silica sand is a main product (European Commission 2017a).

Primary production

Total global production 2015: 189,030,000 tonnes (USGS 2017)

Percentage of silica sand mines mined in 2015 (%) (USGS 2017)



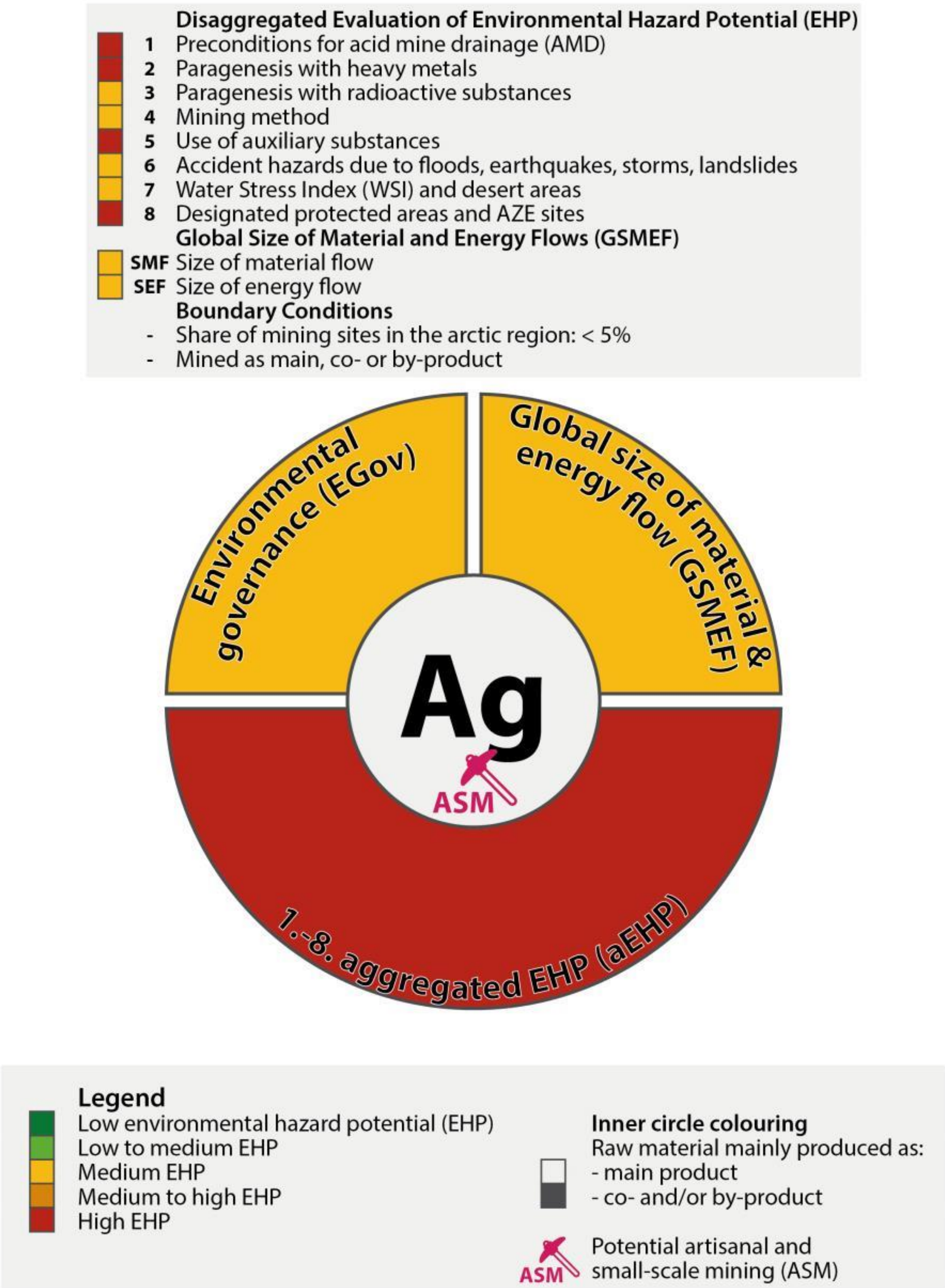
Information on Deposits

Silicon is a lithiphilic element. It is the second most abundant element in the earth's crust and therefore part of a large number of minerals. The most important is the quartz, SiO_2, which forms rocks in many deep rocks. The quartz sand is formed by weathering. It can be found in all sediments with fluvial, marine and aeolian enrichment.

4.48.2 Profile Silica sand

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Generally quartz sand is present in oxidic deposits.	high
Indicator 2: Paragenesis with heavy metals		
Low EHP	Quartz sand is a non-metallic raw material made of inert material. Quartz sand is mostly extracted from deposits that are classified as natural background concentrations of rocks with regard to heavy metal concentrations.	high
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Quartz sand is extracted from sedimentary deposits which predominantly contain low concentrations of radioactive substances.	medium
Indicator 4: Mine Type		
High EHP	surface mining	high
Indicator 5: Use of auxiliary substances		
High EHP	Flotation, among others use of sulphuric acid	low
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for silica range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 48 % low, 23 % medium, 29 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for silica range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 56 % low, 7 % medium, 37 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
High EHP	The results for silica range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 80 % low, 13 % medium, 7 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 70.26.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 206 million t/a results from the $CRD_{specific}$ of 1.1 t/t and the global annual production of 189,030,000 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 54 PJ/a results from the $CED_{specific}$ of 287 MJ-eq/t and the global annual production of 189,030,000 t/a.	low
Indicator 12: Position of mining sites in the arctic region		
Low	The results for silica range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP.	medium

4.49 Silver


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 5%
- Mined as main, co- or by-product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Ag
ASM
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
ASM
Potential artisanal and small-scale mining (ASM)

4.49.1 General Information

Introduction and characteristics

Silver belongs to the precious metals which are resistant to corrosion and has the highest electrical and thermal conductivity of all metals. Moreover, it is very soft, malleable and ductile (European Commission 2017a).

Applications

Due its aesthetic properties and high value silver is used in coins, silverware and jewellery. Industrial applications include the electrical and electronics industry, photovoltaics, its use as a catalyst, as well as the declining use for film photography. Other uses include coatings, cellophane and batteries, or emerging applications e.g. in solid state lighting or as nano silver (European Commission 2017a).

Recycling

According to European Commission (2017a) a high share of silver is recycled during manufacturing. At end-of-life especially coins, silverware and jewellery have very high recycling rates, while in industrial applications these differ by type: in applications where silver use is more dissipative, especially in vehicles, recycling rates are low while for example the use as a catalyst has a relatively high recycling rate.

Substitution

The use of silver for jewellery, silverware and coins is by nature in principle substitutable. In electrical and electronic applications silver can be substituted by other precious metals, copper, or aluminium, but considerations on performance and cost may motivate a tendency to silver. Tin can be a substitute for silver in brazing alloys and solders leading to lower cost but decreased performance. With respect to its use in film photography, there the whole technology is being substituted by digital photography (European Commission 2017a).

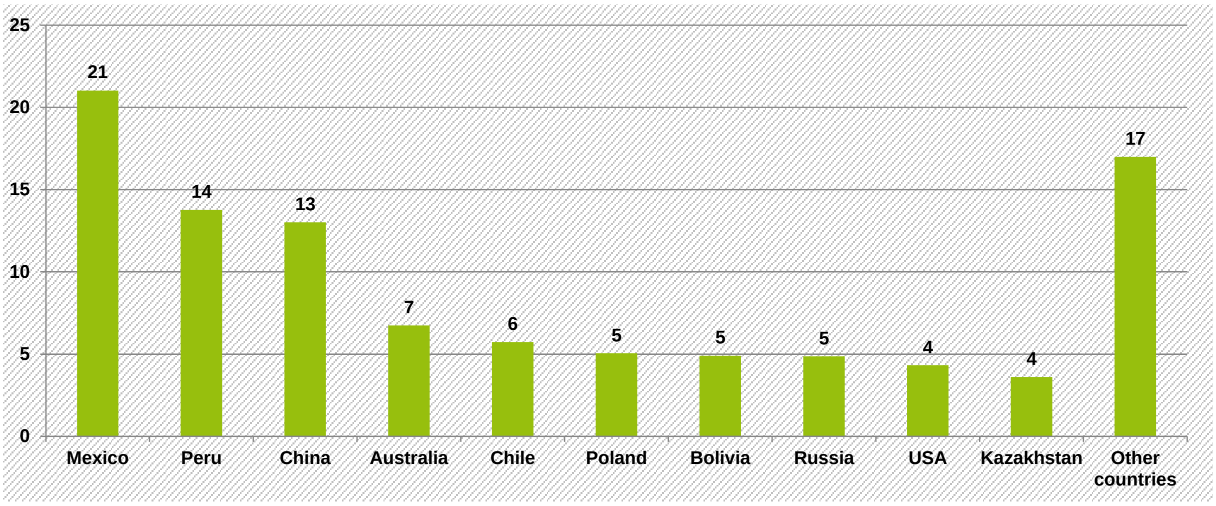
Main product, co-product or by-product

Silver can be a main, a co- or a by-product (European Commission 2017a).

Primary production

Total global production: 27,427 tonnes in 2014 (BGS 2016).

Percentage of silver mines mined in 2014 (%) (BGS 2016)



ASM relevance

The global share of silver production from ASM is estimated by BGR at around 6.8 %, GEUS (2007) gives a number of 10 %.

Important silver producing countries with prominent ASM production are Mexico, Peru, China and Bolivia. 57 % of silver is produced in in countries with ASM.

Information on Deposits

Silver is a chalkophilic element. In nature it occurs mineralally as solid silver and as silver sulphides (e.g. silver luster, argentite, Ag_2S) and sulphosalts (e.g. $Ag_3[SbS_3]$), but a main source of silver is crystallographically dissolved silver in other ore minerals, e.g. galena and copper pyrites. Economically significant silver deposits originate from plutonic and sub-volcanic hydrothermal deposits (veins, stockwork mineralizations and impregnations), from submarine exhalative sedimentary deposits, and from terrestrial weathering deposits in arid areas.

4.49.2 Profile Silver

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	According to the Goldschmidt classification, silver is a chalcophilic element and is generally sulphidic.	medium
Indicator 2: Paragenesis with heavy metals		
High EHP	Approx. 36.5 % of silver production is extracted as a by-product from lead-zinc ores. Another 23.5 % is a by-product of copper ores. This means that at least 60 % of the deposits currently being mined are associated with high concentrations of heavy metals.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Approx. 36.5 % of silver production as a by-product from lead-zinc ores, 23.5 % from copper ores and 10.4 % from gold mining. As lead, zinc and copper mining are valued at a medium EHP (see comments there), silver is also valued at a medium EHP accordingly. This assessment is supported by a general statement from Valkovic (2000).	low
Indicator 4: Mine Type		
Medium EHP	open pit mining, underground mining, stockpile preparation	medium
Indicator 5: Use of auxiliary substances		
High EHP	Flotation, Cyan leaching	
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for silver range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 34 % low, 30 % medium, 36 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for silver range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 47 % low, 4 % medium, 49 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		

Environmental hazard potential	Explanation	Data quality
High EHP	The results for silver range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 90 % low, 7 % medium, 3 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 59.94. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 187 million t/a results from the $CRD_{specific}$ of 6,835 t/t and the global annual production of 27,427 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 90 PJ/a results from the $CED_{specific}$ of 3,280,000 MJ-eq/t and the global annual production of 27,427 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
High	The results for silver range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 98 % low, 2 % medium EHP.	medium

4.50 Talc

4.50.1 General Information

Introduction

Talc is a magnesium silicate mineral with the chemical formula $Mg_3Si_4O_{10}(OH)_2$. The raw form of the mineral is also termed steatite or soapstone. Due to its molecular structure it exhibits a hydrophobic and inert behaviour so that it is practically insoluble in water and weak acids and alkalis. Talc is the softest mineral in the world, and has a high melting point of 1,500°C (European Commission 2017a).

