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Final report

Pilot screening of the environmental hazard potentials of mine sites

ÖkoRess 3

Aissa Rechlin, Christopher Demel
Projekt-Consult GmbH, Hamburg

Claudia Kämper, Regine Vogt, Andreas Auberger
ifeu-Institut für Energie und Umweltforschung, Heidelberg

Peter Dolega, Günter Dehoust
Öko-Institut e.V., Darmstadt

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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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Eulenkrugstraße 82
22359 Hamburg
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Jan Kosmol

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Abstract: Pilot screening of the environmental hazard potentials of mine sites

Aiming to make a knowledge-based contribution to the debate on a responsible supply of raw materials, the project provides validated data and transparent assessments on the environmental aspects of mineral raw material extraction. To this end, the environmental hazard potentials at 100 mine sites are evaluated using the site-related OekoRess evaluation method developed in a precursory project. Supplemental information on the mine site itself, the governance situation in the country and the Corporate Social Responsibility of the mine owner are gathered, and the results are jointly published in an interactive online map on the UBA website. With the application of the mine site-related OekoRess evaluation, the project expands the knowledge base and optimises the evaluation system. Recommendations for the improvement of the measurement instructions, which form the basis of the OekoRess evaluation system, are prepared and implemented and incorporated where possible.

For this pilot screening, 100 mines of the three bulk metal commodities iron ore, copper ore and bauxite were selected. The selection is based on two criteria: firstly, to cover the largest possible share of global annual production and, secondly, to maximize the share of the respective global reserves.

The report covers the mine site selection process as much as the description of the site-related OekoRess evaluation process and its results. Analyses and considerations leading to an optimization of the measurement instructions in its 2nd edition are presented. The results by mine site are presented in an interactive map that is hosted on the UBA website. Information deemed relevant by the user can be selected and displayed individually, complemented by downloadable mine site-specific factsheets.

The project thus provides broad information on 100 mine sites of the three bulk metal commodities iron ore, copper ore and bauxite, as well as an enhanced evaluation method for environmental hazard potentials at mine site level.

Kurzbeschreibung: Pilot-Screening der Umweltgefährdungspotentiale von Bergbaustandorten

Mit dem Ziel, einen wissensbasierten Beitrag zur Debatte um eine verantwortungsvolle Rohstoffversorgung zu leisten, liefert das Projekt validierte Daten und transparente Bewertungen zu Umweltaspekten der mineralischen Rohstoffgewinnung. Dazu werden die Umweltgefährdungspotenziale von 100 Bergbaustandorten mit der in einem Vorläuferprojekt entwickelten standortbezogenen ÖkoRess Evaluierungsmethode bewertet. Ergänzend werden Informationen über den Standort selbst, die Governance-Situation im Land und die Corporate Social Responsibility des Bergwerkseigentümers erhoben und die Ergebnisse gemeinsam in einer interaktiven Online-Karte auf der UBA-Website veröffentlicht.

Mit der Anwendung der standortbezogenen ÖkoRess-Bewertung erweitert das Projekt die Wissensbasis und optimiert das Bewertungssystem. Empfehlungen zur Verbesserung der Messanweisungen, die die Grundlage des ÖkoRess-Bewertungssystems bilden, wurden erarbeitet, und soweit möglich bereits auf die 100 Evaluierungen angewendet.

Für dieses Pilotscreening wurden 100 Bergwerke der drei Massenmetallrohstoffe Eisenerz, Kupfererz und Bauxit ausgewählt. Die Auswahl basiert auf zwei Kriterien: erstens, einen möglichst großen Anteil der globalen Jahresproduktion abzudecken und zweitens, den Anteil an den jeweiligen globalen Reserven zu maximieren.

Der Bericht deckt sowohl den Auswahlprozess der Minenstandorte als auch die Beschreibung des standortbezogenen ÖkoRess-Bewertungsprozesses und seiner Ergebnisse ab. Es werden Analysen und Überlegungen vorgestellt, die zu einer Optimierung der Messanleitung in ihrer 2. Auflage geführt haben. Die Ergebnisse nach Bergwerksstandorten werden in einer interaktiven Karte auf der UBA-Website dargestellt. Vom Nutzer als relevant erachtete Informationen können ausgewählt und individuell angezeigt werden, ergänzt durch herunterladbare Fact Sheets zu den einzelnen Standorten.

Das Projekt bietet somit umfassende Informationen über 100 Bergwerksstandorte weltweit für die drei Massenmetallrohstoffe Eisenerz, Kupfererz und Bauxit sowie eine verbesserte Bewertungsmethode für Umweltgefährdungspotenziale auf Bergwerksstandortebene.

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3T	Tin, tantalum and tungsten
ABA	Acid Base Accounting
aEHP	Aggregated environmental hazard potential
AMD	Acid mine drainage
AR	Arctic region
ARM	Alliance for Responsible Mining
ASGM	Artisanal and small-scale gold mining
ASI	Aluminium Stewardship Initiative
ASM	Artisanal and small-scale mining
ASSF	Australian Steel Stewardship Forum
AZE	Alliance for Zero Extinction
AZO	Aluminium doped zinc oxide
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe [Federal Institute for Geosciences and Natural Resources]
BIF	Banded Iron Formation
BREF	Best Available Techniques Reference
CED	Cumulative energy demand
CIGS	Copper-indium-gallium-selenide
CIS	Copper indium selenide
CM	The Copper Mark
CRD	Cumulated raw material demand
CSR	Corporate Social Responsibility
CTA	Concept of consumption to availability
CTC	Certified Trading Chains
DRC	Democratic Republic of the Congo
DPSIR	Driving forces, Pressures, States, Impacts and Responses
EHP	Environmental Hazard Potentials
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
EITI	Extractives Industry Transparency Initiative
EP	Equator Principles
EOL-RIR	End of life recycling input rate
EPI	Environmental Performance Index
ICMI	International Cyanide Management Institute
ICME	International Council on Metals and the Environment
IFC	International Finance Corporation
INAP	International Network for Acid Prevention
FGD	Flue gas desulfurization
FTO	Fluorine doped tin oxide
GARD	Global Acid Rock Drainage Guide
GCC	Ground Calcium Carbonate
GEUS	Nationale Geologiske Undersøgelser for Danmark og Grønland

GIS	Geographic information system
GSMEF	Global size of material and energy flows
HREE	Heavy rare earth elements
HSLA	High-strength, low-alloy (steels)
IBA	Important Bird Area
ICGLR	International Conference on the Great Lakes Region (al Mineral Certification Framework)
ILO	International Labour Organization
IRMA	Initiative for Responsible Mining Assurance
iTSCi	ITRI Tin Supply Chain Initiative
ISO	International Organization for Standardization
JRC	Joint Research Centre
KBA	Key Biodiversity Area
LED	Light Emitting Diode
LREE	Light rare earth elements
NGO	Non-governmental organisation
NNP	Net Neutralizing Potential
OECD	Organisation for Economic Co-operation and Development
OHS	Occupational Health and Safety
PA	Polyamide
PET	Polyethylene terephthalate
PGM	Platinum-Group Metals
PV	Photovoltaik
RCM	ICGLR Regional Certification Mechanism
REE	Rare earth elements
RJC	Responsible Jewellery Council
RS	Responsible Steel
SEF	Size of energy flows
SMF	Size of material flows
SSM	Small-scale mining
SX-EW	Solvent extraction and electrowinning
Th	Thorium
TSM	Towards Sustainable Mining
U	Uranium
UBA	Umweltbundesamt – German Environment Agency
UGP	Umweltgefährdungspotenzial
UNEP	United Nations Environmental Program
USGS	United States Geological Survey
WB	World Bank
WEEE (Directive)	Waste of Electrical and Electronic Equipment (Directive)
WGI	World Governance Indicators
WTA	Withdrawal to availability
WSI	Water Stress Index

Summary

The German economy imports raw materials from all over the world. These raw materials form the physical basis for production, value creation and consumption in Germany. Metal raw materials are almost entirely imported, both directly in the form of ores and concentrates and indirectly in the form of semi-finished and finished goods. Security of supply is the overriding goal of German raw materials policy. At the same time, public awareness of the conditions under which mineral resources are extracted elsewhere is growing both in Germany and in other early industrialised countries. The use of other natural resources, such as soil, water, air or ecosystems, which goes hand in hand with the extraction of natural mineral resources, as well as its effects on biodiversity and the local population, are increasingly becoming a focus of public attention. In this context, new approaches are being sought at various levels with the aim of reconciling security of supply with a globally understood responsibility for environmental footprints.

Against this background, the project aims to make a knowledge-based contribution to the debate on a responsible supply of raw materials by providing validated data and transparent assessments on the environmental aspects of mineral raw material extraction.

In the precursory project OekoRess I, a site-related assessment method of the environmental hazard potential of mine sites was developed. This assessment method makes it possible to obtain a rapid overview of possible environmental hazards at a site. Geological and technical factors as well as site-specific conditions of the natural environment are included in the assessments. The method can make an important contribution to improving the assessment of the "environmental availability" of raw materials, and thus to being able to take political measures tailored to this availability. The present report comprises the results of a systematic application of the site-related assessment method to three selected raw materials at a total of 100 sites in the OekoRess III project. This "pilot screening" serves to expand the knowledge base and to refine the assessment method, as well as identify proposals for its further development. The approach of analysing a large number of cases of the same raw material opens up the possibility of identifying and comparing location-dependent variations in the evaluation, and also refining the measurement instructions.

This provides the method with a sound basis that both enables further development of the assessment procedure and increases knowledge and acceptance among the various stakeholder groups through broad application. Next to the site-related evaluation, a second raw material-related assessment method for environmental hazard potentials was developed. This method was applied to around 50 raw materials and slightly modified in OekoRess II. However, the OekoRess III project focusses solely on the site-related evaluation method. Relevant results of several UBA projects within the framework of the UFOPLAN/REFOPLAN (including UmSoRess[1], RohPolRess[2], KlimRess[3] and InGoRo[4], as well as OekoRess I[5] and II[6]) are taken into account that deal with the various aspects of raw material extraction and their interaction with environmental and social concerns.

[1] https://www.umweltbundesamt.de/umweltfragen-umsoress

[2] https://www.umweltbundesamt.de/umweltfragen-rohpolress

[3] https://www.umweltbundesamt.de/publikationen/impacts-of-climate-change-on-mining-related

[4] https://www.umweltbundesamt.de/publikationen/international-governance-supply-raw-materials

[5] https://www.umweltbundesamt.de/umweltfragen-oekoress

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

With bauxite, copper ore and iron ore, three bulk metal raw materials are addressed that make up a significant part of the material basis of German industry. These raw materials are mined worldwide and imported in large quantities for the production of goods with a higher vertical range of manufacture. Therefore, they are of particular importance with regard to the debate on Germany's environmental responsibility in relation to mining conditions in the countries of origin.

Factsheets for each mine include the systematically applied site-related evaluation of the environmental hazard potentials according to the measurement instructions (Annex D). To include the broader raw material-country reference in the considerations, the factsheets contain relevant contextual information on the state governance in the field of mining and its environmental impact, as well as Corporate Social Responsibility measures of the mine owners. The results will be published through an interactive online map[7].

The project is structured into four work packages:

- WP 1: Site identification
- WP 2: Data collection
- WP 3: Evaluation according to the site-related OekoRess method
- WP 4: Visualisation on an interactive online map

The report is loosely oriented on the basis of these four work packages. Data collection (WP2) and evaluation (WP3) are strongly interlinked and therefore jointly discussed in Chapter 3. The following Chapter 4 is dedicated to proposed improvements in the measurement instructions, and further research requirements are identified.

Mine site selection

The main criteria for the mine site selection are annual production and size of reserve. The aim was to achieve the largest possible coverage for each commodity in terms of annual global production and, secondarily, the global reserves. While the total number of sites is predefined by project design, the number of selected sites per commodity can be varied. Therefore, the number of sites per commodity that best reflects the objective of achieving the highest possible coverage of the two main criteria were iteratively approximated. Reserve was selected instead of resources because the evaluation system uses the reserve as the basis for one of the indicators (Section 4.2).

The <u>mine site selection</u> is based on the <u>following steps</u>:

1. Annual production volume dates of as many iron ore, copper ore and bauxite mines as possible are gathered from publicly available and own research.
2. Taking into account the project objectives and the results of step 1, the sites are ranked based on the criteria “annual production” followed by “reserves”.
3. Through step-by-step approximation, while maintaining the highest possible coverage of annual production and reserve of all commodities, the number of sites per commodity are selected to create the combined list of 100 proposed sites.
4. During the project, mine sites are deleted, for example, if a mine already belongs to a mine complex as defined in the project (cf. Section 2.4).

[7] 8lnk

Key data for the 100 selected mine sites:

- The selected sites each provide > 55 % coverage of global production (as of 2013),
- Bauxite: 23 mines and mine projects were selected, covering 29.51 % of the global reserve,
- Iron ore: 32 mines and mine projects were selected, covering 32.07 % of the global reserves,
- Copper ore: mines and mine projects were selected, covering 42.27 % of the global reserves.

Factsheet development

The structure of the factsheets is determined in one of the first steps in the project, and is adapted slightly in accordance with new developments. An example of an adaptation is the new criterion "surface extension", which was added during the refinement of the procedure for determining the "natural environment" indicators. For this, the mine's surface extension is determined based on the most current satellite imagery. The criterion "in operation since" is added when developing the refined approach to determine the deposit size and includes historical data as far back as possible.

The factsheets clearly present the relevant information to:

a) Give an overview of the site for orientation,

b) Facilitate and present the assessment according to the site-related OekoRess evaluation and

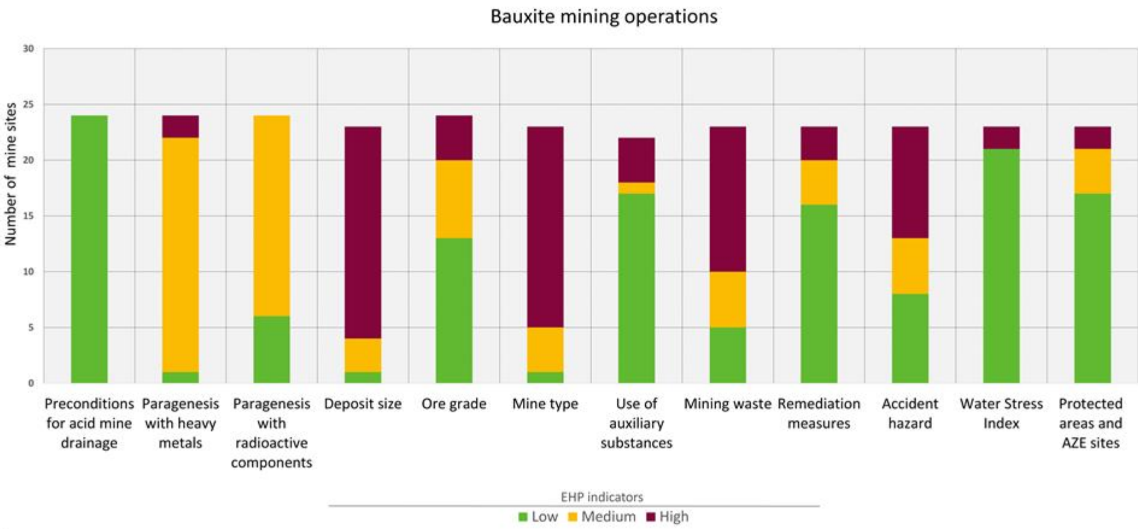
c) Provide additional information on governance and Corporate Social Responsibility (CSR) so that the information from the evaluation can be better placed in an overall context.

Factsheet structure

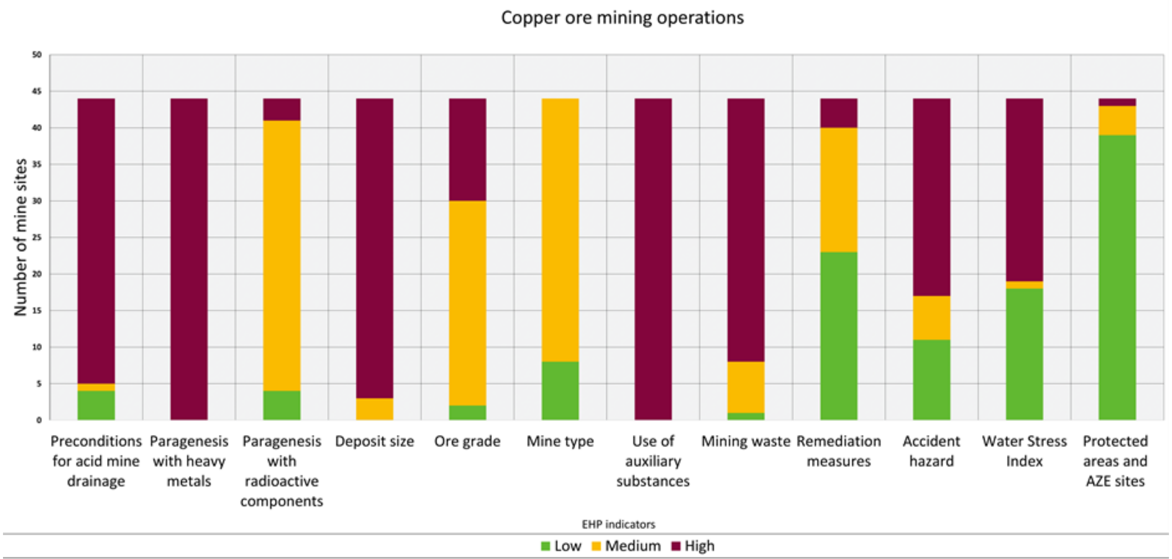
1. General information: includes information on the name, companies involved, geologic and geographic background information, general information on the mine site, such as products and annual production.
2. The main part of the factsheets is based on the site-related evaluation grid developed in the OekoRess I project. The 12 evaluation indicators refer to the three levels geology, technology and site surroundings pointing to specific Environmental Hazard Potentials (EHPs):
    a. Geology level: the likelihood of radioactive contamination, paragenesis with heavy metals and potential for Acid Mine Drainage (AMD) are investigated (indicators 1-3 in the field "raw material-specific"), as well as deposit size and ore grade (indicators 4 and 5 in the field "deposit-specific").
    b. Technology level: the mine type, the use of auxiliary substances, the mine waste and rehabilitation measures are assessed (indicators 6-9). E. g. open-pit operations disturb larger surface areas than underground mines.
    c. Site-surroundings level: The EHPs of this level are assessed by indicators 10-12, looking at accident hazards due to floods, earthquakes, storms, landslides, at the Water Stress Index (WSI) and desert areas, and finally, but importantly, protected areas and Alliance for Zero Extinction (AZE) sites.
3. Governance
    a. Governance indicators (World Governance Indicator (WGI), Environmental Performance Index (EPI) and Extractives Industry Transparency Initiative (EITI) membership)

   b. International agreements
   c. Legal framework (Environment and OHS)
4. Corporate Social Responsibility (CSR)
   a. Voluntary standards (e.g., Aluminium Stewardship Initiative ASI)
   b. ISO and CSR reporting
5. Financing standards (Equator principles, International Finance Cooperation (IFC) standards)

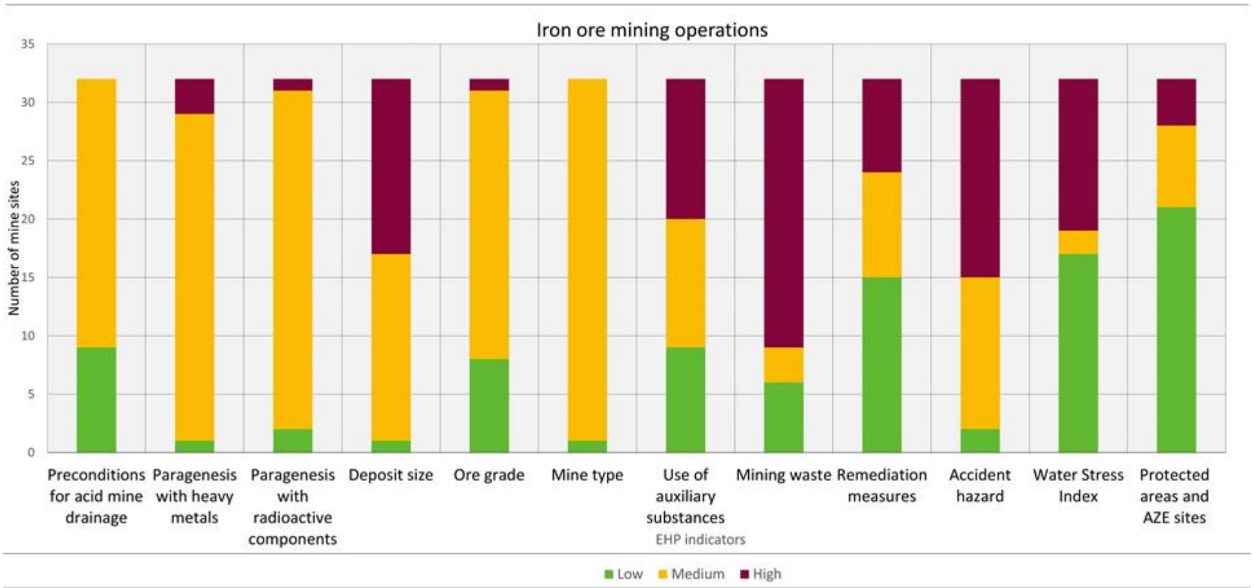
The results show that in the event of data gaps for concrete mines, the application of general assumptions as defined in the measurement instructions based on scientific results and expert knowledge at least allows for a general assessment. However, it is important to communicate the data quality for the respective indicator to avoid false security. Since the evaluation system is based on the precautionary principle, the results may be more conservative in terms of nature conservation. It is assumed that this could show a more diverse picture through increased publication of data. In only a few cases, and only for bauxite, for which the data search was found to be the most difficult, no evaluation result was obtained (see below in bar chart for bauxite mining, indicators *ore grade* and *use of auxiliary substances*).



Source: own visualisation, cf. Figure 7, Projekt-Consult, ifeu Insitut, Öko-Insitut



Source: own visualisation, cf. Figure 8, Projekt-Consult, ifeu Insitut, Öko-Insitut



Source: own visualisation, cf. Figure 9, Projekt-Consult, ifeu Insitut, Öko-Insitut

After the development of the factsheets and the evaluation of the EHPs, the factsheets were reviewed by experts from RMG Consulting (first validation step), who commented on the data quality as well as the measurement instructions and possible improvements. The factsheets were then forwarded to the mine owning companies (second validation step). The project team has received feedback on more than 20 mines from ten companies. The feedback was incorporated where, for example, new publicly available sources influenced the description and/or the evaluation result. All information from the factsheets is stored in a database that feeds into the online presentation of the factsheets on an interactive online map hosted by UBA.

The project not only dealt with single mines but also mine complexes and mine projects, which are all covered by the term mine site in this document for the sake of simplicity. Some mine complexes consist of two to three individual mines which are located in direct geographical proximity to each other. In extreme cases, however, more than 10 pits with maximum distances of up to 180 kilometres are combined into one **mine complex**.

Reasons why mine complexes were considered jointly:

- The individual mine sites on one deposit (e.g. Banded Iron Formation - BIF) usually have nearly identical geological settings, even though in extreme cases they are separated by distances of more than a hundred kilometres.
- The geologic setting also influences the application of technology and processing methods. It can therefore be assumed that the EHP evaluation result will be nearly identical for the individual pits of a complex.
- As a rule of thumb, the individual mines in a complex are mostly managed by the same operator. In the project this will lead to equal evaluation of all aspects of corporate governance.
- Furthermore, the operators of the mine complexes very rarely report the production for the individual mines; therefore, it is difficult to determine a reliable figure for each mine. Although production capacities per mine are sometimes provided, they only reflect the theoretical maximum production values.
- Last but not least, data availability plays an important role in the evaluation of mine complexes. These complexes are often much better known than the individual pits, with information for the entire complex being usually more readily available than for single pits.

Ultimately, there are only two significant differences between evaluating mine complexes or individual mines:

- Firstly, there are differences in the size of the deposits. If the mines are regarded individually, the deposit size becomes accordingly smaller; viewed as a complex, the reserves are always larger, resulting in a higher EHP. However, it can be argued that the deposit size of the mining complex better reflects reality.
- Secondly, the site-specific indicators for assessing the natural environment may be subject to different assessments. If a mine complex consists of several mines, one of which has a high EHP, the entire complex would be evaluated with the corresponding potential. Here, the polygons for each mine could possibly be displayed with their corresponding assessment, showing transparently each individual polygon's EHP.

In summary, many indicators suggest that a mine complex should be regarded as one unit, despite the sometimes large geographical distances. In particular, geological aspects, the business management summary of the operators in terms of a complex, higher public awareness of the complexes and therefore better data availability, speak for the joint consideration as a unit.

Sensitivity analysis: including buffer zones around the mines

For the site-related EHP evaluation, a spatial analysis of all natural environment indicators was conducted. In order to address the proximity of high-rated EHP areas to mining sites, a sensitivity analysis for the indictors "water stress index and desert areas" and "protected areas and AZE sites" was carried out. For these indicators the mine has an influence beyond the mine site environment. The other natural environment indicators address natural hazard events directly at the mine site, which is why a proximity analysis is not necessary.

The buffering tool is a common approach in GIS proximity analysis that can be used to determine which features are within a critical spatial distance from other features. Buffer widths of 10 km and 25 km are applied and tested. Most of the areas are classified as high and low EHP. The map of the indicator "protected areas and AZE sites" consists of 250,000 single features and is globally distributed with high granularity (depending on the country). This characteristic leads to a more continuous increase in EHP distribution by adding different buffers.

The aspect of the proximity of a mine site to potential areas with high EHP should be considered. This applies in particular to protected areas, since a relevant change in results can be observed even by considering a rather small proximity of 10 km.

Recommendations for further development of the site-related evaluation method

Particular attention is paid to optimisation possibilities of the measurement instructions. The measurement instructions were developed und published as part of the OekoRess I project. The current project aims to enhance these instructions, resulting in a 2nd edition that is published as an Annex (Annex D) to this report. This 2nd edition of the site-related approach to evaluate and compare the environmental hazard potentials of mining sites includes several updates and specifications following on from the first edition presented in 2017. Special attention is given to those aspects of the assessment matrix or measurement instructions that could not be implemented in their entirety within the framework of the OekoRess I project. Recommendations for further research are made if the subject of the recommendation goes beyond the scope of the project, with the aim in particular of expanding and improving the database and research results on which the measurement instructions are based.

Most significantly, the indicator "conflict potential with local population" was removed as the underlying data does not reflect the conflict potential at mine site level but on a larger scale. Further relevant changes are the updates to the databases and methodology of the "site surrounding" level indicators. Moreover, the evaluation tool for the "ore grade" indicator was once again expanded to include the elements iron, tin, manganese and aluminium, as well as platinum group metals (PGMs).

A summary of relevant updates introduced in the 2nd edition of the measurement instructions, and discussed in the report, are grouped in accordance with the structure of the measurement instructions:

1. General
    a. Renaming of indicators (ore grade, mine type, mining waste)
    b. Introduction of goals for each indicator to enhance the visibility of where the indicators are pointing. For example, "limiting the effort for extraction" for ore grade.
    c. To avoid the impression that impacts are measured rather than EHPs, the traffic light colours have been replaced with symbols.
2. Geology level
    a. Indicator "AMD": While in the 1st edition of the measurement instructions the EHP was considered "high" for all sulphidic deposits, more specific instructions are now provided to account for:
        i. Analyses determining the acidification capacity
        ii. Extraction of both sulphidic and oxidic ores at the same mine site.
    b. Indicator "paragenesis with radioactive substances": The text has been adapted in two instances:
        i. Ambiguities in the text have been resolved, clarifying which rule to follow for metal mining if no further information is available.

   ii. A recommendation has been introduced to use local / regional data where possible.

   c. Indicator "deposit size"

      i. New proposal to calculate the deposit size for bauxite based on data from Meyer (2004)

      ii. Proposal for the integration of historical data

   d. Indicator "ore grade"

      i. New class boundaries have been introduced based on results from Priester et al 2018

      ii. Class boundaries for ore grade in bauxite mines have been introduced based on data from Meyer (2004)

3. Technology level

   a. Indicator "mine type": Dealing with border cases when two mine types occur at one site

   b. Indicator "use of auxiliary substances":

      i. The drill and blast method is considered to have a low EHP. Previously it was assigned with a medium EHP.

      ii. The 1st edition of the measurement instructions recommended assigning a high EHP for flotation and SX-EW (solvent extraction and electro-winning). For clarity, it is now specified that a low EHP should be assigned, given the availability of concrete information on the subject.

      iii. Indicator "mining waste":

         ▪ The definition of dam height is more reader-friendly, and stronger emphasis is placed on the recommendation to use satellite imagery

4. Level "site-surroundings"

   a. The procedure for mapping the mine sites, which influences all the indicators of the site-surrounding level, has been greatly improved. Today, polygons are given priority over point data. Following the GIS evaluation, the data quality is now rated A (previously B).

   b. Indicator "protected areas and AZE sites": the data set for designated protected areas and for AZE sites was updated, which also led to an update and adaptation of the indicator description.

   c. Indicator "conflict potential with local population" was removed because it did not refer to any database that would map the local level needed for the site-related evaluation. Until a suitable database is available, it is now recommended to use context information on governance and CSR.

Further proposals and ideas for future optimizations have been made for those recommendations which are beyond the scope of the project. Most significantly, the Water Stress Index has been reviewed and a proposal for further optimization has been made.

Presentation of the results on an interactive map

The information compiled in each factsheet represents a comprehensive dataset that will be of interest to many user groups working in the field of environment and governance in the industrial mining sector, and the field of responsible sourcing from global mineral supply chains. The target groups are governmental agencies, policy advisors and consultants, researchers, NGOs, and private companies along the value chain of each individual commodity.

To make the project results easily accessible, the 100 factsheets are made publicly available on an interactive online map platform.

Due to the spatial presentation of the mine sites and the variety of filter and layer functions provided, each user group can easily select and extract the information most relevant to their work.

Users can filter general and specific information, such as indicators and assessment results. In addition to standard map tools such as base maps, thematic layers and a distance meter, the presentation also contains info boxes. These provide background information on the OekoRess III project, the applied site-related EHP instructions, and further links. In general, the user can obtain specific information on individual mine sites, but also derive geographical trends and comparisons of certain indicators between locations.

The online map builds on the ESRI ArcGIS software and is hosted by UBA on its web servers. Consistent with the factsheets, the content of the online map is in English.

Zusammenfassung

Die deutsche Wirtschaft importiert Rohstoffe aus der ganzen Welt. Diese Rohstoffe bilden die physische Grundlage für Produktion, Wertschöpfung und Konsum in Deutschland. Metallische Rohstoffe werden fast vollständig importiert, sowohl direkt in Form von Erzen und Konzentraten als auch indirekt in Form von Halbzeug und Fertigprodukten. Versorgungssicherheit ist das oberste Ziel der deutschen Rohstoffpolitik. Gleichzeitig wächst sowohl in Deutschland als auch in anderen früh industrialisierten Ländern das öffentliche Bewusstsein für die Bedingungen, unter denen mineralische Rohstoffe anderswo abgebaut werden. Die mit der Gewinnung natürlicher mineralischer Rohstoffe einhergehende Nutzung anderer natürlicher Ressourcen wie Boden, Wasser, Luft oder Ökosysteme sowie deren Auswirkungen auf die biologische Vielfalt und die lokale Bevölkerung rücken zunehmend in den Blickpunkt der Öffentlichkeit. In diesem Zusammenhang wird auf verschiedenen Ebenen nach neuen Ansätzen gesucht, um die Versorgungssicherheit mit einer global verstandenen Verantwortung für den ökologischen Fußabdruck in Einklang zu bringen.

Vor diesem Hintergrund will das Projekt einen wissensbasierten Beitrag zur Debatte um eine verantwortungsvolle Rohstoffversorgung leisten, indem es validierte Daten und transparente Bewertungen zu den Umweltaspekten der mineralischen Rohstoffgewinnung bereitstellt.

Im Vorläuferprojekt OekoRess I wurde eine standortbezogene Bewertungsmethode des Umweltgefährdungspotenzials von Bergbaustandorten entwickelt. Diese Bewertungsmethode ermöglicht es, einen schnellen Überblick über mögliche Umweltgefährdungen an einem Standort zu erhalten. Dabei werden sowohl geologische und technische Faktoren als auch die standortspezifischen Bedingungen der natürlichen Umwelt in die Bewertung einbezogen. Die Methode kann einen wichtigen Beitrag dazu leisten, die ökologische Verfügbarkeit von Rohstoffen besser einschätzen zu können und damit politische Maßnahmen zu ergreifen, die auf diese Verfügbarkeit abgestimmt sind.

Der vorliegende Bericht umfasst die Ergebnisse einer systematischen Anwendung der standortbezogenen Bewertungsmethode auf drei ausgewählte Rohstoffe an insgesamt 100 Standorten im Projekt OekoRess III. Dieses "Pilotscreening" dient der Erweiterung der Wissensbasis und der Verfeinerung der Bewertungsmethode sowie der Identifizierung von Vorschlägen für deren Weiterentwicklung. Der Ansatz, eine große Anzahl von Fällen desselben Rohstoffs zu analysieren, eröffnet die Möglichkeit, standortabhängige Variationen in der Bewertung zu identifizieren und zu vergleichen sowie die Messanleitung zu verfeinern. Damit erhält die Methode eine solide Basis, die sowohl eine Weiterentwicklung des Bewertungsverfahrens ermöglicht als auch durch eine breite Anwendung das Wissen und die Akzeptanz bei den verschiedenen Interessengruppen erhöht.

Neben der standortbezogenen Bewertung wurde eine zweite, rohstoffbezogene Bewertungsmethode für Umweltgefährdungspotentiale entwickelt. Diese rohstoffbezogene Bewertungsmethode wurde in ÖkoRess II auf rund 50 Rohstoffe angewendet und leicht modifiziert. Das Projekt ÖkoRess III konzentriert sich jedoch ausschließlich auf die standortbezogene Bewertungsmethode.

Dabei werden relevante Ergebnisse aus UBA-Forschungsprojekten im Rahmen von UFOPLAN/REFOPLAN berücksichtigt(unter anderem UmSoRess[8], RohPolRess[9], KlimRess[10] und InGoRo[11] sowie OekoRess I[12] und II[13]), welche sich mit den verschiedenen Aspekten der Rohstoffgewinnung und deren Wechselwirkungen mit ökologischen und sozialen Belangen beschäftigen.