Applications

The largest applications for talc are in the paper, plastics, cosmetics, ceramics and paint industries (European Commission 2017a). In paper production talc serves as a bulking agent, for deposit control and coating. In plastics it is used to strenghten thermoplastics and as an anti-blocking agent for films. In the paint industry it serves as a bulking agent and to improve properties. Also in ceramics talc serves to enhance their properties and is used as a filler and glazing agent. In cosmetics, talc is used as powder, additive or filler. Other fields where it is used as a carrier, stabilizer, filler, coating or polishing material or to improve processability include fertilizers & pesticides, roofing, rubber industries, food & feed, pharmaceuticals and sealants (European Commission 2017a).

Recycling

Like other industrial minerals talc is recycled in significant quantities but these do not replace primary talc (European Commission 2017a). The end-of-life recycling input rate according to European Commission (2017a) is hence only estimated to be 5 %.

Substitution

In general, talc can be substituted by other minerals which for the specific type of application offer comparable properties. Examples for possible substitutes are bentonite, chlorite, calcium carbonate, kaolin, or mica. Beside technical feasibility, the possibility for substitution depends on its impact on performance and cost. Options for different types of applications are given in (European Commission 2017a).

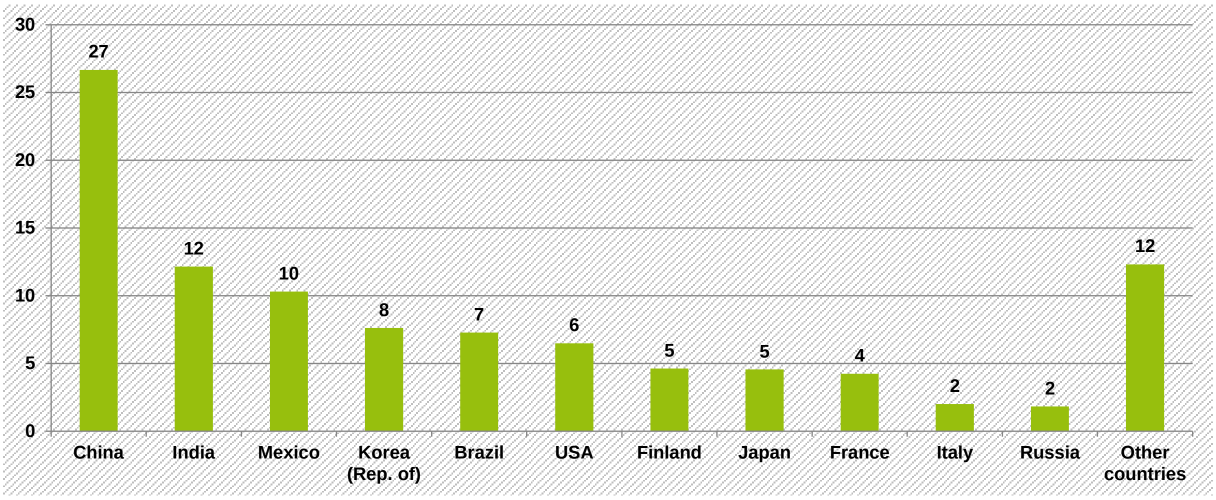
Main product, co-product or by-product

Talc is a co-product (European Commission 2017a)

Primary production

Total global production: 8,252,822 tonnes in 2014 (BGS 2016)

Percentage of talc mines mined in 2014 (%) (BGS 2016)



ASM relevance

Talc is a material occurring only in deposits of small size. At the same time demand and production of this material are limited. Due to these facts Talc is generally mined on a small scale, even more as the exploitation is highly selective and requires handpicking. GEUS (2007) estimates the SSM share of the global production in a range of 90 %.

Mining takes place in weathered silicate rocks and is therefore hardrock opencast. The environmental impact is reduced due to inert material, no soluble heavy metals and no use of toxic reagents for processing.

Accordingly the governance issues are non-critical.

Important talc producing countries with prominent ASM production are China, India, Mexico and Brazil. 59 % of talc is produced in countries with ASM.

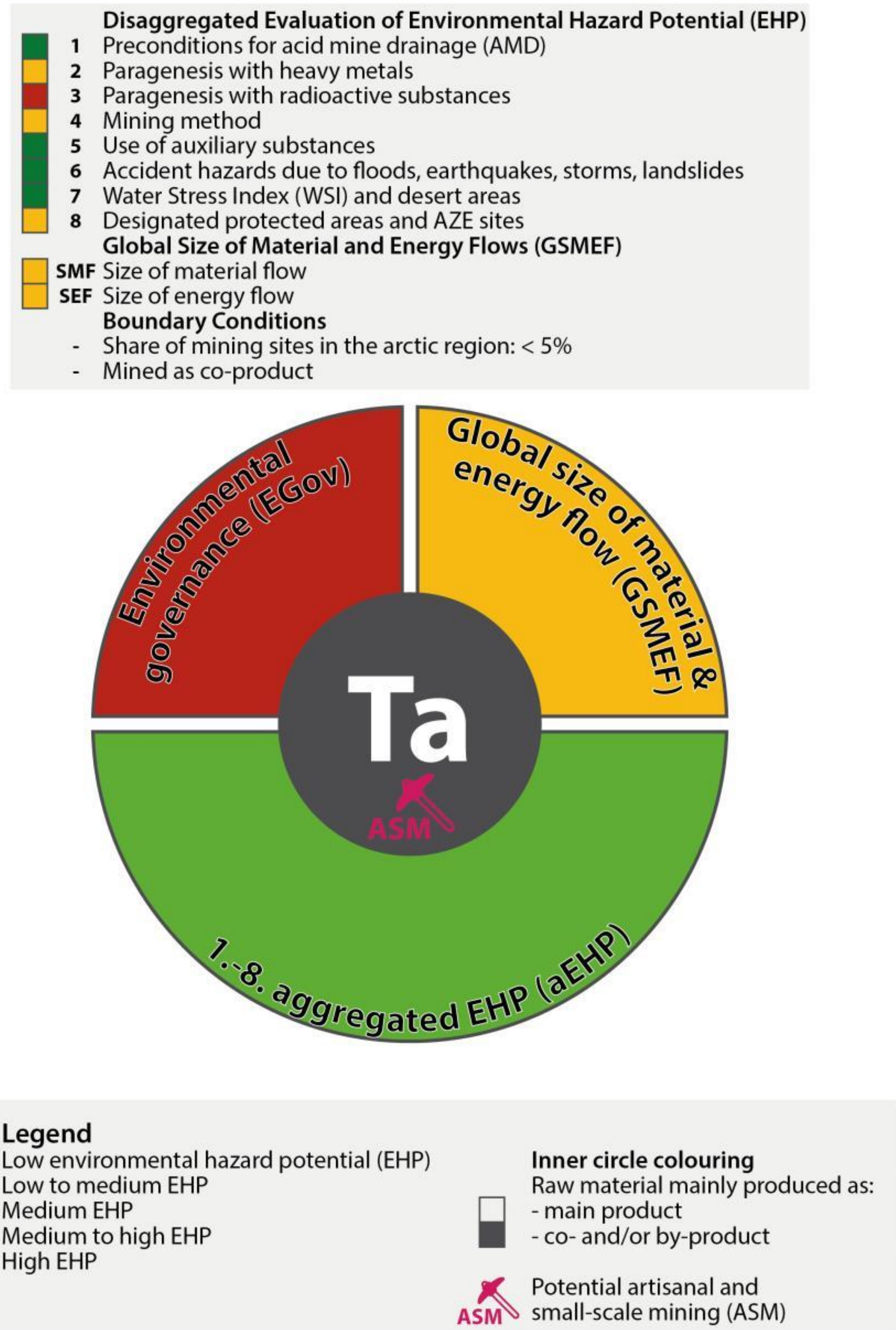
Information on Deposits

Talc, steatite, $Mg_3Si_4O_10(OH)_2$ is a mineral formed by multiple formation conditions, hydrothermal vein mineralization (economically insignificant), and the transformation of sedimentary or basic and ultrabasic deep rocks. It is associated with other silicates and economically valuable where it is free of quartz and limestone.

4.50.2 Profile Talc

Environmental hazard potential	**Explanation**	**Data quality**
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Inert material formed as weathering product: no autooxidation potential.	high
Indicator 2: Paragenesis with heavy metals		
Low EHP	Formed from the weathering of magmatic silicate minerals. Deposits largely free of heavy metals.	medium
Indicator 3: Paragenesis with radioactive substances		
Low EHP	Formed from basic and ultrabasic deep rocks, which generally show only very low concentrations of U and Th.	medium
Indicator 4: Mine Type		
Medium EHP	Surface mining, underground mining	medium
Indicator 5: Use of auxiliary substances		
Low EHP	air flotation	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
N/A	Information not available due to data restrictions	N/A
Indicator 7: Water Stress Index and desert areas		
N/A	Information not available due to data restrictions	N/A
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
N/A	Information not available due to data restrictions	N/A
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 57.95. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 12 million t/a results from the $CRD_{specific}$ of 1.4 t/t and the global annual production of 8,252,822 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 3.6 PJ/a results from the $CED_{specific}$ of 434 MJ-eq/t and the global annual production of 8,252,822 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
N/A	Information not available due to data restrictions	N/A

4.51 Tantalum



4.51.1 General Information

Introduction and characteristics

Tantalum is a transition metal of silvery-grey colour and has some exceptional characteristics like very high melting point (3,020°C), density (16.6 g/cm^3), corrosion resistance and permittivity. It is relatively rare in the earth´s upper crust and does not occur as free metal but in mineral form (esp. microlite, tantalite-columbite). It is mostly produced as co-product, in ore bodies often associated with niobium, tin or lithium. While tantalum was temporarily classified non-critical, according to the latest classification it again belongs to the critical metals (European Commission 2017b).

Applications

About one third of tantalum is used in capacitors. The second biggest use are superalloys, especially in the aerospace sector. Moreover, tantalum is used in sputtering targets for the manufacture of electronic products. Other uses include tantalum chemicals and medicals, mill products, and tantalum carbides used in cutting tools European Commission (2017b).

Recycling

The end-of-life recycling rate of tantalum is below 1 %. There is, however, some recycling of used tantalum-containing products on the industrial level, e.g. of superalloys from aeronautics. Reprocessing of new scrap, especially from the manufacture of electronic items, contributes to about 30 % of tantalum demand (European Commission 2017b).