Mit Bauxit, Kupfererz und Eisenerz werden drei metallische Massenrohstoffe angesprochen, die einen wesentlichen Teil der stofflichen Basis der deutschen Industrie ausmachen. Diese Rohstoffe werden weltweit abgebaut und in großen Mengen für die Produktion von Gütern mit höherer Fertigungstiefe importiert. Sie sind daher für die Diskussion um die ökologische Verantwortung Deutschlands in Bezug auf die Abbaubedingungen in den Herkunftsländern von besonderer Bedeutung.

Die Fact Sheets für jede Mine enthalten die systematisch angewendete standortbezogene Bewertung der Umweltgefährdungspotenziale gemäß der Messanleitung (Anhang D). Um den breiteren Rohstoff-Länder-Bezug in die Betrachtungen einzubeziehen, enthalten die Fact Sheets relevante Kontextinformationen zur staatlichen Governance im Bereich des Bergbaus und seiner Umweltauswirkungen sowie zu Corporate Social Responsibility-Maßnahmen der Minenbetreiber. Die Ergebnisse werden über eine interaktive Online-Karte veröffentlicht.

Das Projekt gliedert sich in vier Arbeitspakete:

- WP 1: Standortbestimmung
- WP 2: Datenerhebung
- WP 3: Auswertung nach der standortbezogenen OekoRess-Methode
- WP 4: Visualisierung auf einer interaktiven Online-Karte

Der Bericht orientiert sich grob an diesen vier Arbeitspaketen. Datenerhebung (WP2) und Auswertung (WP3) sind stark miteinander verknüpft und werden daher gemeinsam im Kapitel 3 behandelt. Das anschließende Kapitel 4 ist den Verbesserungsvorschlägen für die Messanleitung (Annex D) und dem festgestellten weiteren Forschungsbedarf gewidmet.

Auswahl des Minenstandortes

Hauptkriterien für die Auswahl eines Minenstandortes sind die Jahresproduktion und die Größe der Reserven. Ziel ist es, für jeden Rohstoff die größtmögliche Abdeckung in Bezug auf die jährliche globale Produktion und - nachrangig - die weltweiten Reserven zu erreichen. Während die Gesamtzahl der Standorte durch die Konzeption des Projekts vorgegeben ist, kann die Anzahl der ausgewählten Standorte pro Rohstoff variiert werden. Daher wurde die Anzahl der Standorte pro Rohstoff, die das Ziel der höchstmöglichen Abdeckung der beiden Hauptkriterien am besten widerspiegelt, iterativ angenähert.

Die Größe der Reserve wurde statt der Angabe der Ressourcen gewählt, da das Bewertungssystem die Reserve als Grundlage für einen der Indikatoren verwendet (vergl. Abschnitt 4.2).

[8] https://www.umweltbundesamt.de/umweltfragen-umsoress

[9] https://www.umweltbundesamt.de/umweltfragen-rohpolress

[10] https://www.umweltbundesamt.de/publikationen/impacts-of-climate-change-on-mining-related

[11] https://www.umweltbundesamt.de/publikationen/international-governance-supply-raw-materials

[12] https://www.umweltbundesamt.de/umweltfragen-oekoress

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

Die Auswahl der Minenstandorte basiert auf den folgenden Schritten:

1. Die jährlichen Produktionsdaten möglichst vieler Eisenerz-, Kupfererz- und Bauxitminen aus öffentlich zugänglichen und eigenen Daten zusammengetragen.
2. Unter Berücksichtigung der Projektziele und der Ergebnisse von Schritt 1 werden die Standorte nach dem Kriterium "Jahresproduktion", gefolgt von "Reserven", geordnet.
3. Durch schrittweise Annäherung, unter Beibehaltung der höchstmöglichen Abdeckung der Jahresproduktion und der Reserven aller Rohstoffe, wird die Anzahl der Standorte pro Rohstoff für die kombinierte Liste von 100 vorgeschlagenen Standorten ausgewählt.
4. Im Laufe des Projekts werden Minenstandorte gestrichen, z. B. wenn eine Mine per Definition zu einem im Projekt festgelegten Minenkomplex gehört.

Schlüsseldaten für die 100 ausgewählten Minenstandorte:

Die ausgewählten Standorte decken jeweils > 55 % der weltweiten Produktion ab (Stand 2013),

- Bauxit: Es wurden 23 Minen und Minenprojekte ausgewählt, die 29,51 % der weltweiten Reserven abdecken,
- Eisenerz: Es wurden 32 Minen und Minenprojekte ausgewählt, die 32,07 % der weltweiten Reserven abdecken,
- Kupfererz: Es wurden Minen und Minenprojekte ausgewählt, die 42,27 % der weltweiten Reserven abdecken.

Entwicklung der Fact Sheets

Die Struktur der Merkblätter wird in einem der ersten Schritte des Projekts festgelegt und entsprechend neuer Entwicklungen leicht angepasst. Beispiele für Anpassungen sind das neue Kriterium "Oberflächenausdehnung", das bei der Verfeinerung des Verfahrens zur Bestimmung der Indikatoren für die "natürliche Umwelt" hinzugefügt wurde. Hierfür wird die Flächenausdehnung der Bergwerke auf Basis der aktuellsten Satellitenbilder ermittelt. Das Kriterium "in Betrieb seit" wurde bei der Entwicklung des verfeinerten Ansatzes zur Bestimmung der Lagerstättengröße hinzugefügt und bezieht historische Daten so weit wie möglich ein.

In den Merkblättern werden die relevanten Informationen klar dargestellt, um:

a) Einen Überblick über den Standort zur Orientierung zu geben,

b) Die Bewertung gemäß der standortbezogenen OekoRess-Bewertung zu erleichtern und darzustellen und

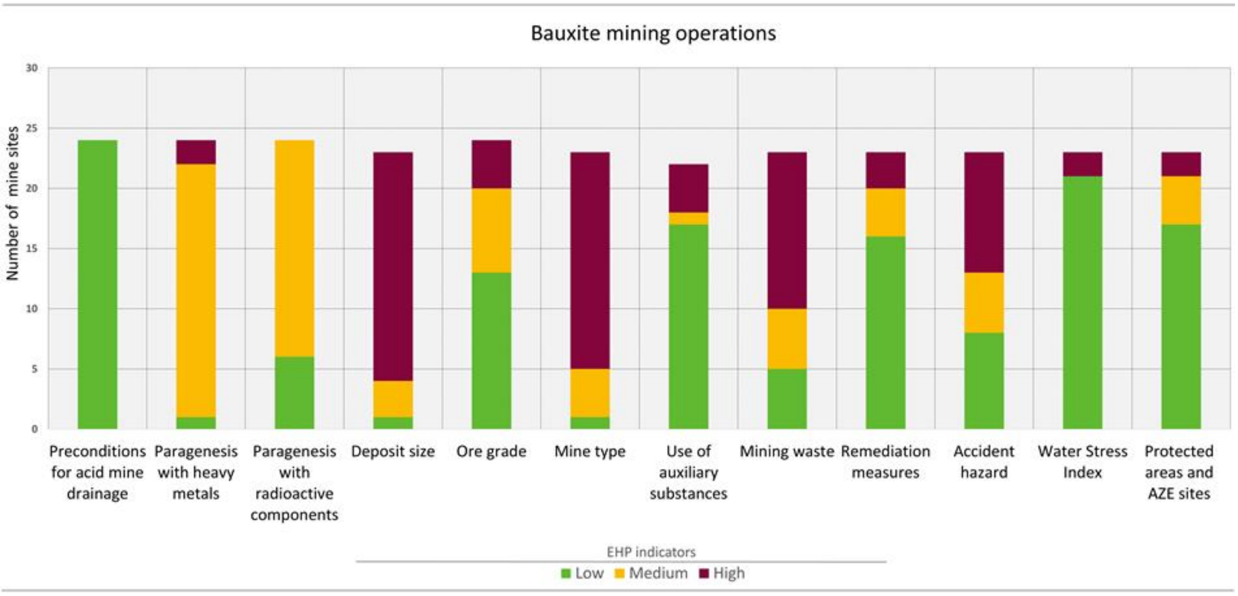
c) Zusätzliche Informationen zu Governance und Corporate Social Responsibility (CSR) bereitzustellen, um die Informationen aus der Bewertung besser in einen Gesamtzusammenhang einordnen zu können.

<u>Aufbau der Fact Sheets</u>

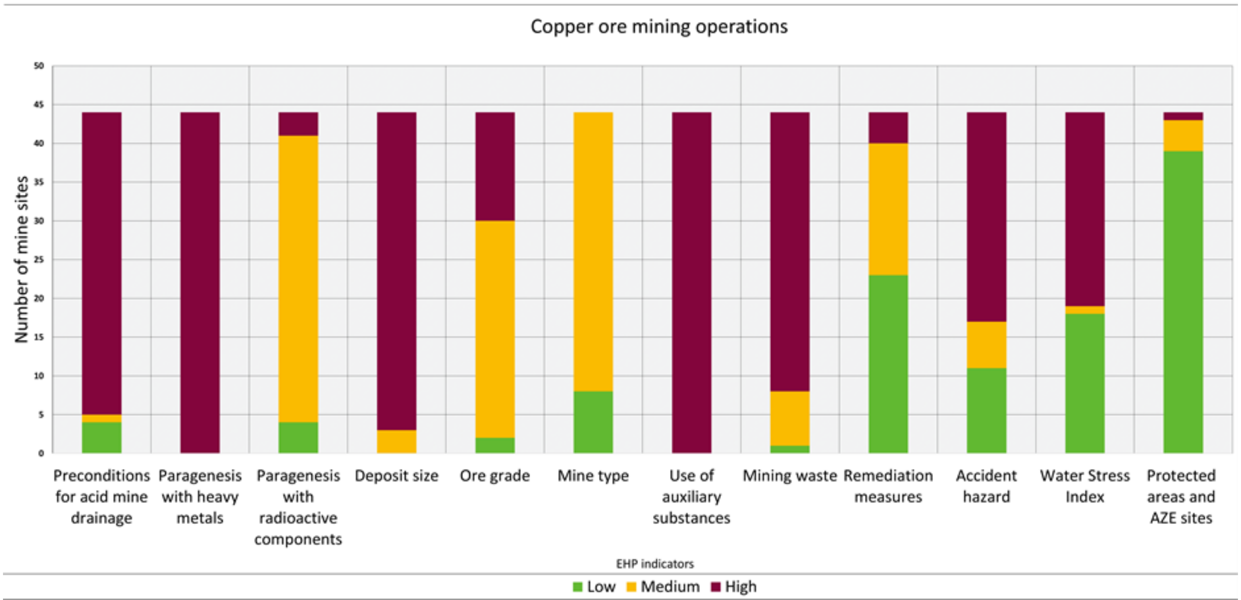
1. Allgemeine Informationen, einschließlich des Namens, die beteiligten Unternehmen, geologische und geografische Hintergrundinformationen, sowie allgemeine Informationen über den Minenstandort, wie Produkte und Jahresproduktion.
2. Der Hauptteil der Fact Sheets basiert auf dem standortbezogenen Bewertungsraster, das im Rahmen des Projekts OekoRess I entwickelt wurde. Die 12 Bewertungsindikatoren beziehen sich auf die drei Ebenen Geologie, Technologie und Standortumgebung und weisen auf spezifische Umweltgefährdungspotenziale (UGPs) hin:

   a. Ebene Geologie: Untersucht werden die Paragenese mit radioaktiven Stoffen, die Paragenese mit Schwermetallen und das Potenzial für Acid Mine Drainage (AMD) (Indikatoren 1-3 im Bereich "rohstoffspezifisch") sowie die Lagerstättengröße und der Erzgehalt (Indikator 4 und 5 im Bereich "lagerstättenspezifisch").
   b. Ebene Technologie: Bewertet werden der Minen Typ -z.B. wird angenommen, dass mit Tagebau tendenziell eine größere Flächeninanspruchnahme einhergeht als mit dem Untertagebau und ein entsprechend höheres UGP vergeben- Einsatz von Hilfsstoffen, Reststoffe und Nachsorgemaßnahmen (Indikatoren 6-9).
   c. Das Standortumfeld wird durch die Indikatoren 10-12 betrachtet, wobei Störfallgefahren durch Überschwemmungen, Erdbeben, Stürme, Hangrutsche (Indikator 10), der Wasserstressindex (WSI) und Wüstengebiete (Indikator 11) und schließlich Schutzgebiete und AZE-Standorte (Indikator 12) Berücksichtigung finden.
3. Governance
   a. Governance-Indikatoren (WGI, EPI und EITI-Mitgliedschaft)
   b. Internationale Vereinbarungen
   c. Rechtlicher Rahmen (Umwelt und Arbeitsschutz)
4. Gesellschaftliche Unternehmensverantwortung (Corporate Social Responsibility - CSR)
   a. Freiwillige Standards (z.B. Aluminium Stewardship Initiative - ASI)
   b. ISO und CSR-Berichterstattung
5. Finanzierungsstandards (Equator-Prinzipien, IFC Standards)

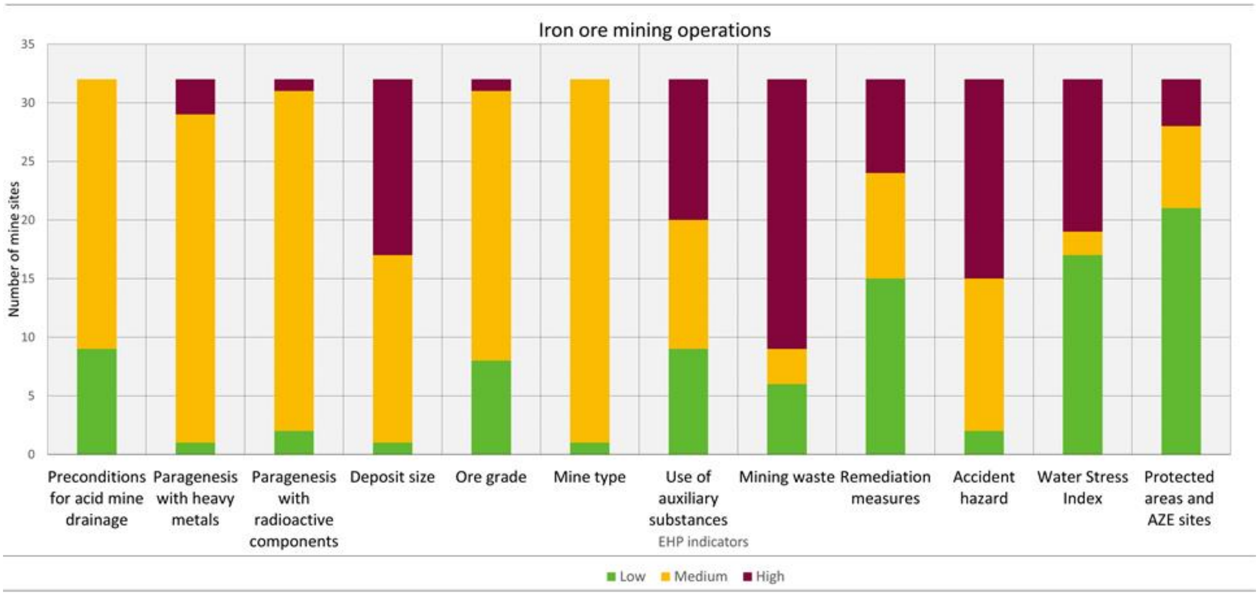
Die Ergebnisse zeigen, dass im Falle von Datenlücken für konkrete Minen die Anwendung allgemeiner Annahmen, wie sie in den Messanweisungen auf der Grundlage wissenschaftlicher Ergebnisse und Expertenwissens definiert sind, zumindest eine allgemeine Bewertung ermöglicht. Allerdings ist es wichtig, die Datenqualität für den jeweiligen Indikator zu kommunizieren, um falsche Sicherheiten zu vermeiden. Da das Bewertungssystem auf dem Vorsorgeprinzip beruht, können die Ergebnisse im Sinne des Naturschutzes eher konservativ ausfallen. Es wird davon ausgegangen, dass sich durch eine verstärkte Veröffentlichung von Daten ein differenzierteres Bild ergeben könnte. Nur in wenigen Fällen für einige Bauxitminen, bei denen sich die Datensuche am schwierigsten gestaltete, wurde kein Bewertungsergebnis erzielt (siehe unten im Balkendiagramm für Bauxitabbau, Indikatoren *Erzgehalt* und *Einsatz von Hilfsstoffen*).



Quelle: Eigene Dartsellung, vergl.Figure 8, Projekt-Consult, ifeu Insitut, Öko-Insitut



Quelle: Eigene Dartsellung, vergl.Figure 8, Projekt-Consult, ifeu Insitut, Öko-Insitut



Quelle: Eigene Dartsellung, vergl. Figure 9, Projekt-Consult, ifeu Insitut, Öko-Insitut

Nach der Entwicklung der Fact Sheets und der Bewertung der UGPs wurden die Fact Sheets von Experten von RMG Consulting geprüft (erster Validierungsschritt), die sich zur Datenqualität sowie zu den Messanweisungen und möglichen Verbesserungen äußerten. Die Fact Sheets wurden anschließend den Minenbetreibern zur Verfügung gestellt (zweiter Validierungsschritt). Das Projektteam hat Rückmeldungen zu mehr als 30 Bergwerken von zehn Unternehmen erhalten. Die Rückmeldungen wurden eingearbeitet, wenn z. B. neue öffentlich zugängliche Quellen die Beschreibung und/oder das Bewertungsergebnis beeinflussten. Alle Informationen aus den Steckbriefen sind in einer Datenbank gespeichert, die in die Online-Präsentation der Steckbriefe auf einer interaktiven Online-Karte einfließt und vom UBA bereitgestellt wird.

Das Projekt befasst sich nicht nur mit einzelnen Minen, sondern auch mit Bergwerkkomplexe und Bergwerkprojekten, die in diesem Dokument alle unter dem Begriff Bergwerkstandort zusammengefasst werden, um langwierige Formulierungen zu vermeiden.

Manche Bergwerkkomplexe bestehen aus zwei bis drei Bergwerken, die in unmittelbarer räumlicher Nähe zueinander liegen. Im Extremfall werden aber auch mehr als 10 Bergwerke mit maximalen Entfernungen von bis zu 180 Kilometern zu einem Komplex zusammengefasst. Gründe, warum Bergwerkkomplexe gemeinsam betrachtet werden, sind:

- Die einzelnen Bergwerkstandorte auf einer Lagerstätte (z.B. Banded Iron Formation - BIF) haben in der Regel nahezu identische geologische Gegebenheiten, auch wenn sie im Extremfall durch Entfernungen von mehr als hundert Kilometern getrennt sind.
- Die geologischen Gegebenheiten beeinflussen auch die Anwendung von Technologien und Verarbeitungsmethoden. Es kann daher davon ausgegangen werden, dass das Ergebnis der UGP-Bewertung für die einzelnen Gruben eines Komplexes nahezu identisch sein wird.
- Als Faustregel gilt, dass die einzelnen Gruben eines Komplexes meist von demselben Betreiber betrieben werden. Dies wird im Projekt zu einer gleichen Bewertung aller Aspekte der Unternehmensführung führen.
- Hinzu kommt, dass die Betreiber der Bergwerkkomplexe nur sehr selten über die Produktion der einzelnen Bergwerke berichten, so dass es schwierig ist, verlässliche Zahlen für jedes Bergwerk zu ermitteln. So werden zwar teilweise

Produktionskapazitäten pro Bergwerk angegeben, doch spiegeln diese nur die theoretischen Höchstwerte der Produktion wider.

- Nicht zuletzt spielt auch die Datenverfügbarkeit eine wichtige Rolle bei der Bewertung von Bergwerkkomplexen. Diese sind oft weitaus besser bekannt als die einzelnen Gruben, so dass Informationen eher für den gesamten Komplex als für einzelne Gruben verfügbar sind.

Letztlich gibt es nur zwei wesentliche Unterschiede in der Bewertung zwischen Bergwerkkomplexen und Einzelbergwerken:

- Erstens gibt es Unterschiede in der Größe der Lagerstätten. Werden die Bergwerke einzeln betrachtet, wird die Lagerstättengröße entsprechend kleiner; bei der Betrachtung als Komplex werden die Reserven immer größer sein, was zu einem höheren UGP führt. Es kann jedoch argumentiert werden, dass die Lagerstättengröße des Bergwerkkomplexes die Realität besser widerspiegelt.
- Zweitens können die standortspezifischen Indikatoren für die Bewertung der natürlichen Umwelt einer unterschiedlichen Bewertung unterzogen werden. Wenn ein Bergwerkkomplex aus mehreren Bergwerken besteht und eines davon einen hohen UGP aufweist, würde der gesamte Komplex mit dem entsprechenden Potenzial bewertet werden. Hier könnten die Polygone für jede Mine mit der entsprechenden Bewertung dargestellt werden, so dass der UGP jedes einzelnen Polygons transparent wird.

Zusammenfassend lässt sich sagen, dass viele Indikatoren dafürsprechen, einen Bergwerkskomplex trotz der teilweise großen geografischen Entfernungen als eine Einheit zu betrachten. Insbesondere geologische Aspekte, betriebswirtschaftliche Zusammenfassung der Betreiber zu einem Komplex, höhere Bekanntheit der Komplexe und damit bessere Datenverfügbarkeit führen zur gemeinsamen Betrachtung als Einheit.

Sensitivitätsanalyse: Einbeziehung von Pufferzonen um die Bergwerke

Für die standortspezifische UGP -Bewertung wird eine räumliche Analyse für alle natürlichen Umweltindikatoren durchgeführt. Um die Nähe von hoch bewerteten UGP -Gebieten zu Bergbaustandorten zu berücksichtigen, wurde eine Sensitivitätsanalyse für die Indikatoren "Wasserstressindex und Wüstengebiete" und "Schutzgebiete und AZE-Standorte" durchgeführt. Bei diesen Indikatoren hat das Bergwerk einen Einfluss, der über die Umgebung des Bergwerksgeländes hinausgeht.

Die anderen Indikatoren für die natürliche Umwelt beziehen sich auf Naturereignisse direkt am Standort des Bergwerks, weshalb eine Analyse der Nähe nicht erforderlich ist.

Das Pufferwerkzeug ist ein gängiger Ansatz in der GIS-Näherungsanalyse, mit dem bestimmt werden kann, welche Merkmale sich innerhalb einer kritischen räumlichen Entfernung von einem anderen Merkmal befinden. Es wurden Pufferbreiten von 10 km und 25 km angewandt und getestet.

Die Mehrheit der Gebiete wird als hoher und niedriger UGP eingestuft. Die Karte des Indikators "Schutzgebiete und AZE-Standorte" besteht aus 250.000 Einzelmerkmalen und ist global mit hoher Granularität (je nach Land) verteilt. Diese Eigenschaft führt zu einem kontinuierlichen Anstieg der UGP -Verteilung durch Hinzufügen verschiedener Puffer.

Der Aspekt der Nähe eines Bergwerkstandortes zu potenziellen Gebieten mit hohem UGP sollte berücksichtigt werden. Dies gilt insbesondere für Schutzgebiete, da sich die Ergebnisse bereits bei einem relativ geringen Abstand von 10 km erheblich verändern.

Empfehlungen zur Weiterentwicklung der standortbezogenen Bewertungsmethode

Besonderes Augenmerk wird auf die Optimierungsmöglichkeiten der Messanleitung gelegt. Die Messanleitung wurde im Rahmen des Projektes OekoRess I entwickelt und veröffentlicht. Die im Projekt realisierten Weiterentwicklung und Empfehlungen sind in die zweite Auflage des standortbezogenen Bewertungssystems eingearbeitet und als Annex D dem vorliegenden Bericht beigefügt. Diese zweite Auflage enthält mehrere Aktualisierungen und Präzisierungen zur ersten Auflage, die 2017 vorgelegt wurde.

Besonderes Augenmerk wird auf diejenigen Aspekte der Bewertungsmatrix bzw. Messanweisungen gelegt, die im Rahmen des Projektes OekoRess I nicht vollständig umgesetzt werden konnten. Empfehlungen für die weitere Forschung werden ausgesprochen, wenn der Gegenstand der Empfehlung über den Rahmen des Projekts hinausgeht. Sie zielen insbesondere auf die Erweiterung und Verbesserung der Datenbasis und der Forschungsergebnisse ab, auf denen die Messanleitung basiert.

Eine markante Änderung stellt die Streichung des Indikators "Konfliktpotenzial mit der lokalen Bevölkerung" dar, da die zugrundeliegenden Daten das Konfliktpotenzial nicht auf der Ebene der Minenstandorte, sondern in einem größeren Maßstab widerspiegeln. Am zweitwichtigsten sind die Aktualisierungen der Datenbanken und der Methodik der Indikatoren für die Ebene "Standort (Umfeld)".

Darüber hinaus wurde das Bewertungsinstrument für den Indikator "Erzgehalt" erneut erweitert und umfasst nun auch die Elemente Eisen, Zinn, Mangan und Aluminium sowie Platingruppenmetalle (PGM).

Eine Zusammenfassung der relevanten Aktualisierungen, die in der 2. Auflage der Messanweisungen eingeführt und im Bericht besprochen wurden, sind entsprechend der Struktur der Messanweisungen gruppiert:

1. Allgemeines
    a. Umbenennung von Indikatoren (Erzgehalt, Minentyp, bergbauliche Reststoffe)
    b. Einführung der Ziele für jeden Indikator, für eine verbesserte Darstellung worauf die Indikatoren hinweisen. Zum Beispiel "Begrenzung des Aufwands für den Abbau" für den Erzgehalt.
    c. Um den Eindruck zu vermeiden, dass nicht die tatsächlichen Auswirkungen, sondern UGPs gemessen werden, werden die Ampelfarben durch die Verwendung von Symbolen ausgetauscht.
2. Ebene Geologie
    a. Indikator AMD: Während in der Ausgabe 1 der Messanleitung der EHP für alle sulfidischen Lagerstätten als "hoch" angesehen wurde, werden nun spezifischere Anweisungen gegeben, um Folgendes zu berücksichtigen:
        i. Analysen zur Bestimmung der Säurebildungskapazität
        ii. Gewinnung sowohl sulfidischer als auch oxidischer Erze am gleichen Standort der Mine.
        iii. Indikatorparagenese mit radioaktiven Substanzen: Der Text wird in zwei Punkten angepasst:
            1. Zweideutigkeiten im Text werden beseitigt, indem klargestellt wird, welche Regel für den Metallbergbau zu befolgen ist, wenn keine weiteren Informationen verfügbar sind.

2. Es wird eine Empfehlung eingeführt, soweit möglich lokale/regionale Daten zu verwenden.

   b. Indikator Lagerstättengröße

      i. Neuer Vorschlag zur Berechnung der Lagerstättengröße für Bauxit auf der Grundlage der Daten von Meyer (2004).

      ii. Vorschlag zur Integration historischer Daten.

   c. Indikator für den Erzgehalt

      i. Neue Klassengrenzen werden auf der Grundlage der Ergebnisse von Priester et al. 2018 eingeführt.

      ii. Es werden Klassengrenzen für den Erzgehalt in Bauxitminen eingeführt, die auf den Daten von Meyer (2004) basieren.

3. Ebene Technik

   a. Indikator Minentyp: Behandlung von Grenzfällen, wenn zwei Minentypen an einem Standort vorkommen

   b. Indikator Einsatz von Hilfsstoffen

      i. Die Methode Drill and Blast wird mit einem niedrigen UGP bewertet, vorher war sie mit einem mittleren UGP bewertet worden.

      ii. In der 1. Auflage der Messanleitung wurde empfohlen, für Flotation und SX-EW (Solvent Extraction and Electrowinning) einen hohen EHP zuzuweisen. Aus Gründen der Klarheit wird nun angegeben, dass ein niedriges UGP zugewiesen werden kann, falls entsprechende konkrete Informationen zu diesem Thema vorliegen.

   c. Indikator bergbauliche Reststoffe

      i. Die Definition der Dammhöhe ist vereinfacht worden und die Empfehlung zur Verwendung von Satellitenbildern wird stärker betont.

4. Ebene Standort (Umfeld)

   a. Das Verfahren zur Kartierung der Bergwerksstandorte, das alle Indikatoren der Ebene Standort (Umfeld) beeinflusst, ist stark verbessert. In der nun vorliegenden 2. Ausgabe der Messanleitung werden Polygone anstelle von Punktdaten verwendet. Aufgrund der GIS-Auswertung wird die Datenqualität nun mit A bewertet (vorher B).

   b. Indikator Schutzgebiete und AZE-Gebiete: Der Datensatz für ausgewiesene Schutzgebiete und für AZE-Gebiete wurde aktualisiert, was zu einer Aktualisierung und Anpassung der Indikatorbeschreibung führte.

   c. Der Indikator "Konfliktpotenzial mit der lokalen Bevölkerung" wurde gestrichen, da er sich auf keine Datenbank bezieht, welche die für die standortbezogene Bewertung erforderliche lokale Ebene abbilden würde. Bis eine geeignete Datenbank zur Verfügung steht, wird nun empfohlen, auf Kontextinformationen zu Governance und CSR zurückzugreifen.

Weitere Vorschläge und Ideen für künftige Optimierungen werden für jene Empfehlungen gemacht, deren Themen den Rahmen des Projektes sprengen würden. Vor allem der Wasserstress-Index wird überprüft und ein Vorschlag zur weiteren Optimierung unterbreitet.

Präsentation der Ergebnisse auf einer interaktiven Karte

Die in den einzelnen Fact Sheets gesammelten Informationen stellen einen umfassenden Datensatz dar, der für viele Nutzergruppen interessant ist, die im Bereich Umwelt und Governance mit Bezug zum industriellen Bergbausektor und verantwortungsvollen Lieferketten mineralischer Rohstoffe arbeiten. Zielgruppen sind Behörden, Politikberater, Forscher, Nichtregierungsorganisationen und private Unternehmen entlang der Wertschöpfungskette jedes einzelnen Rohstoffs. Um die Projektergebnisse leicht zugänglich zu machen, werden die 100 Fact Sheets über eine interaktive Online-Karte öffentlich zugänglich gemacht.

Dank der räumlichen Darstellung der Standorte und der vielfältigen Funktionen für Filter und Ebenen kann jede Nutzergruppe die für ihre spezifische Arbeit wichtigsten Informationen leicht auswählen und extrahieren.

Die Benutzenden können allgemeine und spezifische Informationen, wie Indikatoren und Bewertungsergebnisse, filtern. Zusätzlich zu den Standardkartenwerkzeugen, wie Grundkarten, thematische Ebenen und Entfernungsmesser, enthält die Karte auch Infoboxen. Diese bieten Hintergrundinformationen zum Projekt OekoRess III, die angewandten standortbezogenen UGP-Anweisungen und weiterführende Links. Generell können Nutzende spezifische Informationen zu einzelnen Bergbaustandorten erhalten, aber auch geographische Trends und Vergleiche bestimmter Indikatoren zwischen Standorten ableiten.

Die Online-Karte basiert auf der Software ESRI ArcGIS und wird vom UBA auf seinen Web-Servern gehostet. Der Inhalt der Online-Karte ist wie die Fact Sheets in englischer Sprache verfasst.

1 Introduction

1.1 Project background

The German economy imports raw materials from all over the world. These raw materials form the physical basis for production, value creation and consumption in Germany. Metal raw materials are almost entirely imported, both directly in the form of ores and concentrates and indirectly in the form of semi-finished and finished goods. Security of supply is the overriding goal of German raw materials policy. At the same time, public awareness of the conditions under which mineral resources are extracted elsewhere is growing both in Germany and in other early industrialised countries. The use of other natural resources, such as soil, water, air or ecosystems, which goes hand in hand with the extraction of natural mineral resources, as well as its effects on biodiversity and the local population, are increasingly becoming a focus of public attention. In this context, new approaches are being sought at various levels with the aim of reconciling security of supply with a globally understood responsibility for environmental footprints.

Against this background, the project aims to make a knowledge-based contribution to the debate on a responsible supply of raw materials by providing validated data and transparent assessments on the environmental aspects of mining.

In the previous projects, a site-related assessment method of the environmental hazard potentials of mine sites was developed. This assessment method makes it possible to obtain a quick overview of possible environmental hazards at a site. The assessment includes geological and technical factors, as well as site-specific conditions of the natural environment.

Building on the results of previous projects, the already developed site-related assessment method of environmental hazard potentials developed in the OekoRess I project is systematically applied to three selected raw materials at a total of 100 sites. This pilot screening also serves to identify potential for optimising the method.

With bauxite (aluminium ore), copper ore and iron ore, three bulk metal raw materials are being examined that make up a significant part of the material basis of German industry. These raw materials, which are extremely relevant for Germany as a production location, are mined worldwide and imported in large quantities, partly directly as ores, partly indirectly as semi-finished and finished goods, for the production of goods with a higher vertical range of manufacture, which in turn are mainly exported. They are therefore of particular importance in the debate on Germany's environmental footprint with regard to the mining conditions in the countries of origin.

1.2 Project goal

The project provides validated data and transparent assessments on environmental aspects of raw material extraction in order to strengthen an environmental raw materials policy. The method developed and optimised in the previous projects for the assessment of environmental hazard potentials is applied systematically within the framework of an initial screening at 100 sites for the three bulk raw materials iron ore, copper ore and bauxite. Mines in operation as well as mines in planning and development are included. Factsheets showing the evaluation results are developed for each of the 100 mine sites. Supplementary information on state governance in the field of mining and its environmental impact is provided, along with Corporate Social Responsibility measures of the mine owners. The results are published as factsheets on an interactive online map.

The approach takes into account three levels with indicators pointing to specific Environmental Hazard Potentials:

- Firstly, the geology level: the likelihood of radioactive contamination, paragenesis with heavy metals and potential for Acid Mine Drainage (AMD) are investigated (indicators 1-3 in the field “raw material-specific”), as well as deposit size and ore grade (indicators 4 and 5 in the field “deposit-specific”). E.g., raw materials that tend to occur in sulphidic ores pose a higher Environmental Hazard Potential for Acid Mine Drainage than raw materials occurring in oxidic sedimentary ores.
- Secondly, at the technology level, the mine type, the use of auxiliary substances, the mine waste and rehabilitation measures are assessed (indicators 6-9). E. g. open-pit operations disturb larger surface areas than underground mines, which is reflected in the indicator “mine type”.
- Thirdly, the site surroundings are assessed (indicators 10-12) by looking at the geographic location. Indicators assessed include accident hazards due to floods, earthquakes, storms, landslides, the Water Stress Index (WSI) and desert areas and, last but not least, the protected areas and AZE sites. E.g. if a majority of mines for a certain raw material are located in areas with frequent flooding, the Environmental Hazard Potential for the raw material is more likely to be high.