Substitution

According to European Commission (2017b) current tantalum useage is already limited to applications where it is deemed unreplaceable with respect to performance and quality. In capacitors it is only used in cases where its superior performance and robustness (reliability, size, security) is required. In cutting tools it can be in principle replaced by other refractory metals, but these are in general expensive themselves and tungsten and niobium are also classified critical European Commission (2017b). In superalloys tantalum is added in precise amounts to guarantee a specific performance and any substitution would change the precisely engineered characteristics. Due to this critical contribution to the properties and its comparably minor cost in these applications the substitution of tantalum in already designed superalloys is unlikely (European Commission 2017b).

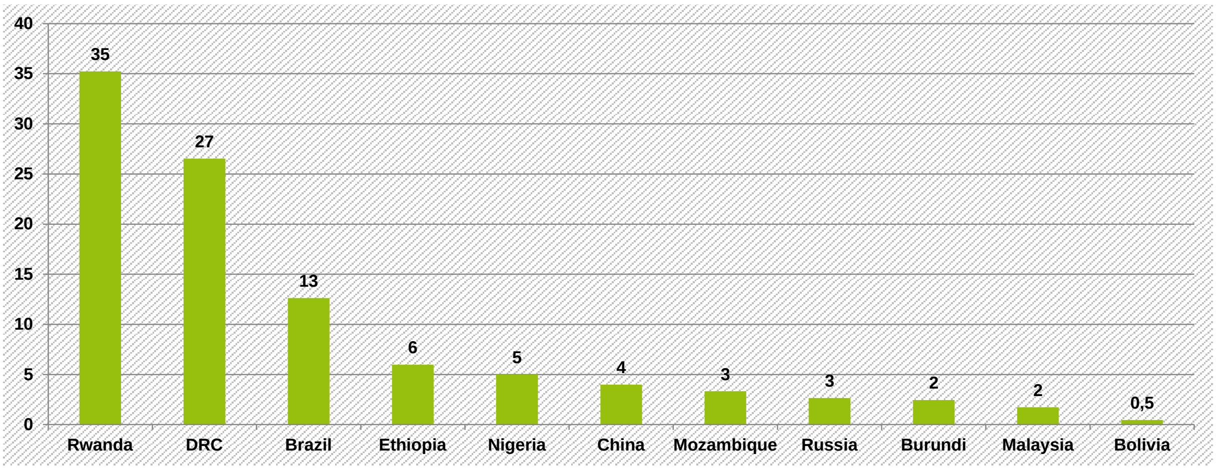
Main product, co-product or by-product

Tantalum is mostly a co-product with niobium or tin & lithium (European Commission 2017b).

Primary production

Total global production: 1,504 tonnes in 2014 (Reichl et al. 2016).

Percentage of tantalum mines mined in 2014 (%) (Reichl et al. 2016)



ASM relevance

The global share of Tantalum production from ASM is estimated by BGR at around 20 %, Dorner et al. (2012) give a number of 26 %.

Tantalum is one of the 3T minerals (tin, tungsten and tantalum), which occur in the same type of deposits and are mostly produced together.

ASM is currently operating in alluvial tantalum deposits (main mineral being columbite and tantalite) as well as in the weathering zone of pegmatites.

Related to conflict financing in Central Africa.

Tantalum mining and trade is regulated or targeted by international laws, regulations and stewardship initiatives, such as the Dodd-Frank-Act, the EU Conflict mineral regulation, the OECD Due Diligence Guidance for Conflict Minerals/Minerals from Conflict Regions.

Specific certification schemes such as: iTSCi, CTC, ICGLR RCM and others.

The trade and raw material value chains, especially in the tantalum ASM from Central Africa are extremely complex and long: sometimes more than 10 intermediaries, transporters, processors, exporters are involved before the material reaches the smelters in China.

Important tantalum producing countries with prominent ASM production are Rwanda, Congo, Brazil, Ethiopia, Nigeria, China and Mozambique. 93 % of tantalum is produced in countries with ASM.

Information on Deposits

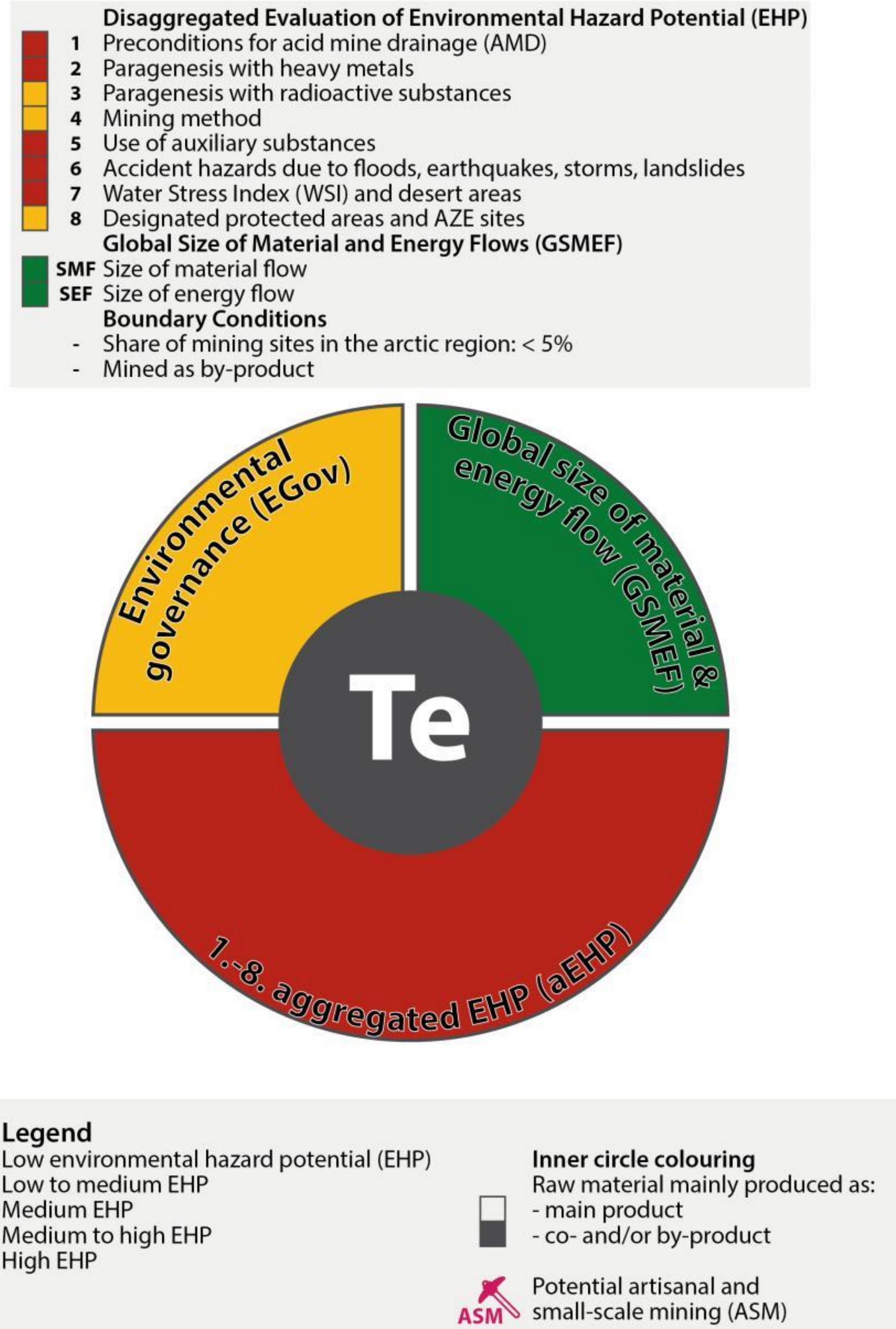
Tantalum is lithophilic and has its economic importance in niobium-tantalum deposits of pegmatitic and pneumatolytic genesis as well as in carbonatites. The most important ore mineral is columbite tantalite (coltan). This often has thorium contents. Otherwise, columbitol is often found in parageneses with tin calcite, tungsten and other pegmatite minerals. Since these minerals are resistant to weathering, they can also be found in alluvial and residual deposits.

4.51.2 Profile Tantalum

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		

Environmental hazard potential	Explanation	Data quality
Low EHP	Both primary and secondary (sedimentary) occurrences of tantalum minerals are paragentially free or very poor in sulfidic compounds, which could have an autooxidation potential.	high
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Tantalum itself is not a heavy metal. Data from Nigerian deposits show increased Cd concentrations (> 5,000 ppm). This, together with the recommendations of the method description, indicates a medium potential for environmental hazard.	medium
Indicator 3: Paragenesis with radioactive substances		
High EHP	Tantalum is usually associated with high concentrations of U and/or Th. This is confirmed by data from Chinese deposits (5.1 % of world production). Up to 10 Bq /g	high
Indicator 4: Mine Type		
Medium EHP	Solid rock surface mining, loose rock surface mining, underground mining, alluvial mining.	high
Indicator 5: Use of auxiliary substances		
Low EHP	Gravimetry, magnetic separation	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for tantalum range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 40 % low, 45 % medium, 15 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Low EHP	The results for tantalum range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 97 % low, 0 % medium, 3 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for tantalum range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 92 % low, 8 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 43.76. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 11 million t/a results from the $CRD_{specific}$ of 9,180 t/t and the global annual production of 1,504 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 5.4 PJ/a results from the $CED_{specific}$ of 4,360,000 MJ-eq/t and the global annual production of 1,504 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Low	The results for tantalum range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 100 % low, 0 % medium EHP.	medium

4.52 Tellurium



4.52.1 General Information

Introduction and characteristics

Tellurium is a silvery-grey metalloid with a melting point of 450 °C (European Commission 2017a). It is one of the rarest elements in the earth´s crust and commonly found in compounds that also contain base or precious metals. It is hence mainly produced as a by-product with the main source being anode muds from electrolytic copper refining (European Commission 2017a).

Applications

The main applications of tellurium are in thinfilm PV cells and in thermoelectric devices. Moreover, tellurium is used as an additive in metal alloys and in the processing of rubber. Other uses are in the chemical industry (e.g. production of synthetic fibres or in oil refining), as a pigment in glass and ceramics or as an additive in lubricants (European Commission 2017a).

Recycling

Many of the end uses of tellurium are dissipative and the end-of-life recycling rate of tellurium is below 1 %. A very small quantity is currently recovered from end-of-life electrical products. Depending on the market penetration of cadmium-tellurium PV cells more end-of-life material may become available for recycling in the future. For tellurium also the quantities of new scrap for recycling are very small (European Commission 2017a).

Substitution

In PV cells silicon is the major alternative to tellurium-containing cells. Moreover, CIGS (copper-indium-gallium-selenide) cells can be used instead. Gallium, indium and silicon are classified critical according to (European Commission 2017b). In thermo-electric devices according to European Commission (2017a) only silicon-germanium is currently a commercially viable potential substitute, however, at greater cost and reduced performance. Both silicon and germanium are classified critical (European Commission 2017b). For alloying metals several potential substitutes exist: bismuth, calcium, lead, phosphorus, selenium and sulphur (European Commission 2017a). Bismuth and phosphate rock are classified critical (European Commission 2017b).