The factsheets produced are made available to the public via an interactive online map. Furthermore, the systematic application of the method continuously expands the knowledge base and further develops the assessment system. Relevant results of previous research projects such as UmSoRess[14], OekoRess II[15], KlimRess[16] and other related projects are taken into account.

[14] https://www.umweltbundesamt.de/umweltfragen-umsoress

[15] https://www.umweltbundesamt.de/publikationen/environmental-criticality-of-raw-materials

[16] https://www.umweltbundesamt.de/publikationen/impacts-of-climate-change-on-mining-related

2 Identification of 100 mine sites for evaluation

Based on two main criteria, annual production and size of reserve, 100 mining sites for iron ore, copper ore and bauxite are selected for evaluation.

2.1 Selection process

The purpose of selecting 100 mining sites is to achieve the largest possible coverage for each commodity in terms of annual global production and, secondarily, the global reserves. Therefore, the number of sites per commodity are iteratively approximated to achieve the highest possible coverage of the two main criteria.

Both current and future mining sites are included in the analysis, based on the idea of keeping the project results up to date until the end of the project.

The following sections detail the working steps and present the resulting list of 100 sites.

Listed here are the steps for selecting the mine sites to be evaluated in the project:

- In a first step, annual production volume data of as many iron ore, copper ore and bauxite mines as possible is gathered from publicly available and own data.
- Taking into account the project objectives and the results of step 1, the criteria are ranked to complete the basis for selecting the 100 locations. Annual production is defined as the most relevant criterion, followed by the reserves. Further possible criteria such as global mine site distribution are disregarded because they would detract from the two main criteria.
- The sites are reviewed and ranked by relevance based on the defined criteria. As a baseline, the year 2013 was used to compare and select the mine sites. Using a step-by-step approach, maintaining the highest possible coverage of production and reserve for all commodities, the number of sites was reduced to the combined list of 100 proposed sites.
- The primary criterion was to maximise the coverage of production for all three commodities through step-by-step approximation.
- The coverage of reserves was then maximised by adding high reserve sites to the list of sites for each commodity identified.

2.2 Selection of sites according to production

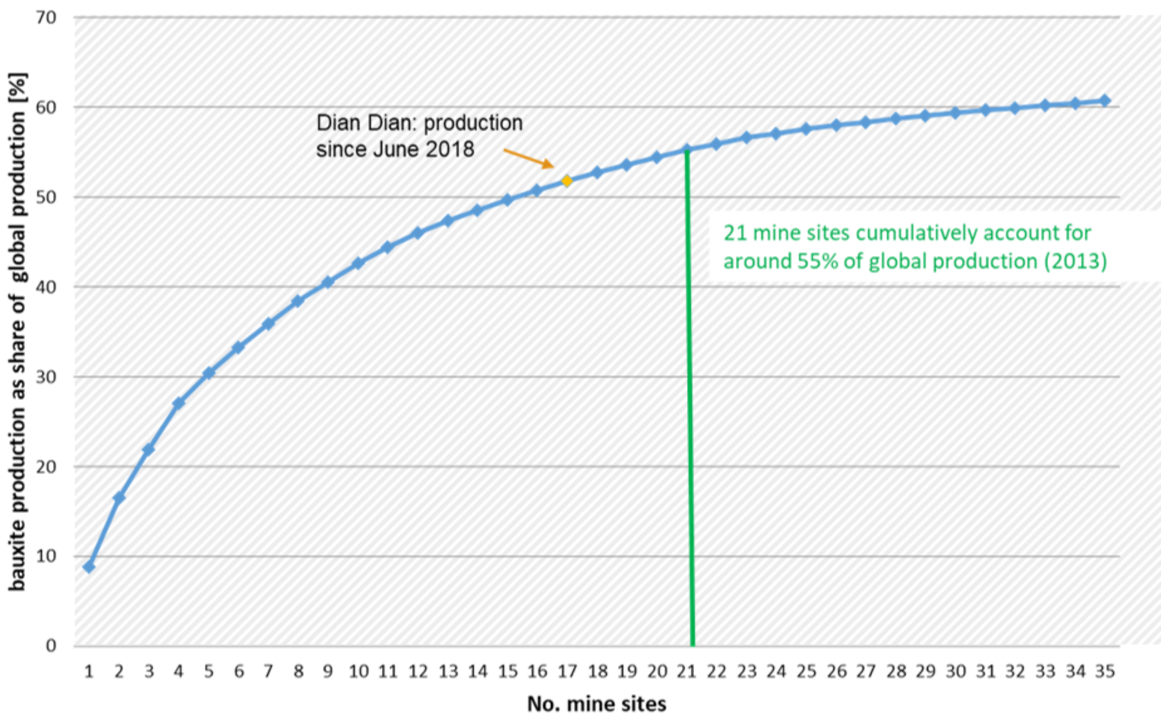
Global production quantities of the three raw materials for 2013 are displayed in Table 1 based on BGS and USGS data. The information on global production (ore in tonnes) is used in the project to estimate the extent to which the percentage adds to the global production.

Table 1: Global production values

Raw material	Global production
Bauxite	298,000 [kt/a] in 2013 (BGS 2016)
iron ore	2,230,000 [kt/a] in 2013 (USGS 2017)
copper ore	18,300 [kt of metal cont.] in 2013 (British Geological Survey 2016)

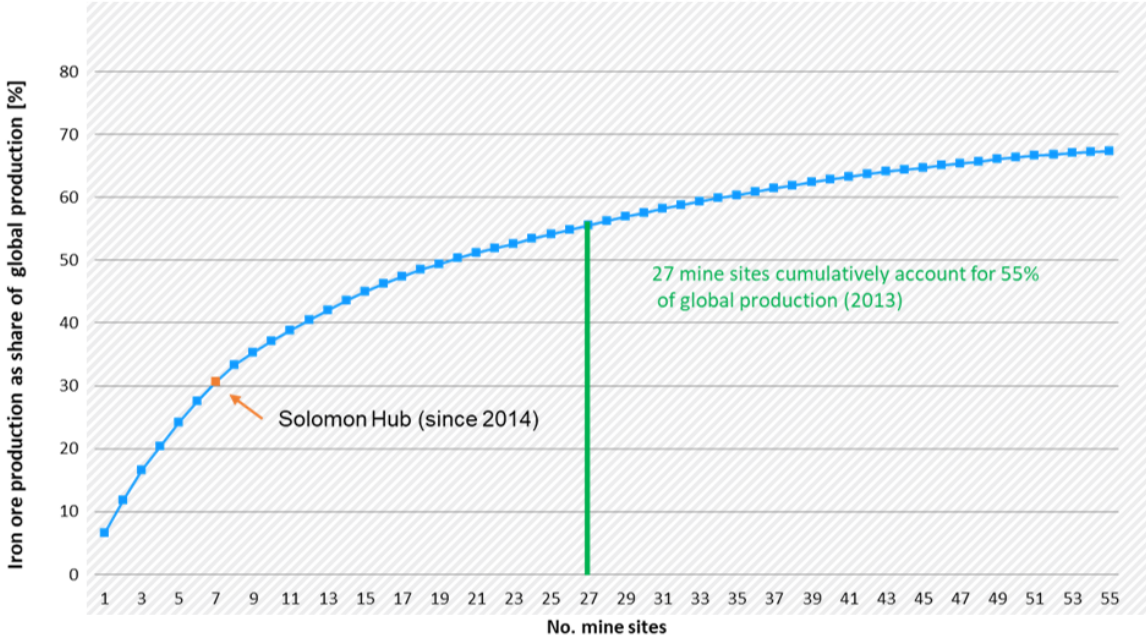
Disregarding mines with an obviously low contribution to global production, a consolidated list of mines for each commodity is established that forms the basis for Figure 1 to Figure 6. For bauxite, iron ore and copper ore a total of 35, 55 and 75 active sites respectively are included in these considerations. The cumulative curves in Figure 1 to Figure 3 show that for each of the three raw materials, a high coverage is already being achieved with comparatively few sites. The 55 % bar (in green) marks the approximate percentage of global annual production in 2013 that is mapped in this project. For factsheet development, the most recent production data is used rather than information from the same reference year, thus making the most up-to-date data available to the public.

Figure 1: Cumulative curve of bauxite as share of world production



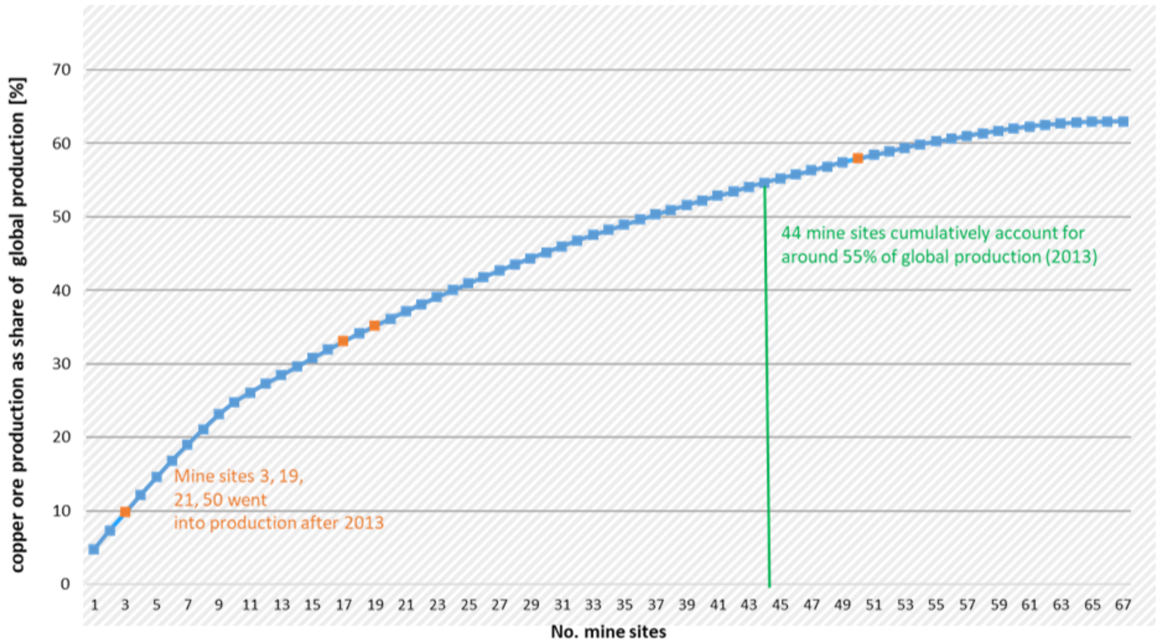
Source: own visualisation, Projekt-Consult, ifeu Insitut, Öko-Insitut

Figure 2: Cumulative curve of iron ore production as share of global production



Source: own visualisation, Projekt-Consult, ifeu Insitut, Öko-Insitut

Figure 3: Cumulative curve of copper production as a share of world production



Source: own visualisation, Projekt-Consult, ifeu Insitut, Öko-Insitut

It is assumed that no major mines are disregarded and that the global production unaccounted for is distributed among smaller and less known sites. Nonetheless, the existence of exceptions cannot be completely ruled out.

2.3 Identifying global and site-specific reserves

The information on the reference values of the reserves is more heterogeneous than the annual production data as this value is not estimated each year for a mine. Hence, the most recent data available is used. For the further work in the project it is assumed that information on reserves refers to "mineral reserves" (probable + proven reserves) if not otherwise specified.

Compared to the comprehensive information on production volumes at the individual sites, for reserve data there are more data gaps – especially for bauxite.

To analyse the contribution of a mine site's[17] reserve to the global reserve (Table 2), it was necessary to define the global reserve of a raw material. In Table 2, the rows marked in green are used for the estimations in the project as they present the most recent data available at the time the project was started.

Table 2: Global reserves of the three raw materials bauxite, copper ore and iron ore

Raw material	Global reserve (Mt)	Reference year	Source
Bauxite	29,240 (ore)	2011	BGR (BGR 2013)
Bauxite	28,000 (ore)	2017	USGS (USGS 2017a)
Copper	790 (metal cont. in ore)	2017	USGS (USGS 2017b)
Copper	741 (metal cont. in ore)	2017	Statista (Statista 2017)
Copper	635 (metal cont. in ore)	2010	BGR (BGR 2012)
Iron	170,000 (ore)	2018	USGS (USGS 2018)
Iron	83,000 (metal cont. in ore)	2018	USGS (USGS 2018)
Iron	172,000 (ore)	2016	NRC (Natural Resources Canada 2016)

Rows in green are used for the estimations in the project as they present the most recent data available at project start.

Figure 4 to Figure 6 show the reserves plotted against the annual production of the mine sites. A total of 92 sites are selected on the basis of the production data for a coverage of the annual global production (as of 2013) of approximately 55 % for each raw material (all mines at the right side of the green bar in Figure 4: Bauxite - reserves vs. annual production of mine sites

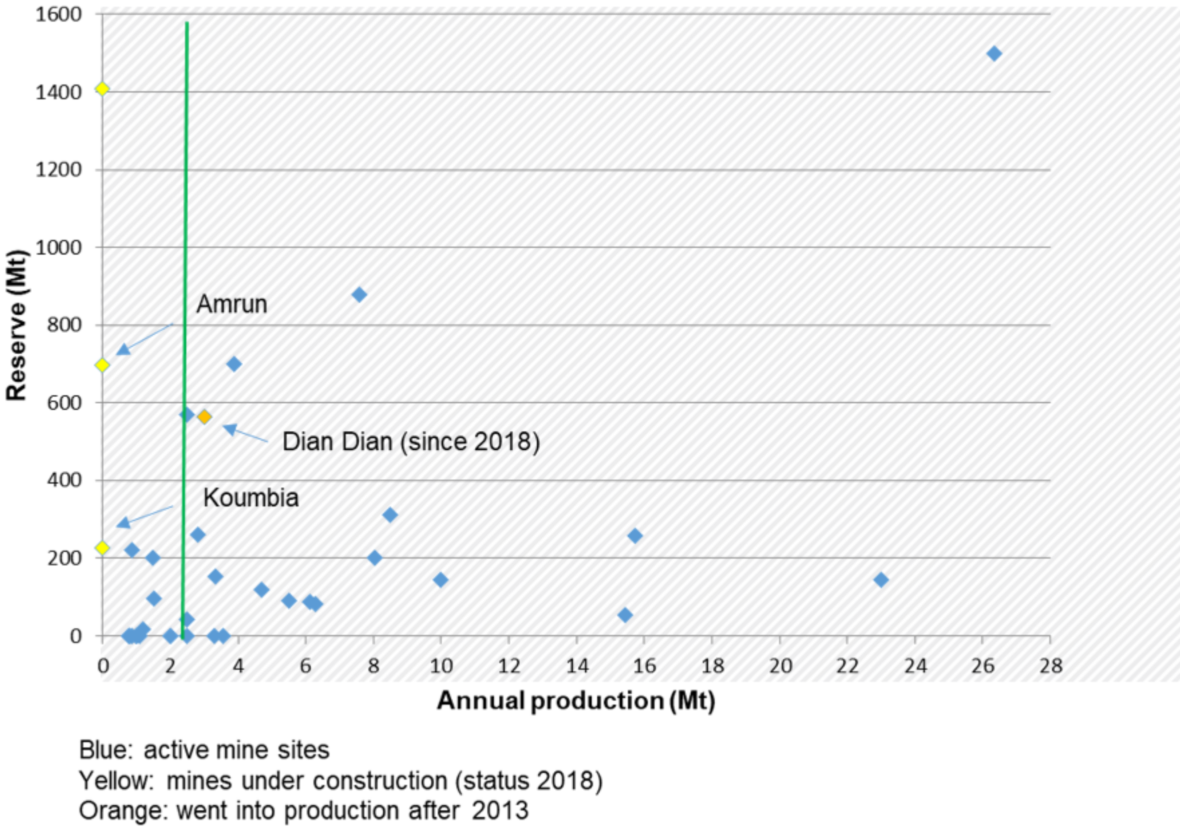
to Figure 6). As a rule of thumb, most mines with significant reserves are already included in these 92 mine sites (Figure 4: Bauxite - reserves vs. annual production of mine sites

to Figure 6). For iron only, another 2 mines are considered due to high reserves. Mine sites under construction (advanced mining projects – displayed as yellow squares in Figure 4: Bauxite - reserves vs. annual production of mine sites

to 6) are included in the list of 100 sites to be evaluated with 3 projects for iron (Serra Sul, Yeristovskoye, Marillana), 2 for bauxite (Amrum, Koumbia) and 1 for copper ore (Cobre Panamá).

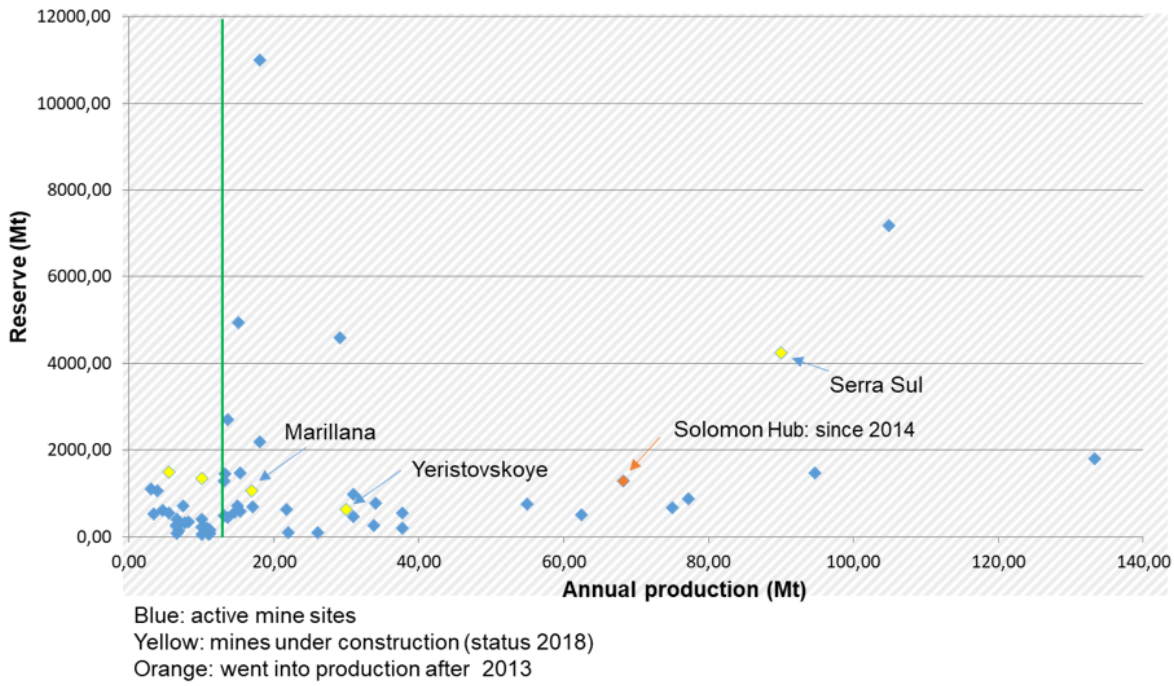
[17] Referring throughout the report to mining projects, (active) mines and mine complexes.

Figure 4: Bauxite - reserves vs. annual production of mine sites



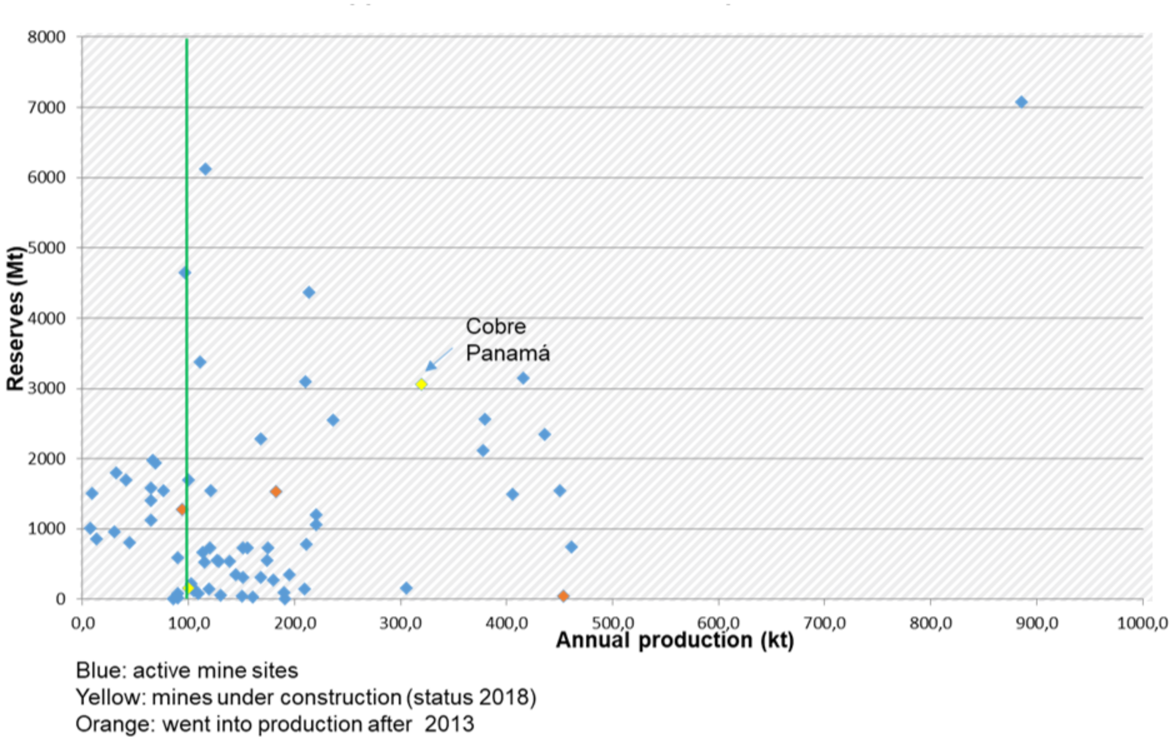
Source: own visualisation, Projekt-Consult, ifeu Insitut, Öko-Insitut

Figure 5: Iron ore - reserves vs. annual production of mine sites



Source: own visualisation, Projekt-Consult, ifeu Insitut, Öko-Insitut

Figure 6: Copper ore - reserves vs. annual production of mine sites



Source: own visualisation, Projekt-Consult, ifeu Insitut, Öko-Insitut

Summary of the results of the selection process:

- The selected sites each provide > 55 % coverage of global production as at 2013
- The selected 23 bauxite sites cover 29.51 % of the global reserve,
- the reserves of the 32 sites for iron ore add up to 32.07 % of the global reserves, while the
- 45 sites for copper ore cover a reserve 42.27 %.
- The list of the 100 sites can be found in Annex B.

2.4 Dealing with mine complexes

Within the 100 selected case studies there are a number of sites that consist of several individual pits. Depending on the example considered, these can vary greatly as to the number of pits and their spatial distance. Some mine complexes consist of two to three individual mines which are located in direct geographical proximity to each other. In extreme cases, however, more than 10 pits with maximum distances of up to 180 kilometres are combined into one complex.

Mine complexes can occur for all three considered raw materials. However, iron ore mining is particularly prone to large mining complexes due to the geology of the mined deposits. Iron ore is very often mined on Banded Iron Formation (BIFs). These are sedimentary rocks with a characteristic layer structure that consists of alternating silicate mineral layers and layers rich in iron (e.g. hematite). These deposits are typically several metres to several hundred metres thick and extend from a few kilometres to several hundred kilometres (Eriksson et al. 2004).

There are a number of reasons why the team has decided, in close consultation with the Contracting Authority, to jointly evaluate mine sites of one complex if the mines have the same owner:

- The individual mine sites on one deposit (e.g. BIF) usually have nearly identical geological settings, even though in extreme cases they are separated by distances of more than a hundred kilometers.
- The geologic setting also influences the application of technology and processing methods. It can therefore be assumed that the EHP evaluation result will be nearly identical for the individual pits of a complex.
- As a rule of thumb, the individual mines in a complex are mostly managed by the same operator. In the project this will lead to equal evaluation of all aspects of corporate governance.
- Furthermore, the operators of the mine complexes very rarely report the production for the individual mines; therefore, it is difficult to determine a reliable figure for each mine. Although production capacities per mine are sometimes provided, they only reflect the theoretical maximum production values.
- Last but not least, data availability plays an important role in the evaluation of mine complexes. These complexes are often much better known than the individual pits, with information for the entire complex being usually more readily available than for single pits.

Ultimately, there are only two significant differences between evaluating mine complexes or individual mines:

- Firstly, there are differences in the size of the deposits. If the mines are regarded individually, the deposit size becomes accordingly smaller; viewed as a complex, the reserves are always larger, resulting in a higher EHP. However, it can be argued that the deposit size of the mining complex better reflects reality.
- Secondly, the site-specific indicators for assessing the natural environment may be subject to different assessments. If a mine complex consists of several mines, one of which has a high EHP, the entire complex would be evaluated with the corresponding potential. Here, the polygons for each mine could possibly be displayed with their corresponding assessment, showing transparently each individual polygon's EHP.

In summary, many indicators suggest that a mine complex should be regarded as one unit, despite the sometimes large geographical distances. In particular, geological aspects, the business management summary of the operators in terms of a complex, higher public awareness of the complexes and therefore better data availability, speak for the joint consideration as a unit.

2.5 Final selection of mine sites for evaluation

The final selection of mine sites for the project is detailed in Table 3. Some mines, first considered individually, were attributed to a mining complex as defined in Section 2.4. for the project purposes. (e.g. Serra Sul, belonging to Carajas Northern System, as well as Pocos de Caldas in Brazil). The Germano Iron ore Mine in Brazil, belonging to the Mariana complex, is mined out and therefore not further considered. For copper, at some sites there is mining on oxides and sulphides with subsequent differing processing steps on-site. However, this has hardly any influence on the evaluation result (Escondida, Chuquicamata, Morenci, Kansanshi, Buenavista de Cobre). In total, three more mines are included and evaluated: Guelb el Rhein Iron Ore Mine (Mauretania), Mirai Bauxite Mine (Brazil) and Tilden Iron Ore Mine (USA).

Table 3: Final list of 100 mine sites evaluated in the project

Country	Site	Resource	Owner
Australia	Hamersley Iron Ore Mines	Iron ore	Rio Tinto
Brazil	Vale Northern System (Carajas) Iron Ore Mines	Iron ore	Vale
Australia	Chichester Range Iron Ore Mines	Iron ore	Fortescue Metals Group
Australia	Yandi Iron Ore Mine	Iron ore	BHP Billiton
Australia	Solomon Hub	Iron ore	Fortescue Metals Group
Australia	Mount Newman Iron Ore Mines	Iron ore	BHP
Australia	Robe River Iron Mines	Iron ore	Rio Tinto
Australia	Area C Iron Ore Mine	Iron ore	BHP
Brazil	Minas Centrais Iron Ore Complex	Iron ore	Vale
Brazil	Mariana Iron Ore Complex	Iron ore	Vale
Brazil	Itabira Iron Ore Complex	Iron ore	Vale
Australia	Hope Downs Iron Ore Mine	Iron ore	Rio Tinto (50%) / Hancock Prospecting (50%)
Brazil	Minas Itabirito Iron Ore Complex	Iron ore	Vale
South Africa	Sishen Iron Ore Mine	Iron ore	Anglo American
Russia	Lebedinsky Iron Ore Mine	Iron ore	Metalloinvest
Brazil	Paraopeba Iron Ore Complex	Iron ore	Vale
Brazil	Vargem Grande Iron Ore Complex	Iron ore	Vale

Country	Site	Resource	Owner
Mauretania	Guelb el Rhein Iron Ore Mine	Iron ore	Societé Nationale Industrielle et Minière (SNIM)/State of Mauritania
Canada	Mont Wright Iron Ore Mine	Iron ore	Arcelor Mittal
Russia	Mikhailovsky Iron Ore Mine	Iron ore	Metalloinvest
Sweden	Kiruna Iron Ore Mine	Iron ore	LKAB
Brazil	Casa de Pedra Iron Ore Mine	Iron ore	Companhia Siderúrgica Nacional (CSN)
Canada	Carol Iron Ore Mines	Iron ore	Rio Tinto
Russia	Stoylensky Iron Ore Mine	Iron ore	NLMK
Ukraine	ArcelorMittal Ukrainian Mines (Krivoi Rog Iron Ore Mine)	Iron ore	Arcelor Mittal
USA	Minntac Iron Ore Mine	Iron ore	US Steel
Ukraine	Inguletsky Iron Ore Mine	Iron ore	Smart N.V.
Iran	Gole Gohar Iron Ore Mine	Iron ore	State of Iran
Iran	Chogart Iron Ore Mine	Iron ore	State of Iran
USA	Tilden Iron ore Mine	Iron ore	Cliffs
Ukraine	Yeristovo Iron Ore Mine	Iron ore	Ferrexpo
Australia	Marillana Iron Ore Deposit	Iron ore	Brockman
Chile	Escondida Copper Mine	Copper ore	BHP
Peru	Antamina Copper/Zinc Mine	Copper ore	Glencore (33.75 %), BHP (33.75 %)

Country	Site	Resource	Owner
Peru	Las Bambas Copper Mine	Copper ore	MMG
Chile	El Teniente Copper Mine	Copper ore	CODELCO
Papua New Guinea	Grasberg/Ertsberg Copper/Gold Mine	Copper ore	Freeport
Chile	Collahuasi Copper Mine	Copper ore	Anglo American
Chile	Los Pelambres Copper Mine	Copper ore	Antofagasta
Chile	Radomiro Tomic Copper Mine	Copper ore	CODELCO
Chile	Los Bronces Copper Mine	Copper ore	Anglo American
Saudi Arabia	Al Ba'itha Bauxite Mine	Bauxite	Ma´aden (Saudi Arabian Mining Company)
Chile	Andina Copper Mine	Copper ore	CODELCO
Iran	Sar-Cheshmeh Copper Mine	Copper ore	IMIDRO
Chile	Chuquicamata Copper	Copper ore	CODELCO
Peru	Cerro Verde Copper Mine	Copper ore	SMM
USA	Bingham Canyon Copper Mine	Copper ore	Rio Tinto
USA	Morenci Copper Mine	Copper ore	Freeport-McMoRan
DR Congo	Tenke Fungurume Copper/Cobalt Mine	Copper ore	China Molybdenum
Poland	Rudna Copper Mine	Copper ore	KGHM
Zambia	Sentinel	Copper ore	First Quantum
Russia	Norilsk mining complex	Copper ore	Norilsk Nickel

Country	Site	Resource	Owner
Peru	Toromocho Copper Mine	Copper ore	State of Venezuela
Poland	Polkowice-Sieroszowice Copper Mine	Copper ore	KGHM
Chile	Esperanza (Antofagasta) Copper Mine	Copper ore	Antofagasta
Australia	Olympic Dam Copper/Gold Mine	Copper ore	BHP
Peru	Cuajone (SPCC) Copper Mine	Copper ore	Southern Copper
Chile	La Candelaria Copper/Gold Mine	Copper ore	Lundin Mining
DR Congo	Kamoto Copper/Cobalt Mines	Copper ore	Katanga Mining Limited (Glencore)
Chile	El Abra Copper Mine	Copper ore	51% Freeport-McMoran; 49% CODELCO
Chile	Spence Copper Mine	Copper ore	BHP
Zambia	Kansanshi Copper Mine	Copper ore	First Quantum Minerals
DR Congo	Mutanda Copper/Cobalt Mine	Copper ore	Glencore
Kazakhstan	Zhezkazgan Copper Mines	Copper ore	Kazakhmys JSC
Peru	Antapaccay Copper Mine	Copper ore	Glencore
Australia	Mount Isa Copper Mine	Copper ore	Glencore
Chile	Gabriela Mistral Copper Mine	Copper ore	CODELCO
Chile	Zaldivar Copper Mine	Copper ore	Antofagasta 50 %, Barrick Gold 50%

Country	Site	Resource	Owner
Mongolia	Erdenet Copper Mine	Copper ore	51% State of Mongolia, 49% Mongolian Copper Corporation LLC (100% subsidiary of Erdenet Corporation)
Mexico	La Caridad	Copper ore	First Quantum Minerals
Brazil	Sossego Copper Mine	Copper ore	Vale
Mexico	Buenavista del Cobre Mine	Copper ore	Grupo Mexico
Zambia	Lumwana Copper Mine	Copper ore	Barrick
Canada	Highland Valley Copper Mine	Copper ore	Teck
Peru	Toquepala (SPCC) Copper Mine	Copper ore	Grupo Mexico
Argentina	Alumbrera Gold/Copper Mine	Copper ore	Glencore
Panamá	Cobre Panamá Copper/Gold Mine	Copper ore	First Quantum
Australia	Weipa Bauxite Mine	Bauxite	Rio Tinto
Australia	Huntly Bauxite Mine	Bauxite	Alcoa Mining
Brazil	Trombetas Bauxite Mine	Bauxite	Vale
Guinea	Boke/Sangaredi Bauxite Mine	Bauxite	49 % Guinean Government, 51 % Halco Mining Inc. (Alcoa, Rio Tinto and Dadco Investments)
Australia	Willowdale Bauxite Mine	Bauxite	Alcoa
Australia	Boddington (Worsley) Bauxite Mine	Bauxite	BHP

Country	Site	Resource	Owner
Australia	Gove Bauxite Mine	Bauxite	Rio Tinto
Brazil	Paragominas Bauxite Mine	Bauxite	Norsk Hydro
India	Panchpatmali (Damanjodi) Bauxite Mine	Bauxite	NALCO (State of India)
China	Pingguo Bauxite Mine	Bauxite	Chinalco
Kazakhstan	Krasnooktyabrsk Bauxite Mine	Bauxite	Eurasian Resources Group
Jamaica	Discovery Bay Bauxite Mine	Bauxite	State of Jamaica
Brazil	Juruti Bauxite Mine	Bauxite	Alcoa-Alumina Limited
China	Xiaoyi Bauxite Mine	Bauxite	Chinalco
Guinea	Kindia Bauxite Mine	Bauxite	Compagnie des Bauxites de Kindia (subsidiary of RUSAL)
Jamaica	Jamalco Bauxite Mine	Bauxite	Jamalco
Guinea	Dian Dian Bauxite Deposit	Bauxite	RUSAL
Russia	Timana Bauxite Mine	Bauxite	RUSAL
Brazil	Mirai	Bauxite	Companhia Brasileira de Aluminio CBA (Votorantim)
Russia	North Urals Bauxite Mine	Bauxite	RUSAL
Venezuela	Los Pijiguaos Bauxite Mine	Bauxite	State of Venezuela
Australia	Amrun	Bauxite	Rio Tinto
Guinea	Koumbia Bauxite Deposit	Bauxite	AMC

3 Evaluation of mine sites

For each mine selected, the site-related evaluation of environmental hazard potentials is carried out and embedded in further contextual information. In the following section, firstly the factsheet structure is presented, giving an overview of the information gathered and of how the results are presented; secondly, the evaluation method itself is briefly introduced. The full and updated measurement instructions for the evaluation are attached in Annex D; thirdly, the evaluation results are presented.