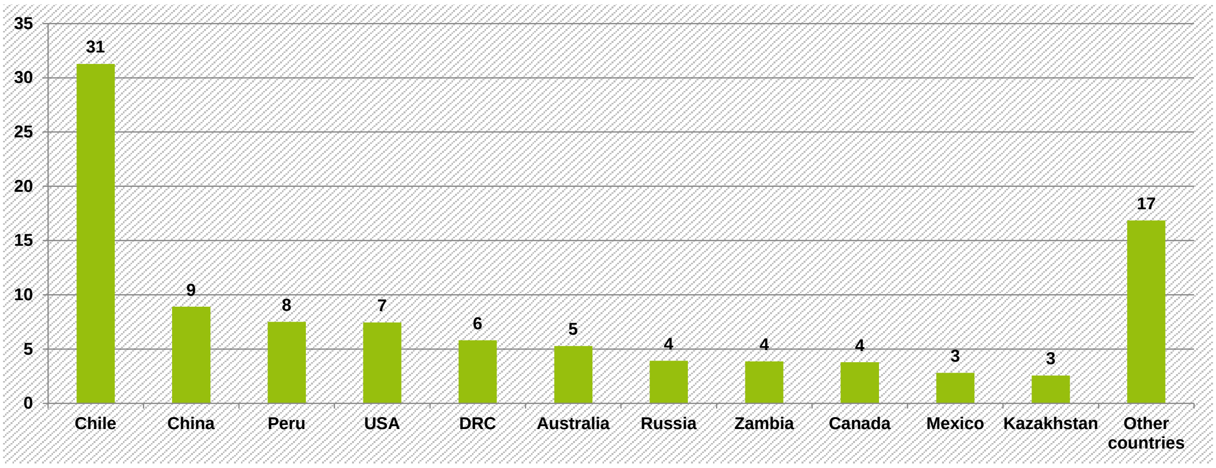
Main product, co-product or by-product

Tellurium is a by-product of copper (European Commission 2017a).

Primary production

Total global production: 152 tonnes in 2014 (BGS 2016).

Percentage of tellurium mines mined in 2014 (%) (BGS 2016)



Information on Deposits

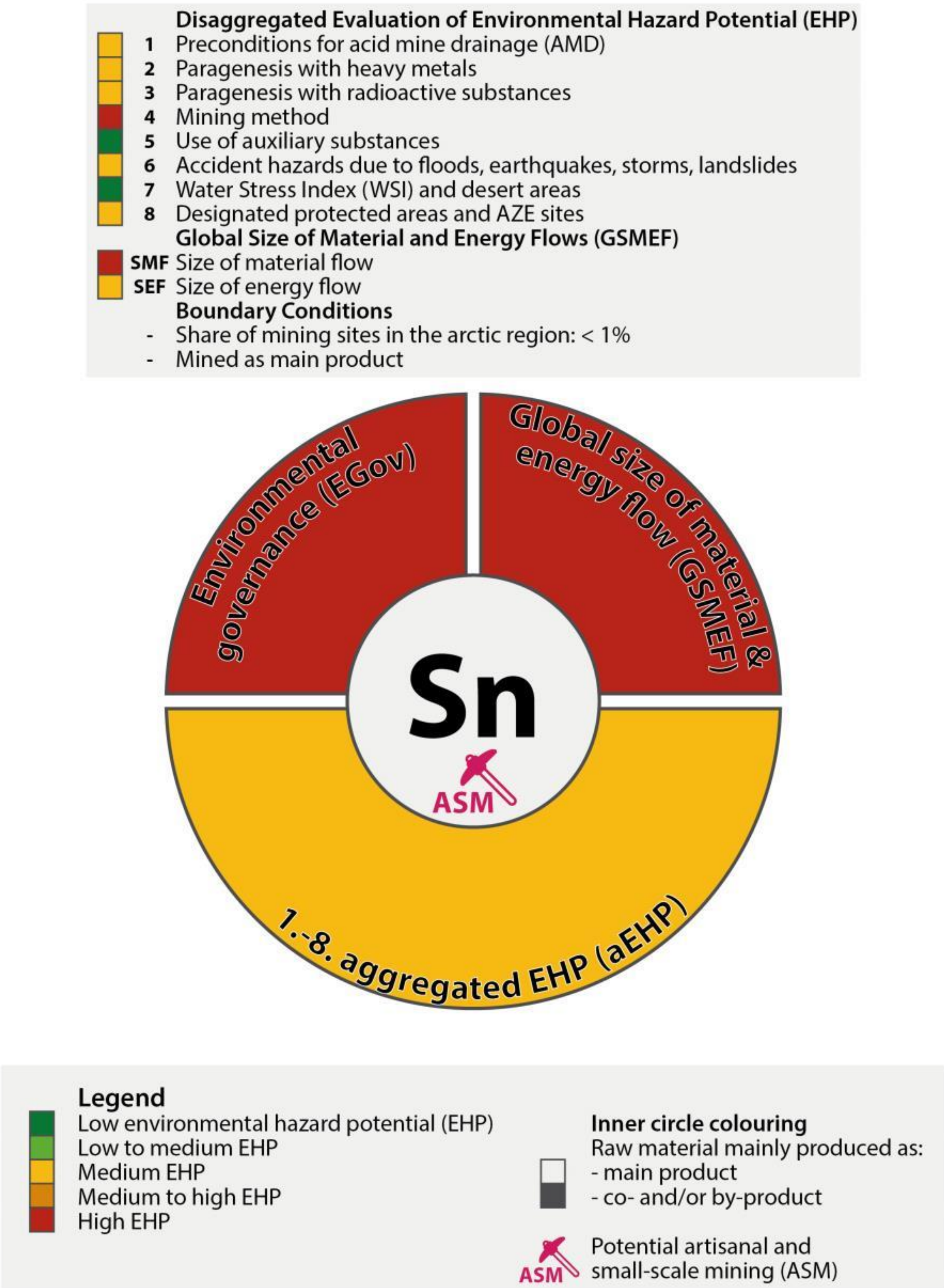
Tellurium is chalkophilic. It occurs in sulphide ores of liquid magmatic segregations, e.g. the nickel magnetic gravel deposits, as well as in hydrothermal veins as lead, silver and gold tellurides (no economic extraction from the latter).

4.52.2 Profile Tellurium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Tellurium is a chalcophilic element according to the Goldschmidt classification and is generally sulfidic.	medium
Indicator 2: Paragenesis with heavy metals		
High EHP	More than 90 % of tellurium production is a by-product of copper ores. Another 10 % is a by-product from lead-zinc ores. This means that a large proportion of the deposits currently being mined are associated with high concentrations of heavy metals.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Tellurium is mainly extracted from copper ores (see valuation for copper).	medium
Indicator 4: Mine Type		
Medium EHP	By-product of copper (same valuation)	medium
Indicator 5: Use of auxiliary substances		
High EHP	Amalgamation	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
High EHP	The results for tellurium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 33 % low, 14 % medium, 53 % high EHP.	low
Indicator 7: Water Stress Index and desert areas		
High EHP	The results for tellurium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 42 % low, 1 % medium, 57 % high EHP.	low
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for copper range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results	low

Environmental hazard potential	Explanation	Data quality
	for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 96 % low, 2 % medium, 2 % high EHP.	
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 57.95.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Low	CRD_{global} of 0.01 million t/a results from the $CRD_{specific}$ of 102 t/t and the global annual production of 152 t/a.	medium
Indicator 11: Cumulated energy demand of global production CED_{global}		
Low	CED_{global} of 0.1 PJ/a results from the $CED_{specific}$ of 435,000 MJ-eq/t and the global annual production of 152 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for tellurium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium EHP.	low

4.53 Tin


Disaggregated Evaluation of Environmental Hazard Potential (EHP)
1 Preconditions for acid mine drainage (AMD)
2 Paragenesis with heavy metals
3 Paragenesis with radioactive substances
4 Mining method
5 Use of auxiliary substances
6 Accident hazards due to floods, earthquakes, storms, landslides
7 Water Stress Index (WSI) and desert areas
8 Designated protected areas and AZE sites
Global Size of Material and Energy Flows (GSMEF)
SMF Size of material flow
SEF Size of energy flow
Boundary Conditions
- Share of mining sites in the arctic region: < 1%
- Mined as main product
Environmental governance (EGov)
Global size of material & energy flow (GSMEF)
Sn
ASM
1.-8. aggregated EHP (aEHP)
Legend
Low environmental hazard potential (EHP)
Low to medium EHP
Medium EHP
Medium to high EHP
High EHP
Inner circle colouring
Raw material mainly produced as:
- main product
- co- and/or by-product
Potential artisanal and small-scale mining (ASM)

4.53.1 General Information

Introduction and characteristics

Tin is a silvery-white, malleable metal with a very low melting point (232 °C). It is alloyed with copper to form bronze or with copper and zinc to from brass. In the earth´s crust it is rather rare, especially compare to other usual industrial metals, like aluminium or copper. Important properties are its resistance to corrosion and good electrical conductivity (European Commission 2017a).

Applications

Major uses of tin include solders (in electronics and industrial applications), tin plate (tin-coated steel esp. in the packaging sector) and chemicals (e.g. organo-tin chemicals for PVC stabilisers). Tin-containing alloys are used in different industrial applications e.g. in the automotive sector. Moreover, tin is used in float glass production, pewter items, tin powders and batteries (European Commission 2017a).

Recycling

Tin is recycled in relevant quantities, the overall share of secondary materials in total tin use being estimated to be 30-35 % globally. The end-of-life recycling rates depend on the applications; while high values are obtained for tinplate in the packaging sector, they are lower for solders in electronics and become negligible in the case of chemical applications (European Commission 2017a).

Substitution

In packaging tinplate can be replaced by glass, plastic, or aluminium. In electronics epoxy resins constitute a potential substitute for metallic solders. While in metallic lead-free solders tin content has gone up there is a general tendency in industry to decrease tin quantities on a per product basis (European Commission 2017a).

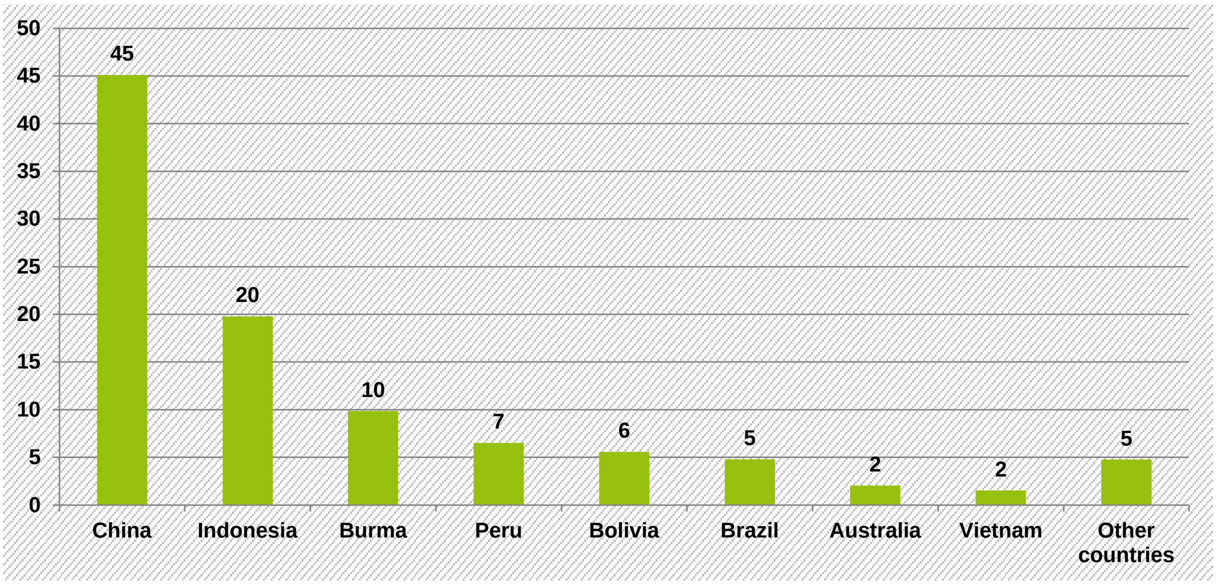
Main product, co-product or by-product

Tin is almost always a main product (European Commission 2017a).

Primary production

Total global production: 354,641 tonnes in 2014 (BGS 2016).

Percentage of tin mines mined in 2014 (%) (BGS 2016)



ASM relevance

Tin is an important target of ASM: global tin production share of ASM is according to BGR 30 %, to GEUS (2007) (SSM) 15 % and to Dorner et al. (2012) 25 %.

In Central Africa in mixed ores with Tantal and Tungsten and related to armed conflicts.

Tin is one of the 3T minerals (tin, tungsten and tantalum), which occur in the same type of deposits and are mostly produced together.

ASM is currently operating in alluvial tin deposits (main mineral being cassiterite) both from rivers and fluviatile terraces as well as from marine coastal deposits as well as in primary hydrothermal vein deposits.

The ASM tin mining operations in Bangka-Belitung in Indonesia have been described in detail in the case studies from both ÖkoRess I and UmSoRess, explaining as well the aggravating factors, such as the involvement of economic and political elites and the difficulties to apply the pertinent legal framework, which are important barriers to formalize the operations and limit the environmental impact of the tin extraction.

Tin mining and trade is regulated or targeted by international laws, regulations and stewardship initiatives, such as the Dodd-Frank-Act, the EU Conflict mineral regulation, the OECD Due Diligence Guidance for Conflict Minerals/Minerals from Conflict Regions.

Specific certification schemes such as: iTSCi, CTC, ICGLR RCM and others.

Important tin producing countries with prominent ASM production are China, Indonesia, Peru, Bolivia, Brazil and Vietnam. 96 % of tin is produced in countries with ASM.

Information on Deposits

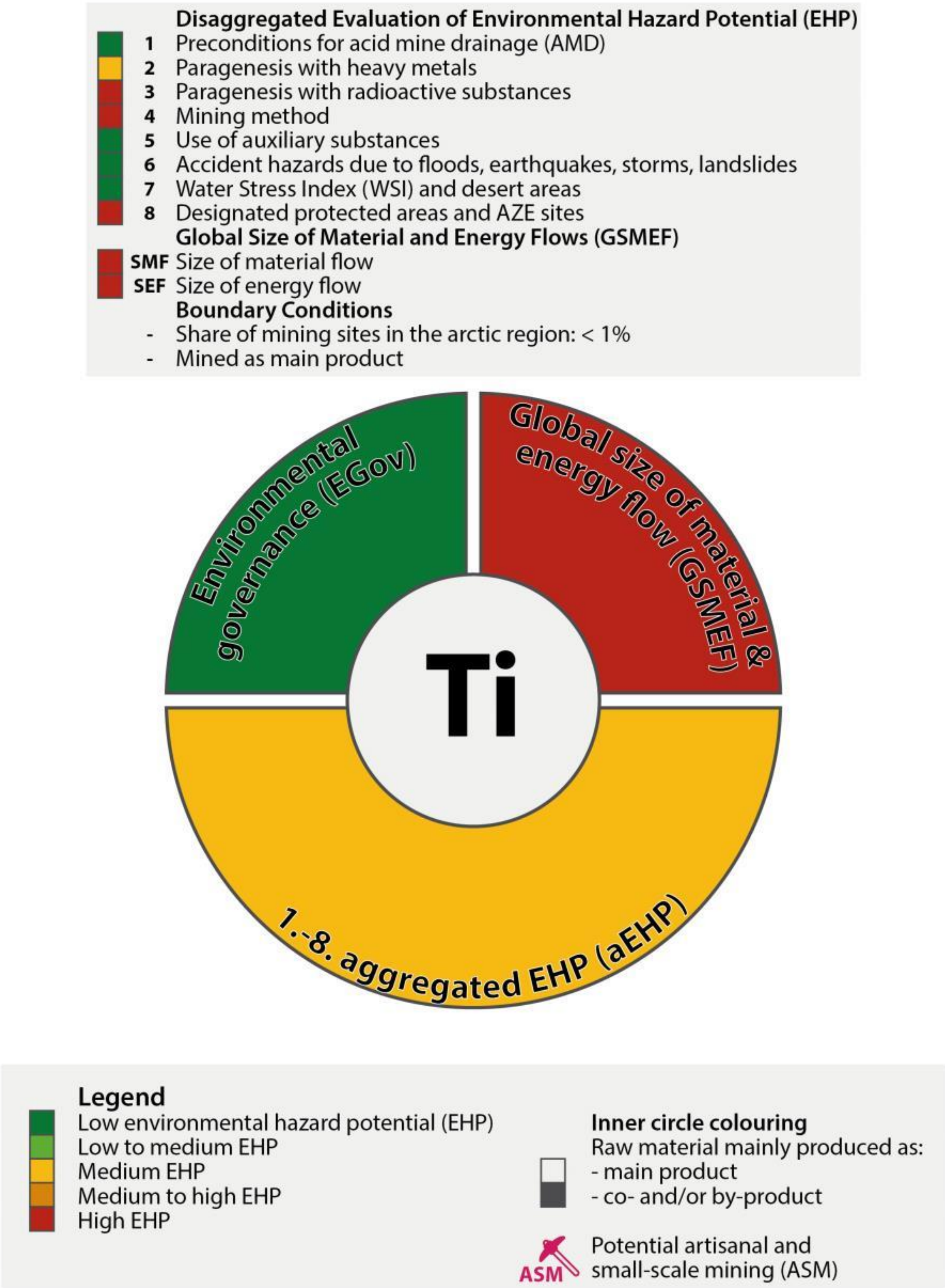
Tin is a siderophilic element with tin calcite (cassiterite, SnO_2) and tin pyrites (stannite, Cu_2FeSnS_4), as well as some rare sulfosalts, e.g. cylindrite, as ore minerals. The formation conditions differ considerably: Tin calculus in pneumatolytic and pegmatitic deposits (then also with tantalite, tungsten etc.) and hydrothermal ducts of acidic magmas, in old irons and - economically most important - as tin soaps. Stannite and the tin sulfosalts rarely on tinstone deposits, rather hydrothermal with zinc blende, galena, arsenopyrite, copper pyrite and pyrite.

4.53.2 Profile Tin

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Medium EHP	Tin is mainly extracted from oxidic deposits, only part of it is extracted from sulphidic (tin pyrites and sulphosalt) deposits, from which there is then a potential for autooxidation of the residues.	low
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Tin itself is not a heavy metal, but is mostly extracted from deposits under the association of heavy metals.	medium
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Average data on Chinese tin deposits (37,4 % of world production) suggest that in many cases tin is associated with slightly elevated concentrations of uranium and/or thorium.	high
Indicator 4: Mine Type		
High EHP	Alluvial mining, placers, underground mining, stockpile preparation	high
Indicator 5: Use of auxiliary substances		
Low EHP	"Gravimetry flotation (for tin pyrites and tin sulphosalts, the latter in exception	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for tin range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 24 % low, 47 % medium, 29 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Low EHP	The results for tin range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 94 % low, 0 % medium, 6 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for tin range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 90 % low, 7 % medium, 3 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 51.75. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 418 million t/a results from the $CRD_{specific}$ of 1,179 t/t and the global annual production of 354,641 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 114 PJ/a results from the $CED_{specific}$ of 321,000 MJ-eq/t and the global annual production of 354,641 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for tin range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment.	medium

Environmental hazard potential	Explanation	Data quality
	The results of the GIS assessment are: 99 % low, 1 % medium EHP.	

4.54 Titanium



4.54.1 General Information

Introduction and characteristics

Titanium is a light (density 4.51 g/cm³) lustrous-white metal. Its melting point is 1 668 °C but its high mechanical strength prevails only at low temperatures (sharp drop at 426 °C). At low temperatures it is also resistant to many inorganic acids. Pulverized titanium is pyrophorus (European Commission 2017a).

Applications

The major application of titanium is a titanium dioxide (TiO_2) as an inorganic pigment. The main sector is paints, but also plastics, papers or porcelain glazes. Titanium and its alloys are used in the chemical industry, medical applications (implants, pins, pacemaker capsules), and in the transport sector (automotive and especially aerospace) (European Commission 2017a).

Recycling

There is an established titanium recycling. According to European Commission (2017a) the end-of-life recycling input rate for titanium is estimated to be 19 %.

Substitution

The potential substitutes for titanium depend on the properties required for a specific application: while substitutes offering corrosion resistance are aluminium, nickel, specialty steels or zirconium, high mechanical strength can alternatively be provided by superalloys, steel, aluminium and composites. Titanium dioxide as a pigment can be substituted in some cases by calcium carbonate, kaolin or talc, with calcined clays being under study (European Commission 2017a).

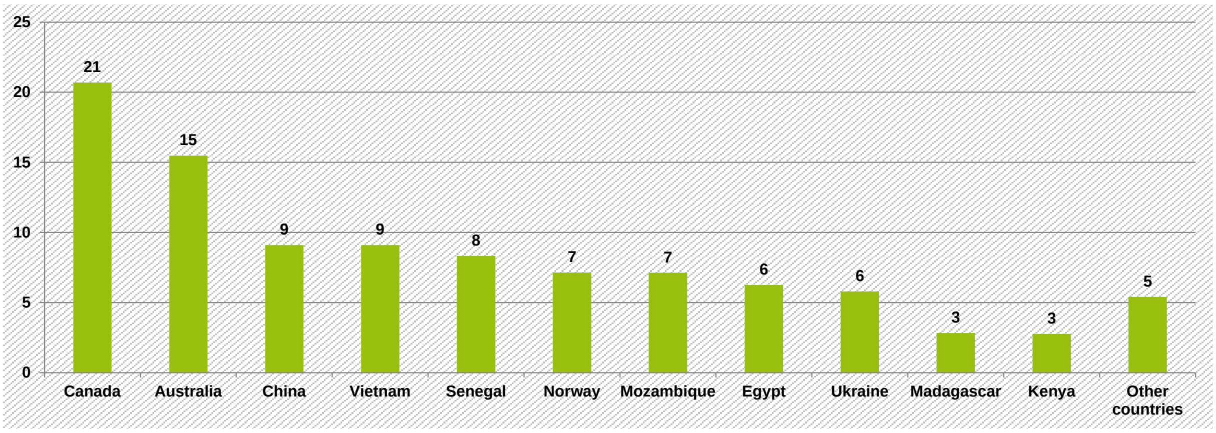
Main product, co-product or by-product

Titanium is almost always a main product (European Commission 2017a).

Primary production

Total global production: 12,083,746 tonnes in 2014 (BGS 2016).