3.1 Data collection

The structure of the factsheets shows what data is collected and how it is structured and presented. The structure of the factsheets was determined as one of the first steps in the project, and was slightly adapted in accordance with new developments in the course of the project. For example, the criterion “surface extension” was added in the course of the refinement of the procedure for determining the “natural environment” indicators. For this, the mines’ surface extension was determined based on the most current satellite imagery. The criterion “in operation since” was added when developing the refined approach to determine the deposit size, and also includes historical data as far as possible.

The aim is to develop a template that clearly presents the relevant information in order to a) give an overview of the site for orientation, b) facilitate and present the assessment according to the site-related OekoRess evaluation scheme and c) provide additional information on governance and CSR, so that it is easier to put the information from the evaluation in an overall context.

The main part of the factsheets is based on the site-related evaluation grid developed in the OekoRess I project. The 12 evaluation indicators refer to the three fields (or topics) geology, technology and site surroundings (Table 4 to Table 7).

Table 4: Factsheet template: General information

Indicator or criterion	Description and values
Name of mine	
Description of mining area	
Surface extension	
In operation since	
Operator	
Owner	
Closest town	
Province	
Country	

Indicator or criterion	Description and values
Longitude	
Latitude	
Altitude	
Main product and by-products	
On-site processing stages	
Annual production	
Proven reserves	
Probable reserves	

Table 5: Factsheet template: Site-related evaluation

Field	Indicator or criterion	Description and values	Explanation	Evaluation result	Data quality
Geology	Preconditions for acid mine drainage (AMD)				
	Paragenesis with heavy metals				
	Paragenesis with radioactive components				
	Deposit size				
	Ore grade				
Technology	Mine type				
	Use of auxiliary substances				
	Mining waste				
	Remediation measures				

Field	Indicator or criterion	Description and values	Explanation	Evaluation result	Data quality
Site (surroundings) Natural Environment	Accident hazard due to floods, earthquakes, storms, landslides				
	Water Stress Index (WSI) and desert areas				
	Protected areas and AZE sites				

Table 6: Factsheet template: context information - Governance

Category		
Governance Indicators	World Governance indicator (WGI) 1 -Voice and Accountability	
	WGI 3 - Government Effectiveness	
	WGI 5 - Rule of Law	
	EPI	
International Agreements	ILO (International Labour Organization) 176	
Legal framework	Area of Law: Environment	

Table 7: Factsheet template: context information - Corporate Social Responsibility (CSR)

Category	Indicator or field	Description
Voluntary Standards	Aluminium Stewardship Initiative (ASI): Is the mine-owning company a member?	
	Aluminium Stewardship Initiative (ASI): Is the mine certified?	
	International Council of Mining & Metals (ICMM): Is the mine-owning company a member?	
	Towards Sustainable Mining (TSM) Is the mine-owning company a member of the Mining Association of Canada (MAC)?	
	Towards Sustainable Mining (TSM) outside Canada: Are TSM standards implemented*?	
	Initiative for Responsible Mining Assurance (IRMA): Is the mine-owning company a member?	
	Initiative for Responsible Mining Assurance (IRMA): Is the mine certified?	
	The Copper Mark (CM): Is the mine-owning company a member of CM?	
	The Copper Mark (CM): Is the mine certified?	
	Responsible Mining Index (RMI): Has the mine been rated?	
	Responsible Mining Index Company indicator “Working conditions”	
	Responsible Mining Index Company indicator “Environmental sustainability”	

Category	Indicator or field	Description
	Responsible Steel (RS): Is the mine owner a member of the RS?	
	Responsible Steel (RS): Is the mine certified?	
	Australian Steel Stewardship Forum (ASSF): Is the mine owner a member of the ASSF?	
	Australian Steel Stewardship Forum: Is the mine certified?	
ISO and CSR reporting	ISO 14001 (ISO 14004): Is the mine ISO 14001 certified?	
	CSR-directive 2014/95/EU: Does the mine-owning company have its headquarters in an EU country?	
	OECD (Organisation for Economic Co-operation and Development) Guidelines: Does the company have its headquarters in a signatory state?	
	ISO 26000: Does the mine implement ISO 26000?*	
Financing Standards	IFC Performance Standards: Is the mine financed to a major extent by the IFC?	
	Equator Principles (EP): Is the mine financed to a major extent by a bank adherent to the EP?	

*by company's own account.

The collected and edited information had to fulfil the UBAs requirements for online publication and at the same time allow for a smooth data exchange between the project partners and the various experts working on the different factsheets during the development and the 2-step validation process (process described in Section 3.2). The factsheets were therefore first created in MS Word for better data exchange and to allow for commenting on specific mine sites, and later transferred to an Access database.

3.1.1 State governance

Information on state governance provided in the factsheets consists of information on generally accepted governance indicators and international agreements, as well as free texts on the topic of laws dealing with issues related to a) mining and environment, and b) occupational health and safety.

In the first step, the Fraser Policy Perception Index was considered and then disregarded because of the subjectivity of the indicator, which is based on surveys of investors, as to how certain political factors in a country affect investment decisions. Furthermore, the Fraser Policy Perception Index only covers 54 countries (cf. OekoRess II report[18]). The EITI membership was included later in the project as the EITI had recently started to cover environmental aspects as well.

To ensure the consistency of the free texts on the areas of law, the team developed the following guidelines:

Guidelines for Areas of Law: Environment

1. Is environmental law implemented in the country?
2. Are there special rules for mining?
3. Which authorities are familiar with approving the plan and monitoring the project?
4. Are there further relevant regulations and authorities?
5. Is the instrument of environmental impact assessment (EIA) implemented?
6. Are public consultations carried out?
7. Are there requirements for mine closure and rehabilitation?
8. Are there any relevant particularities?

Guidelines for Areas of Law: Occupational Health and Safety (OHS)

1. Is a set of rules on occupational health and safety implemented in the country?
2. Which authority inspects the compliance with occupational health and safety regulations?
3. Are there special regulations for mining?
4. Are there requirements for employers and employees?
5. How are violations handled?

3.1.2 Corporate Social Responsibility

Information on CSR in the factsheets consists of naming the participation of the main owning company in relevant voluntary standards, reporting standards (e.g. ISO 26000) and financing standards (e.g. IFC Performance Standards). Most indicators for the state governance can be researched reasonably quickly. However, for the financing standards, little information is available.

The uncommented consideration of voluntary standards and initiatives has led to criticism in the Advisory Board. Fears were expressed that the presentation of mine owners' memberships is too uncritical without an evaluation of the standard's performance. The current presentation, according to the criticism, may lead to an overly positive presentation of the mine owner's efforts. This could contribute to greenwashing and reduce the momentum towards increased efforts for environmental protection.

[18] https://www.umweltbundesamt.de/publikationen/comparative-analysis-of-case-studies-for-mining

However, an evaluation of transparency and credibility of standards is beyond the scope of this project. It is recommended, however, to obtain further information on the standards in question.

Several projects have been carried out in Germany in recent years – for example, the UmSoRess[19] project – which discuss the performance and credibility of standards. To meet this demand, a disclaimer is inserted in the factsheets stating that the performance, credibility and transparency of the standards have not been evaluated, and that the inclusion of a standard does not reflect a positive or negative judgement on the part of the authors or UBA.

3.2 Validation process

The factsheets are reviewed by mining experts from RMG Consulting. The review includes quality checks on data and sources, the plausibility of the conclusions drawn based on the measurement instructions, as well as recommendations for possible optimisations of the evaluation method. The proposals for further optimisation of the measurement instructions in Chapter 3.3.2 are partly based on this input and subsequent discussions. The feedback on the factsheets was largely taken into account.

In a second step, the mine owners are contacted and the corresponding factsheets sent to them for review. To this end, contact information was collected from commonly available sources (e.g. company websites). Relevant associations (ICMM, Aluminium Stewardship Initiative and Responsible Steel) have been contacted to request support with contacting their members. A total of 48 companies were contacted, of which 9 responded. Ultimately, there was feedback on a total of 21 mine sites (Table 8). In this context, it should be noted that some companies have multiple mine sites that were assessed as part of the project. The companies' feedback included general comments, criticisms and questions about the methodology applied, but also further relevant site-specific information were provided on the basis of which the EHP assessments could be adjusted in some cases. The EHP assessments was only modified if the companies referred to publicly available data, as otherwise the assessment would not be transparently comprehensible to third parties. Internal documents that were only available to the project team were consequently not taken into account. The communication often required several feedback loops to account for questions and receive further published data.

Table 8: Response from mine-owning companies in validation step 2 to date

Mine-owning company	FS no.	Mine name	Commodity	Country
Alcoa	79	Huntly Bauxite Mine	bauxite	Australia
Alcoa	82	Willowdale Bauxite Mine	bauxite	Australia
Alcoa	90	Juruti Bauxite Mine	bauxite	Brazil
Anglo American	14	Sishen Iron Ore Mine	iron ore	South Africa
Anglo American / Glencore	38	Collahuasi Copper Mine	copper ore	Chile

[19] https://www.umweltbundesamt.de/umweltfragen-umsoress

Mine-owning company	FS no.	Mine name	Commodity	Country
Anglo American	41	Los Bronces Copper Mine	copper ore	Chile
China Molybdenum	49	Tenke Fungurume Copper/Cobalt (SX-EW) Mine	copper ore	DR Congo
Ferrexpo	31	Yeristovo Iron Ore Mine	iron ore	Ukraine
Fortescue Metals Group	3	Chichester Range Iron Ore Mines	iron ore	Australia
Fortescue Metals Group	5	Solomon Hub	iron ore	Australia
Glencore / Katanga Mining Ltd.	59	Kamoto Copper/Cobalt Mines	copper ore	DR Congo
Glencore	63	Mutanda Copper/Cobalt Mine	copper ore	DR Congo
Glencore	65	Antapaccay Copper Mine	copper ore	Peru
Glencore	66	Mount Isa Copper Mine	copper ore	Australia
Glencore	76	Alumbrera Gold/Copper Mine	copper ore	Argentina
RUSAL / Compagnie des Bauxites de Kindia	92	Kindia Bauxite Mine	bauxite	Guinea
RUSAL	94	Dian Dian Bauxite Deposit	bauxite	Guinea
RUSAL	95	Timana Bauxite Mine	bauxite	Russia
RUSAL	97	North Urals Bauxite Mine	bauxite	Russia
New Day Aluminum LLC / State of Jamaica	89	Discovery Bay Bauxite Mine	bauxite	Jamaica
US Steel	26	Minntac Iron Ore Mine	iron ore	USA

3.3 Environmental Hazard Potentials

3.3.1 Evaluation procedure

The evaluation of environmental hazard potentials in the site-related OekoRess method was developed with a view to facilitating an easy and resource-efficient initial assessment for identifying potential and likely "environmental hotspots". Using such an assessment, interested stakeholders with no background in mining, geology or environmental sciences, e.g. representatives from government authorities or civil society, can identify relevant topics to analyse further. It should be noted, however, that such an initial assessment of potential hazards is no substitute for an in-depth environmental impact assessment.

The evaluation scheme presented in Table 3.1 of Annex D was developed within project OekoRess I, and can be used for such an assessment. It is essentially based on indicators, each of which are assigned to an environmental goal (e.g. avoiding pollution risks) and a level of consideration. This double assignment to goals and consideration levels is designed to ensure easy manageability. The level of consideration, in particular, should facilitate the type of data collection by progressing from the general to the specific (Geology level – Technology level – Site (surroundings) level). Each indicator is classified as high, middle or low EHP, according to the simple traffic light rating system. The site-related evaluation system is directed at mine sites and differs from the raw material-related OekoRess evaluation scheme. The two approaches may have similarities but different goals, different use cases, and thus relevant discrepancies. For more information on the raw material-related OekoRess scheme, the reader can refer to the publication of Dehoust et al. 2017[20] and Dehoust et al. 2020 [21].

The evaluation results make up the main part of the factsheets based on the site-related evaluation grid. The evaluation considers 12 indicators which are assigned to the three levels Geology, Technology and Site (surroundings), pointing to specific Environmental Hazard Potentials (EHPs):

a) Geology level: the likelihood of radioactive contamination, paragenesis with heavy metals and potential for Acid Mine Drainage (AMD) are investigated (indicators 1-3 in the field "raw material-specific"), as well as deposit size and ore grade (indicators 4 and 5 in the field "deposit-specific").
b) Technology level: the mine type, the use of auxiliary substances, the mine waste and rehabilitation measures are assessed (indicators 6-9). E. g. open-pit operations disturb larger surface areas than underground mines.
c) Site-surroundings level: The EHPs of this level are assessed by indicators 10-12, looking at accident hazards due to floods, earthquakes, storms, landslides, at the Water Stress Index (WSI) and desert areas, and finally, but importantly, protected areas and Alliance for Zero Extinction (AZE) sites.

The evaluation scheme is originally based on the experience gained while working on 40 case studies within OekoRess I, in combination with the authors' expertise on evaluation issues. It is described in full in the 2nd edition of the measurement instructions in Annex D. The evaluation considers mine site-specific data from publicly available sources. In the factsheets, all sources used are provided in a list of references. Information based on hearsay is not taken into account.

[20] https://www.umweltbundesamt.de/publikationen/discussion-of-the-environmental-limits-of-primary

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

However, it is not always possible to find publicly available data on all indicators. In such cases, the measurement instructions derive "general rules" from scientific work combined with expert knowledge.

Of course, specific knowledge about the mine site is preferable to this general approach. In order to remain transparent and not suggest false reliability, the rules stipulate that the data quality is communicated along with the result (Table, 3.1 in Annex D). Nevertheless, reliable indications of the EHPs can be drawn from the general rules. In the factsheets, the data quality and the evaluation result are complemented by a short description of the database for the evaluation, and a justification of the evaluation results.

3.3.2 Evaluation results

This chapter discusses the evaluation results and problems encountered. The mines are not compared with each other. Comparison is not the aim of the evaluation, and could quickly give the impression that some mines are worse or better for the environment than others. However, such a comparison cannot be deduced from the evaluation results, as neither the management nor the technical solutions at a mine are evaluated. Also, no in-depth Environmental Impact Assessment (EIA) was carried out. Thus, no statement can be made as to a mine's performance, or whether the mine is adequately designed or managed with regard to the EHPs.

The bar charts detailing evaluation results for all 12 indicators in Figure 1 (bauxite), Figure 2 (copper ore) and Figure 3 (iron ore) give a clear idea of the distribution of the results between high, medium and low EHP for each indicator.

For Bauxite, gaps in the evaluation of EHPs in the bar chart in Figure 7and the corresponding matrices in Annex B.1 show where evaluation was not possible due to a lack of data (e.g. Huntly, May Pen) or several indicators (Xiaoyi), which reflects the much more difficult search for data in comparison to iron ore and copper mines. For the latter raw materials, finding relevant data was not always possible for each indicator. However, an evaluation could be carried out in most cases using general rules provided by the measurement instructions. This procedure shows how robust the evaluation system is – recognising the generalisation and simplification of the realities at the sites. The search for data depended to a great extent on regional differences and was especially difficult for Chinese mines. This might be an effect of the language barrier even though the Project Team has done its best to overcome this hurdle by making use of colleagues with Chinese language skills to conduct desktop research.

As expected, none of the bauxite mines indicate an elevated **precondition for acid mine drainage**, while most copper mines show a high EHP. Raw materials are connected to certain types of deposits and mineralisations. Variations occur to a limited extent. The reader can get a very good idea of this based on the table for Cissarz (1965) in the measurement instructions in Annex D. This table shows the geochemical distribution of the elements and the most important minerals and deposits.

In discussions with experts (e.g. from BGR) throughout the course of the project, the concern was voiced that some raw materials will always show a certain outcome for specific indicators, especially those in the field **"raw material-specific"** of the Geology level. For example, the concern is that copper will always be assigned with a high EHP for the precondition for AMD. However, the results show that this is not the case, and that the publication of concrete results, for example from tests as described in the updated measurement instructions, can lead to a lower EHP result. In many cases, general rules had to be applied due to a lack of data.

With improved data, i.e. when mine operators make more information about their mines publicly available, the results could possibly improve and the bar charts would show greater variability. Data on thorium and uranium in particular is rarely published (**paragenesis with radioactive components**). It is possible that at a mine that does not publish such data, there are simply no anomalies and therefore no reports are made.

In such cases, more general rules are applied (see measurement instructions in Annex D), which tend to assume higher EHPs according to the precautionary principle. Increased transparency and publication of data could therefore have a positive impact on the results.