Percentage of titanium mines mined in 2014 (%) (BGS 2016)



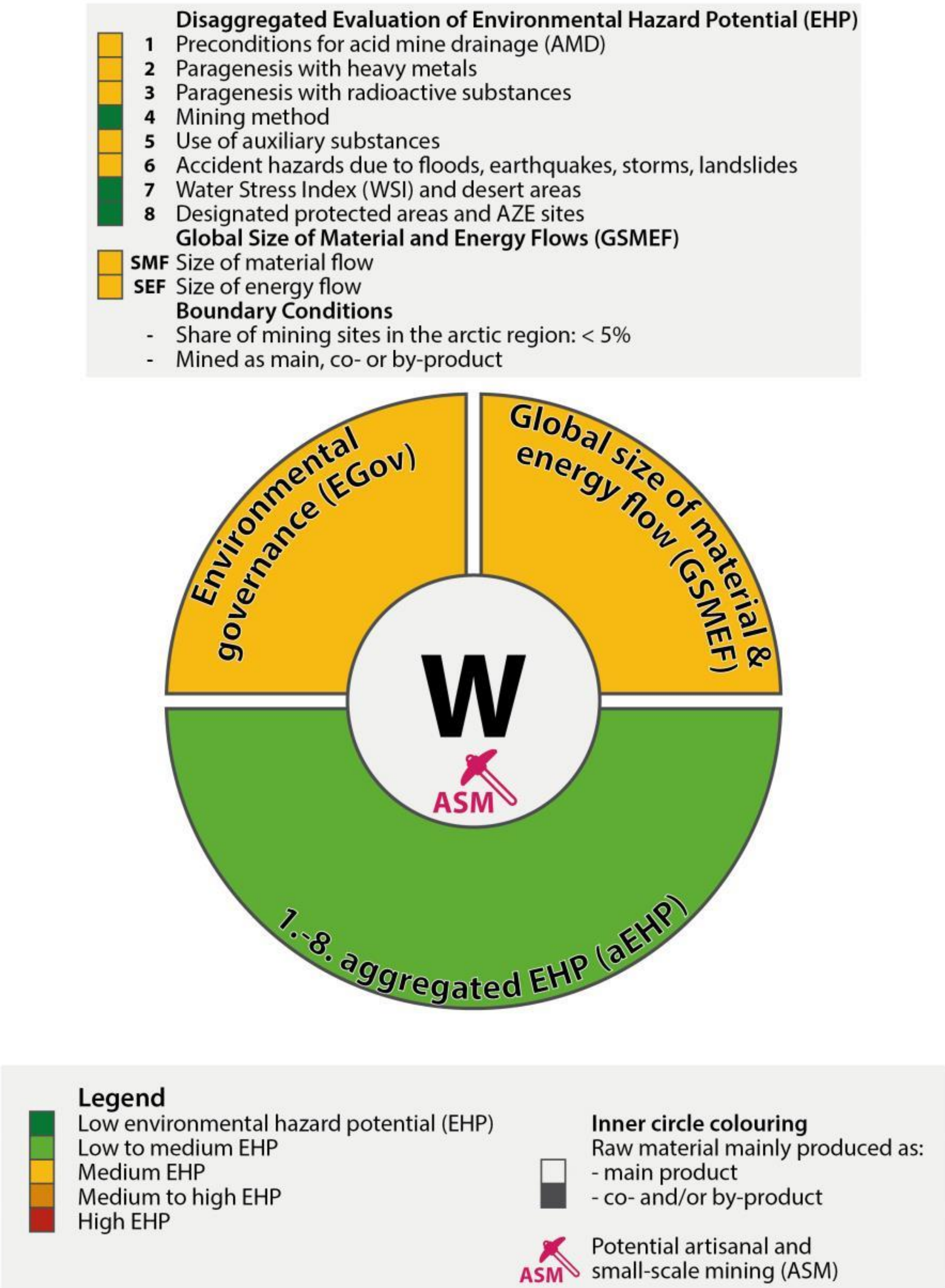
Information on Deposits

Titanium is a lithophilic element. Titanium minerals are rutile, titanite and - economically most important - ilmenite ($FeTiO_3$). Titanium is also present in titanium-containing magnetite. It is formed by silicate crystallization of basic magmatic rocks, as well as in pegmatites, more rarely in hydrothermal veins. Due to the weathering resistance as titanium sand in marine placers. There partly together with zircon, monazite and other minerals.

4.54.2 Profile Titanium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Low EHP	Titanium-containing deposits (ilmenite & rutile) are generally oxidic.	high
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Mostly extracted from placers, which usually contain low concentrations of heavy metals.	medium
Indicator 3: Paragenesis with radioactive substances		
High EHP	Ilmenite and rutile deposits (the economically most important Ti minerals) usually contain strongly elevated U and Th concentrations.	high
Indicator 4: Mine Type		
High EHP	Alluvial mining, placers on ilmenite	high
Indicator 5: Use of auxiliary substances		
Low EHP	Gravimetry, magnetic separation, leaching, acid separation	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Low EHP	The results for titanium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 38 % low, 42 % medium, 20 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Low EHP	The results for titanium range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 85 % low, 5 % medium, 10 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
High EHP	The results for titanium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 81 % low, 8 % medium, 11 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Low	From the EPI and the production share of the individual countries results an EGov-Score of 60.66.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
High	CRD_{global} of 478 million t/a results from the $CRD_{specific}$ of 40 t/t and the global annual production of 12,083,746 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 1,390 PJ/a results from the $CED_{specific}$ of 115,000 MJ-eq/t and the global annual production of 12,083,746 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for titanium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99.8 % low, 0.2 % medium EHP.	medium

4.55 Tungsten



4.55.1 General Information

Introduction and characteristics

Tungsten is a hard, rare metal with the chemical symbol W, derived from its other name wolfram. In nature it only occurs in mineral form, mainly in scheelite and wolframite. The free metal is very robust, with a very high density (19.3 g/cm^3) and the highest melting point of all the elements (European Commission 2017b). Tungsten has been classified critical through all EC assessments (European Commission 2017b).

Applications

Due to the specific properties of tungsten concerning wear and heat resistance its main application is as tungsten carbides (hardmetals) in tools, especially for cutting, milling, mining and construction. Also tungsten-containing steels (high speed steels) serve for the manufacture of cutting tools among others. Tungsten alloys and superalloys are especially used in the aeronautic, marine and energy sectors. Tungsten metal uses include lighting and the electronic and electrical industry (e.g. fabrication of wires and filaments). In the chemical industry tungsten is used in catalysts and pigments. Moreover, tungsten has military application in penetrating projectiles (European Commission 2017b).

Recycling

In cases where the tungsten content in the scrap is high in comparison to the ore, recycling is economically very attractive. Thus e.g. recycling of high speed steel is high and also cemented carbides are recycled in different ways depending on their degree of contamination. Recycling in applications like lamp filaments, welding electrodes and chemical uses is, however, low, because concentrations are low, making it economically unattractive. Overall, an end-of-life recycling input rate of 42 % has been estimated (European Commission 2017b).

Substitution

Tungsten has a very special performance so that in general substitution is not promising with respect to product performance and cost (European Commission 2017b). At very high cost of tungsten molybdenum was once used as a subsitute. Also copper was sometimes used to replace it but for the same performance twice the amount was needed. For tungsten carbides in mill and cutting tools, molybdenum carbides and cermets constitute a potential substitute but at reduced performance. There are some other marginal options for alternative materials but they are more expensive and performance is mostly lower. Only for ligthing applications tungsten filament lamps are being replaced by phosphorescent lamps and LEDs, which contain less or no tungsten. Tungsten itself is used as a substitute for hazardous metals like depleted uranium and lead (European Commission 2017b).

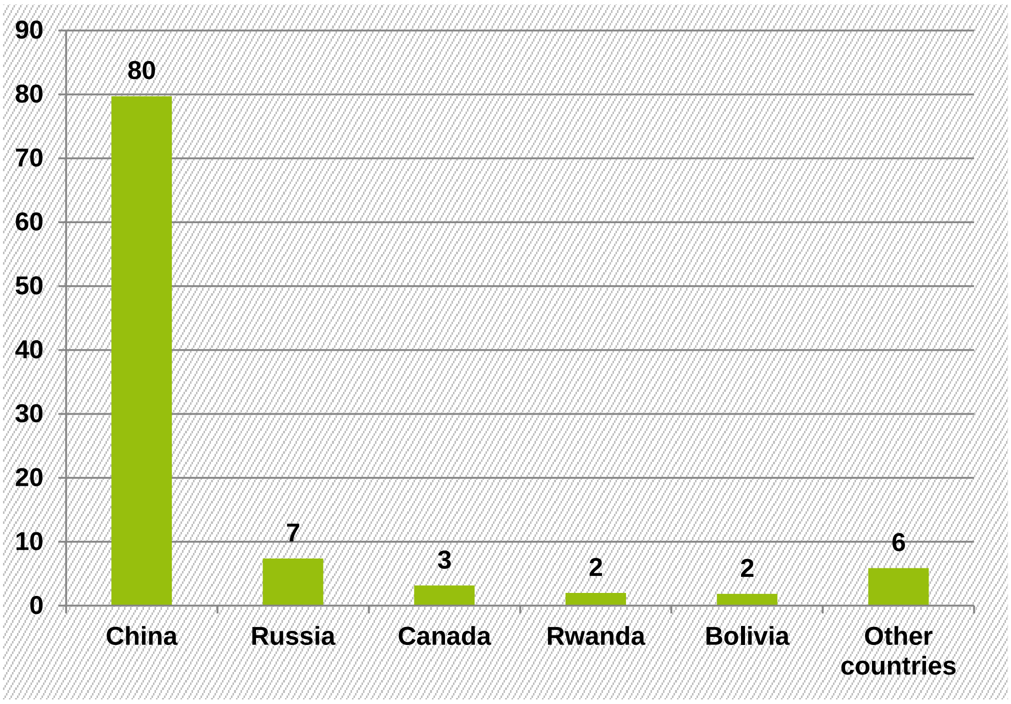
Main product, co-product or by-product

Tungsten is a main product (European Commission 2017b).

Primary production

Total global production: 85,292 tonnes in 2014 (BGS 2016).

Percentage of tungsten mines mined in 2014 (%) (BGS 2016)



ASM relevance

Tungsten is an important product of ASM: BGR estimates 6 %, Dorner et al. (2012) as well 6 % of the global production being provided by ASM, GEUS (2007) gives 80 % for the global share of SSM.

Tungsten is one of the 3T minerals (tin, tungsten and tantalum), which occur in the same type of deposits and are mostly produced together.

ASM is currently operating in alluvial tungsten deposits (main mineral being wolframite) as well as in the weathering zone of primary hydrothermal vein deposits.

Tungsten ASM is related to conflict financing in Central Africa.

Tungsten mining and trade is regulated or targeted by international laws, regulations and stewardship initiatives, such as the Dodd-Frank-Act, the EU Conflict mineral regulation, the OECD Due Diligence Guidance for Conflict Minerals/Minerals from Conflict Regions.

Specific certification schemes such as: iTSCi, CTC, ICGLR RCM and others.

Important tungsten producing countries with prominent ASM production are China, Rwanda and Bolivia. 86 % of tungsten is produced in ASM countries.

Information on Deposits

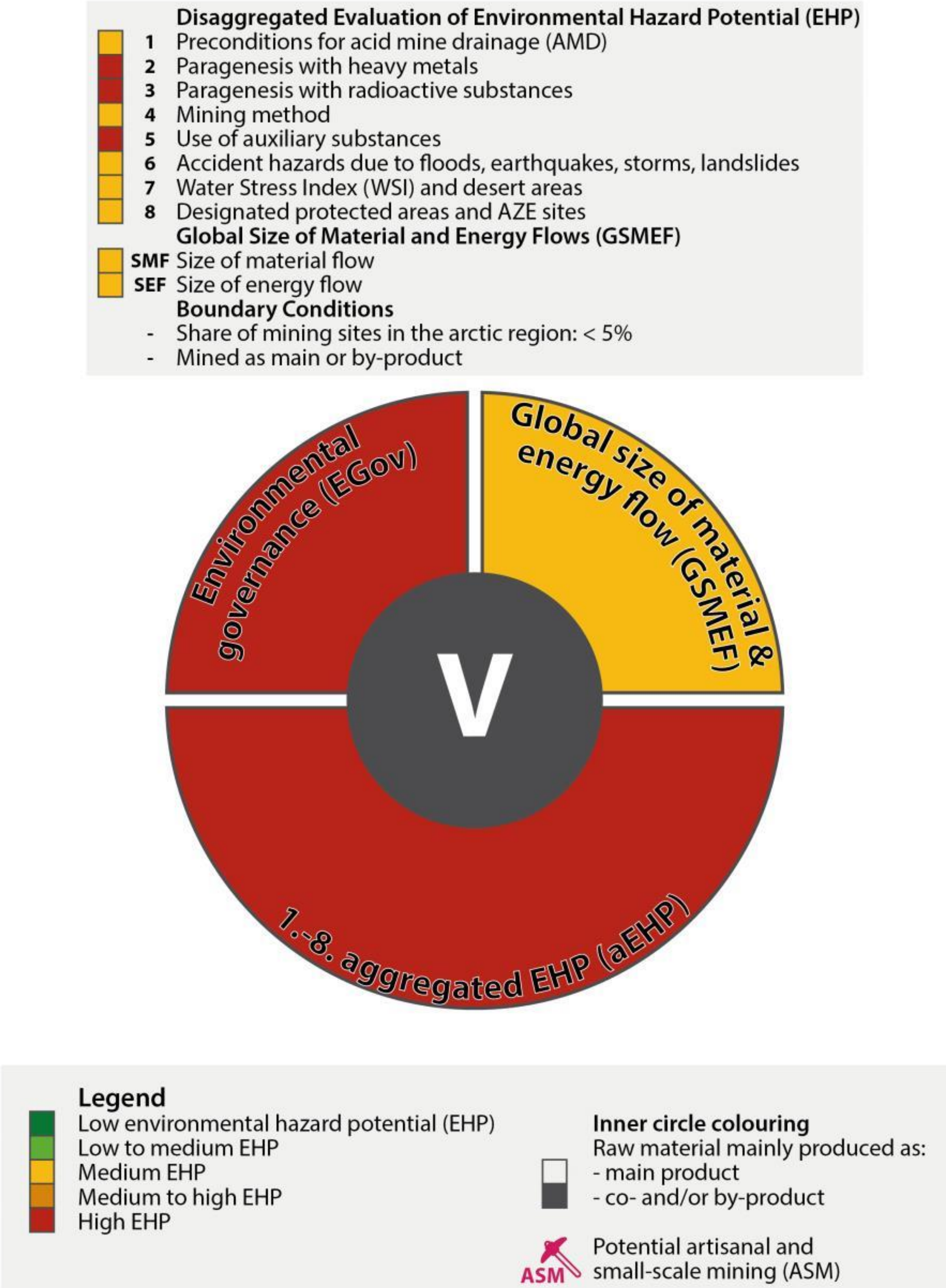
Tungsten is a lithophilic element. Ore minerals are the tungsten, $(Fe,Mn)WO_4$, and the scheelite, $Ca[WO_4]$. Wolframite can be found in deposits of the sequence of acidic magmas (granites), i.e. in pneumatolytic and pegmatitic deposits, as well as in low thermal veins (also in stockworks and porphyries, as well as disseminated and layered). The tungsten is often associated with quartz, apatite, tourmaline, molybdenite, fluorspar. Scheelite also in pneumatolytic and pegmatitic occurrences in the presence of limestone, as well as contact metasomatically (skarn deposits). Scheelite also from hydrothermal and hydrothermal-metasomatic deposits.

4.55.2 Profile Tungsten

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Medium EHP	According to the Goldschmidt classification, tungsten is a siderophilic element (sulfur-loving) and is present both sulfidically and oxidically. Especially in highly thermal formations tungsten is associated with pyrite, copper pyrite, molybdenum luster, bismuth luster, galena luster and zinc blende, all minerals that tend to autooxidize.	high
Indicator 2: Paragenesis with heavy metals		
Medium EHP	Tungsten is mainly extracted from tungsten and scheelite, which often contain heavy metals in low concentrations. Tungsten deposits in China (from where a large part of the world production originates) show considerable concentrations of heavy metals. According to the method description, an average environmental hazard potential is assigned.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Pegmatitic deposits, which form part of the W deposits (particularly in the PRC), are occasionally associated with niobium and tantalum, which may be associated with radioactive materials.	low
Indicator 4: Mine Type		
Low EHP	Tungsten is mined as tungsten or scheelite in underground mining, since the deposits are usually corridor deposits or metasomatic deposits that are small in size and require selective extraction.	high
Indicator 5: Use of auxiliary substances		
Medium EHP	Tungsten ores are processed by gravimetric methods and heavy turbidity separation, rarely by refining with indirect flotation (flotation of the polluting accompanying minerals), magnetic or electrostatic separation.	high
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for tungsten range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 7 % low, 71 % medium, 22 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Low EHP	The results for tungsten range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 98 % low, 0 % medium, 2 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Low EHP	The results for tungsten range in the low quantile area ≤ 25 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium, 0 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 53.12. Relevant quantities are produced in ASM countries.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		

Environmental hazard potential	Explanation	Data quality
Medium	CRD_{global} of 29 million t/a results from the $CRD_{specific}$ of 343 t/t and the global annual production of 85,292 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 11 PJ/a results from the $CED_{specific}$ of 133,000 MJ-eq/t and the global annual production of 85,292 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
High	The results for tungsten range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 97 % low, 3 % medium EHP.	medium

4.56 Vanadium



4.56.1 General Information

Introduction and characteristics

Vanadium is a steel-grey, bluish, shimmering metal. It is ductile element with a comparably low density (6.1 g/cm^3) but a rather high melting point (1 910°C). Due to an oxidic film on its surface vanadium is resistant to corrosion. It occurs in many minerals and is basically obtained as a by-product from the production of steel. In the latest EC assessment vanadium was classified critical for the first time (European Commission 2017b).

Applications

Most of the vanadium consumed is used for the production of alloys with high strength and corrosion resistance. About 80 % is used in HSLA (high-strength low-alloy) steels or in carbon steels (ferro-vanadium alloys). The alloys are used e.g. for tools and construction purposes and in the automotive and aeronautics sector. In oxidic form vanadium is used as a catalyst for sulfuric acid and maleic anhydride production, and in making glass and ceramics. Also in hydrocarbon processing vanadium-bearing catalysts are used to remove nickel and vanadium (European Commission 2017b).

Recycling

The two relevant sources for vanadium recycling are vanadium-alloyed steel scrap and spent catalysts. Another secondary source of vanadium is fossil fuel processing where vanadium can be recovered from ash, slag, spent catalyst or residue. The share of vanadium from secondary sources in total vanadium input is estimated at around 44 % with the major contribution being from alloy recycling. Excluding alloy recycling reduces the figure to 15 % (European Commission 2017b).

Substitution

Manganese, molybdenum, niobium, titanium, and tungsten constitute potential substitutes for vanadium as an alloying component in steel. In catalyst applications platinum and nickel can serve as substitutes in several chemical processes and in paints and varnishes titanium is an alternative. Emerging vanadium-based batteries could probably be substituted by batteries containing more conventional materials (European Commission 2017b).

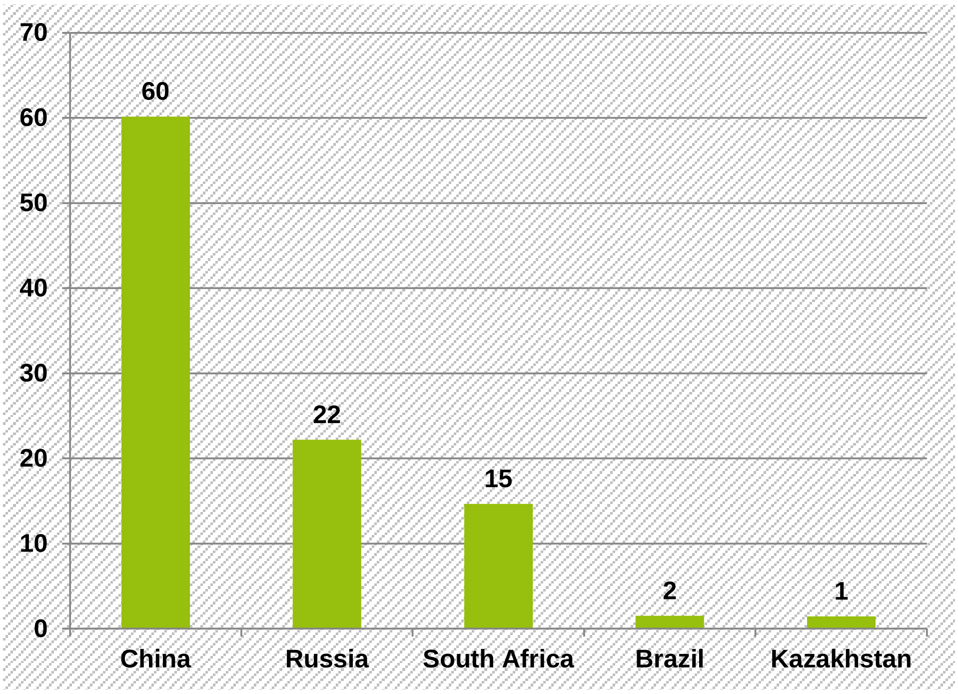
Main product, co-product or by-product

Vanadium can be a main product but is mostly a by-product of titanium (European Commission 2017b).

Primary production

Total global production: 68,157 tonnes in 2014 (BGS 2016).

Percentage of vanadium mines mined in 2014 (%) (BGS 2016)



Information on Deposits

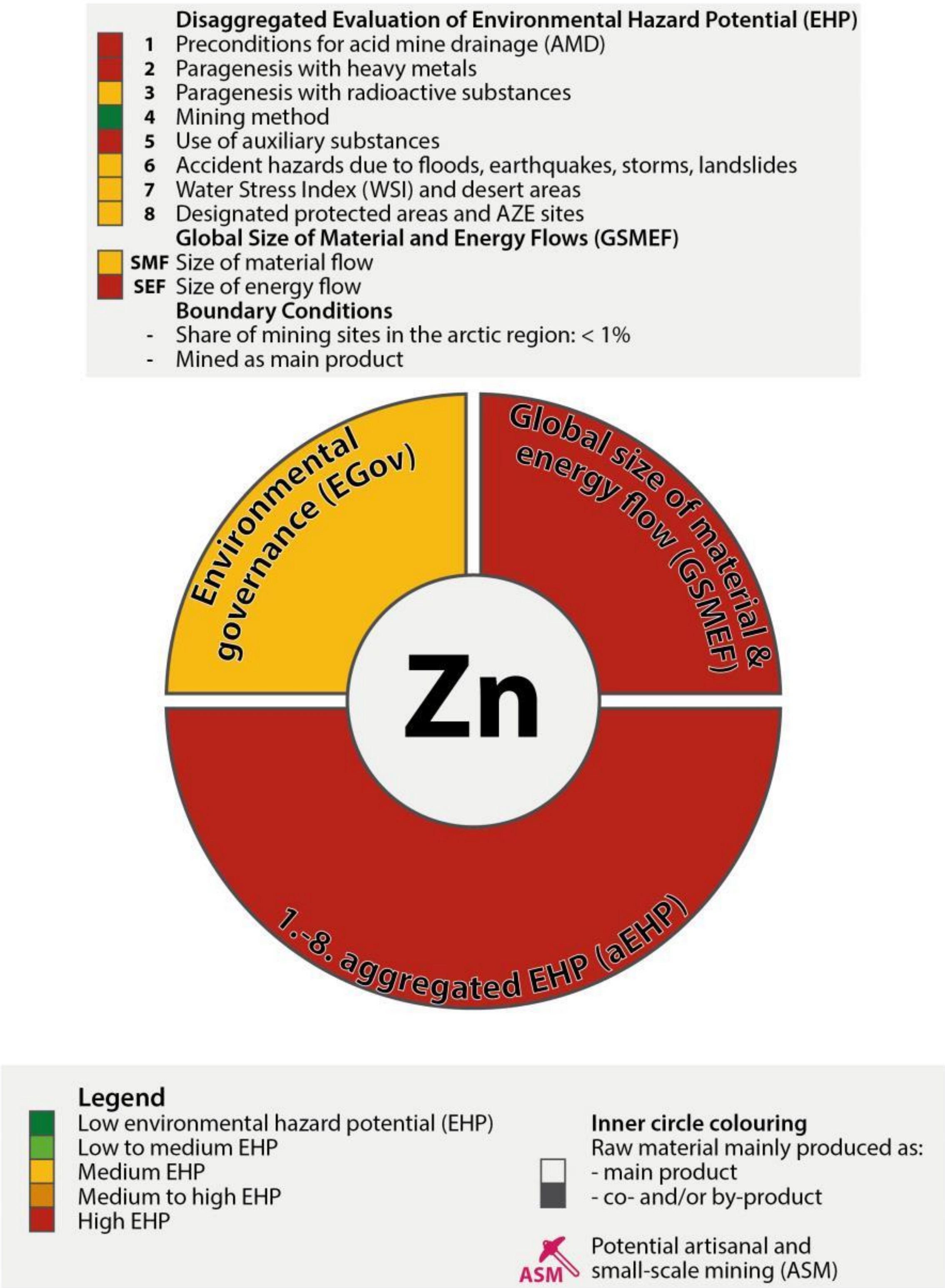
Vanadium is a lithophilic element. Important vanadium minerals are roscoelite, carnotite, vanadinite, descloizite, volborthite, patronite. These occur mainly in sandstones, then frequently with uranium minerals. More important vanadium sources are titanium ores, lead-zinc ores and iron ores from which it is extracted by metallurgy. Subordinated also from bitumen and crude oil.

4.56.2 Profile Vanadium

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
Medium EHP	Despite its classification as a lithophilic element, vanadium is obtained as a by-product from ores that partly originate from sulphidic formation conditions. In this respect, the evaluation is carried out with a medium EHP	low
Indicator 2: Paragenesis with heavy metals		
High EHP	Vanadium is largely extracted from deposits of lead-zinc mineralization.	medium
Indicator 3: Paragenesis with radioactive substances		
High EHP	Vanadium is usually associated with high concentrations of U and/oeder Th. This is confirmed by data from Chinese deposits (51.9 % of world production).	high
Indicator 4: Mine Type		
Medium EHP	Surface mining, underground mining	low
Indicator 5: Use of auxiliary substances		
High EHP	Mostly by-product of other ores, therefore varied	low
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for vanadium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment.	medium

Environmental hazard potential	Explanation	Data quality
	The results of the GIS assessment are: 55 % low, 10 % medium, 35 % high EHP.	
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for vanadium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 55 % low, 10 % medium, 35 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for vanadium range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 97 % low, 2 % medium, 1 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
High	From the EPI and the production share of the individual countries results an EGov-Score of 52.96.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 45 million t/a results from the $CRD_{specific}$ of 656 t/t and the global annual production of 68,157 t/a.	low
Indicator 11: Cumulated energy demand of global production CED_{global}		
Medium	CED_{global} of 35 PJ/a results from the $CED_{specific}$ of 516,000 MJ-eq/t and the global annual production of 68,157 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
High	The results for vanadium range in the high quantile area > 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 97 % low, 3 % medium EHP.	medium

4.57 Zinc



4.57.1 General Information

Introduction and characteristics

Zinc is a shimmering bluish metal. It has a density of 7.1 g/cm^3 and a low melting point (419.5 °C). While at room temperature and above 200 °C it is brittle, between 100°C and 150 °C it is malleable. Above 900 °C zinc burns oxidising to zinc oxide, also called philospher's wool. Zinc is fairly abundant and the known reserves are spread all over the globe (European Commission 2017a).

Applications

Steel galvanizing accounts for approximately half of all zinc use. About one third is consumed for zinc alloy production, used e.g. in the die casting industry and the production of brass and bronze. Other uses include electrical equipment (batteries and accumulators) and pigments (European Commission 2017a).

Recycling

For zinc an end-of-life recycling input rate of 31 % is estimated. The main sources are old and new brass scrap, residues from the galvanizing industry, foundry dusts and die cast zinc alloys from automobile parts (European Commission 2017a).

Substitution

With respect to corrosion protection alternatives for zinc are aluminium alloys, cadmium, and plastic coatings and galvanized plates can be replaced by aluminium, plastics or steel. Aluminium and plastics as well as magnesium principally constitute alternatives for diecast zinc parts. Zinc itself is a potential substitute for other materials in thinfilm PV cells like indium or tin (European Commission 2017a).

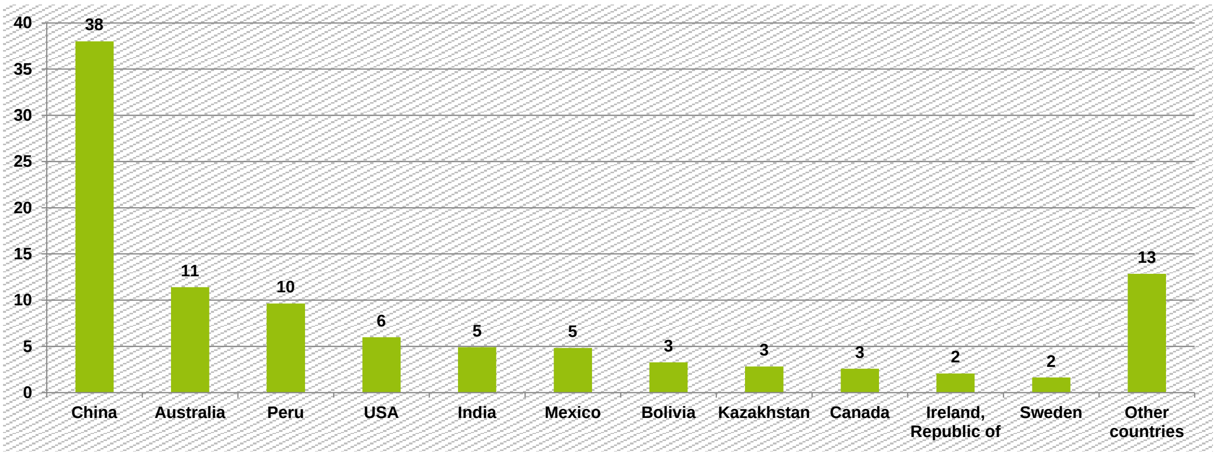
Main product, co-product or by-product

Zinc is a main product (European Commission 2017a).

Primary production

Total global production: 13,679,568 tonnes in 2014 (BGS 2016).

Percentage of zinc mines mined in 2014 (%) (BGS 2016)



Information on Deposits

Zinc is a chalcophilic element with zinc blende (Sphalerite ZnS) as the most important ore mineral, and more rarely zinc weathering minerals in oxidation zones. Zinc blende is very often associated with galena, often with pyrite, arsenic pyrites, copper pyrites. It is formed in pneumatolytic and (plutonic, as well as sub-volcanic) hydrothermal deposits, but also submarine exhalatively synsedimentary (black smokers).

4.57.2 Profile Zinc

Environmental hazard potential	Explanation	Data quality
Indicator 1: Pre-Conditions for acid mine drainage (AMD)		
High EHP	Zinc is a chalcophilic element according to the Goldschmidt classification and is generally sulfidic.	high
Indicator 2: Paragenesis with heavy metals		
High EHP	Zinc is extracted from lead-zinc ores. Zinc is usually associated with high concentrations of the heavy metal lead.	high
Indicator 3: Paragenesis with radioactive substances		
Medium EHP	Average data on Chinese lead-zinc deposits (37.3 % of world zinc production) suggest that zinc is associated in many cases with slightly elevated concentrations of uranium and/or thorium.	high
Indicator 4: Mine Type		
Low EHP	underground mining	medium
Indicator 5: Use of auxiliary substances		
High EHP	Flotation, roasting, leaching	medium
Indicator 6: Accident hazards due to floods, earthquakes, storms, and landslides		
Medium EHP	The results for zinc range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 39 % low, 30 % medium, 31 % high EHP.	medium
Indicator 7: Water Stress Index and desert areas		
Medium EHP	The results for zinc range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 60 % low, 4 % medium, 36 % high EHP.	medium
Indicator 8: Designated protected areas and Alliance for Zero Extinction (AZE) sites		
Medium EHP	The results for zinc range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 92 % low, 5 % medium, 3 % high EHP.	medium
Indicator 9: Environmental governance in major production countries (EPI)		
Medium	From the EPI and the production share of the individual countries results an EGov-Score of 58.10.	high
Indicator 10: Cumulated raw material demand of global production CRD_{global}		
Medium	CRD_{global} of 185 million t/a results from the $CRD_{specific}$ of 14 t/t and the global annual production of 13,679,568 t/a.	high
Indicator 11: Cumulated energy demand of global production CED_{global}		
High	CED_{global} of 711 PJ/a results from the $CED_{specific}$ of 52,000 MJ-eq/t and the global annual production of 13,679,568 t/a.	high
Indicator 12: Position of mining sites in the arctic region		
Medium	The results for zinc range in the medium quantile area > 25 % quantile and ≤ 75 % quantile of the combined assessment results for 42 raw materials where sufficient data availability allowed the GIS assessment. The results of the GIS assessment are: 99 % low, 1 % medium EHP.	medium

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