The first thing that can be seen with regard to **deposit size** in Figure 7 is that despite the fact that large mines are evaluated in this project, the EHP for deposit size for one mine is low, and therefore the deposit size supposedly small. The mine in question is Xiaoyi mine in China (cf. Annex C.1). For this mine, it was not possible to estimate previously excavated material, as was done for other sites, to estimate the total excavated material to date.

Furthermore, reserve numbers are sometimes lowered artificially. A solution might be to use resources instead, but there is no information available that the evaluation system could be used to determine class boundaries according to a simple traffic light rating system (cf. Section 3.2). This is one example of how data quality and availability must always be considered as well. As the new class boundaries for bauxite were developed during the project, those cases for which the evaluation results differ have been adapted according to the class boundaries based on Meyer (2004). Following the new classification based on the data from Meyer (2004), the evaluation results for bauxite mines include two more “medium EHP” cases – Huntly and North Urals – in addition to the Pingguo and Juruti mines. As the data from Meyer was obtained late in the project, after the factsheets and evaluation had already been completed, the evaluations of the deposit size in Figure 7 and Annex C.1, as well as the factsheets themselves, are those based on Petrov’s class division as described in the 1st edition of the measurement instructions.

The most interesting feature of the **mine type** is that there is an underground bauxite mine located in Russia (Nothern Urals Bauxite Mine). Bauxite mining is mostly done on weathering layers where the rock bond is loosened to a high degree and the EHP is therefore considered equal to unconsolidated sediments. However, the 1st edition of the measurement instructions did not explicitly state that such strongly weathered horizons should be rated with a high EHP. Accordingly, the description is widened to “strongly weathered horizons”.

One further point for discussion here: there are two mines, Krasnooktyabrsk Bauxite Mine (No. 88) and Xiaoyi Bauxite Mine (91), which have been assigned a medium EHP. Krasnooktyabrsk Bauxite Mine is an open-pit mine on volcanic layers interlaced with carbonate rock covered by a 40 m sediment layer of overburden. In Xiaoyi, the only information obtained is that this is an open-pit mine, but no information on the rock type is provided. The poor data quality led to discussions on whether to apply the evaluation at all, given that it remains unclear if the EHP should be evaluated as middle or high. It could be argued that the majority of bauxite mines exhibit a high EHP for the indicator mine type, and that in the event of doubt a more conservative approach should be taken. However, it does not seem justifiable to assume that the rock consists of unconsolidated material based on results from other non-regional case studies, as is also demonstrated by Krasnooktyabrsk. The evaluation result is therefore based on the verifiable information of open-pit mining with a medium EHP.

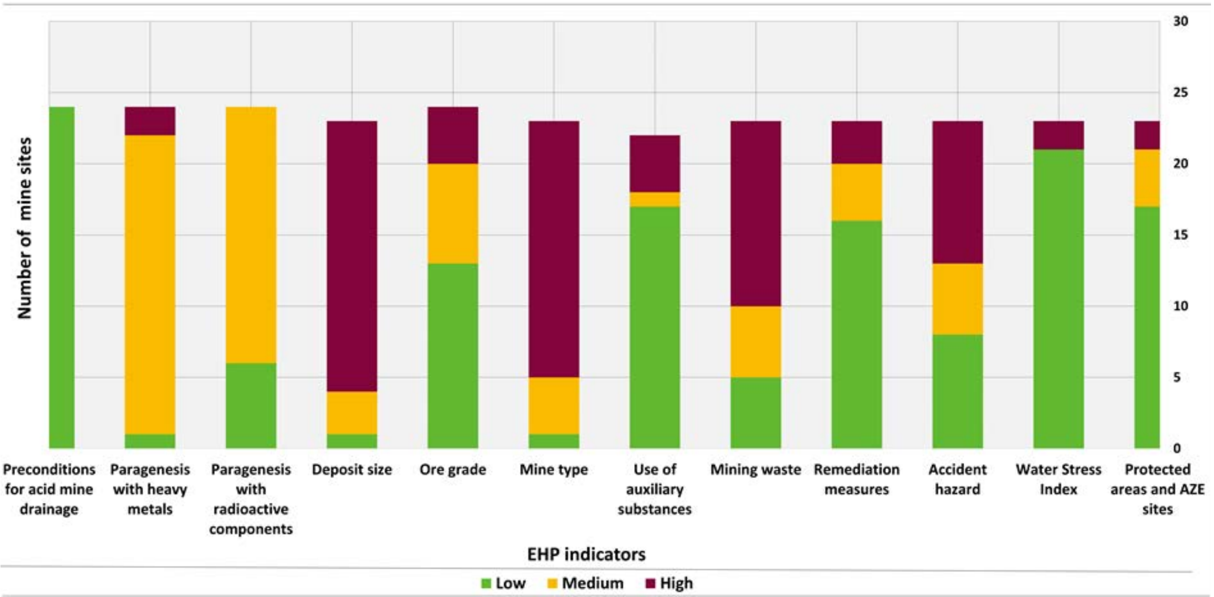
Even if different methods are used on-site for processing in copper mining, the evaluation result for the indicator **use auxiliary substances** is always high for copper mine sites. Iron ore mining shows a much more varied picture, and bauxite mining is most often even assigned a low EHP. Reviewing these results, it should be kept in mind that the site-related EHP evaluation only reviews the processing steps on-site and not those that may be carried out elsewhere.

Given that copper ore has a significantly lower ore grade, the ore is usually processed on-site, resulting in high-grade copper ore concentrate or even pure copper that can then be transported. Bauxite and iron ore, however, may be transported first and then processed further elsewhere, which is then no longer taken into account in the evaluation. The result should therefore not be understood as an overall assessment of the processing steps of mining mineral raw materials.

The mining waste indicator considers how and in what quantities mining waste is stored. The chemical and physical properties of mining waste are of course highly relevant to environmental impact, in addition to the safe storage, use and quantity of the material. In the context of the present assessment, however, such an in-depth assessment was not possible. Also, such information is rarely to be found, which was also confirmed during the preparation of the factsheets. As must be expected for large and very large mines in the confines of the OekoRess evaluation system, the (quantitative) **mining waste** indicator shows a high percentage of high-evaluation results in all raw materials. Bauxite shows the most medium to low results, which might be an effect of strip mining, where material is filled into the already exploited strips (back-filling). Very often, remediation measures such as reforestation are carried out on these strips, and the previous extent of the mine is less obvious. Mining waste from iron ore mining is also sometimes used for backfilling, even though also storage in TFSs is widely used depending on the type of mining waste. Copper ore processing on site most often include processes like flotation or SX-EW, producing tailings that have to be stored accordingly in TFSs.

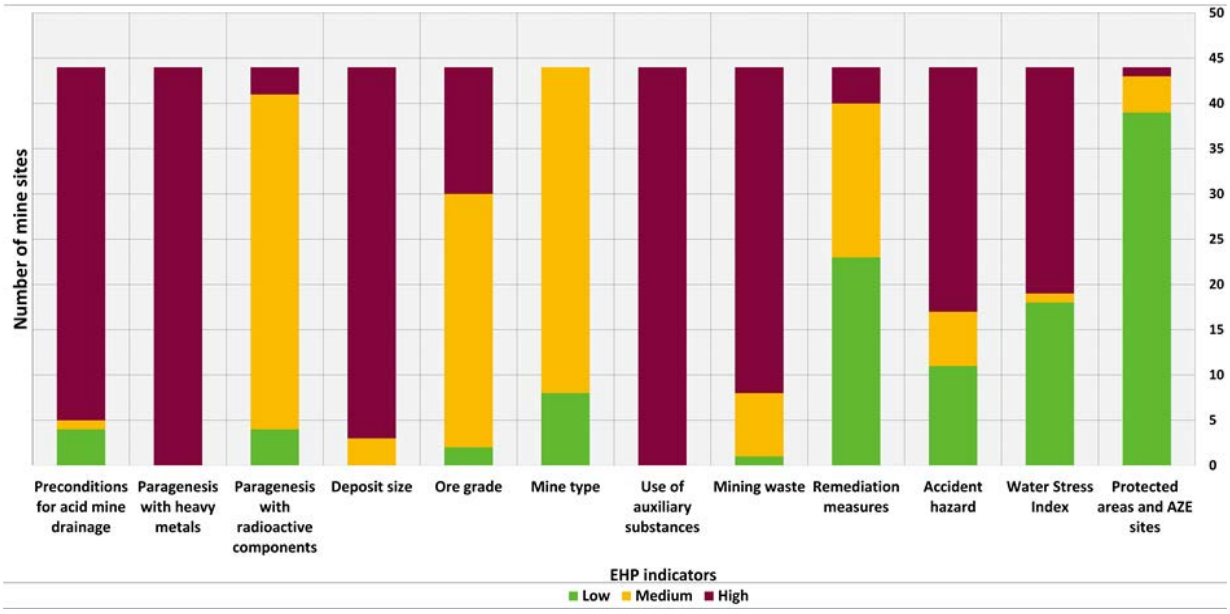
The variation of the **site-surrounding indicators** is quite high, as expected. Nonetheless, it becomes obvious that bauxite mines are rarely situated in areas with high water stress while more than 50% of copper mines are located in areas with high water stress or desert areas. About two-thirds of the bauxite mines are situated in areas with medium to high natural accident hazards, while most iron ore mines are located in areas with medium to high natural accident hazard potential. Even with the incorporation of buffer zones, only a small percentage of the 100 mines show a high EHP with regard to potential effects on protected areas and AZE sites as a sensitivity analysis (cf. sensitivity analysis in Section 3.3.1).

Figure 7: Bar chart of EHP evaluation results for bauxite



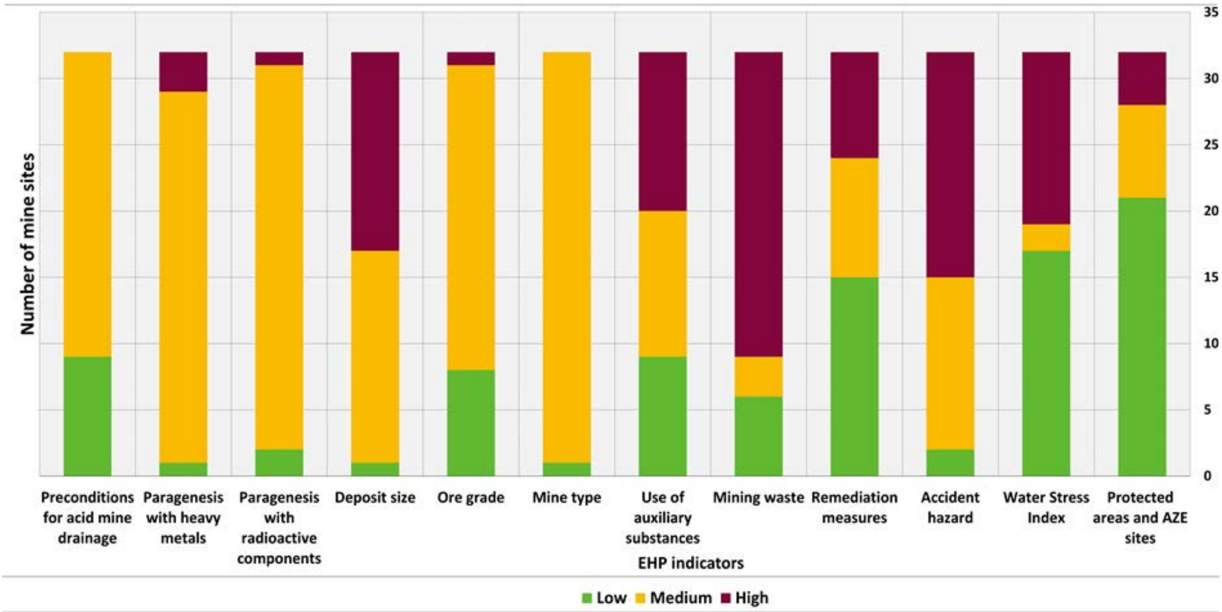
Source: own visualisation, Projekt-Consult, ifeu Insitut, Öko-Insitut.

Figure 8: Bar chart of EHP evaluation results for copper ore



Source: own visualisation, Projekt-Consult, ifeu Insitut, Öko-Insitut

Figure 9: Bar chart of EHP evaluation results for iron ore



Source: own visualisation, Projekt-Consult, ifeu Insitut, Öko-Insitut

3.3.3 Sensitivity analysis: Spatial extension buffer of 10 km and 25 km

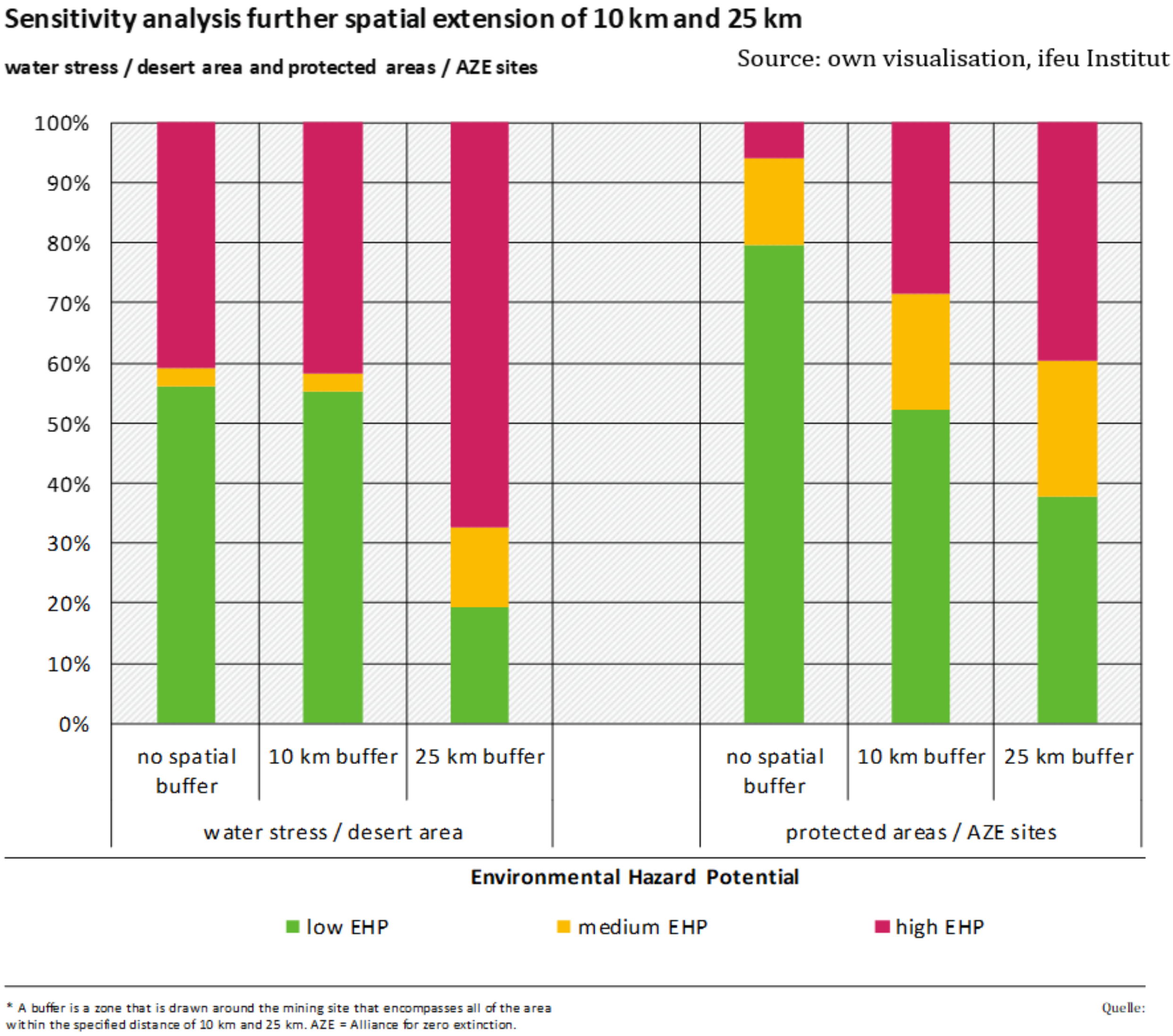
For all indicators in the field "natural environment", a spatial analysis is conducted. In order to address the proximity of high-rated EHP areas to mining sites, a sensitivity analysis for the indicators "water stress index and desert areas" and "protected areas and AZE sites" is carried out. For these indicators, the mine has an influence on the environment beyond its own limits. The other natural environment indicators in the field "natural environment" address the natural hazard of accident events at the mine site, which is why a proximity analysis of the factors determining the hazard is not necessary, although accidents can cause damage far beyond the limits of the mine site.

The buffering tool is a common approach in GIS proximity analysis that can be used to determine which features are within a critical spatial distance from another feature. A defined area is drawn around the polygon feature and dissolved into a new polygon. In the next step, a new spatial analysis is carried out to detect intersections between the buffered polygons and the EHP indicator maps.

The dataset of mine sites is globally distributed. This is an important aspect for spatial analysis, where accurate areas and distances are necessary. The dataset is available in the WGS 84 coordinate reference system. If specific spatial analysis with metric area and distance calculations was necessary, the dataset was usually transferred to a Pseudomercator (or Web-Mercator, EPSG: 3857) projection. However, the buffering tool does not deliver satisfying results in terms of accuracy. This is due to the fact that distortions in Pseudomercator projections occur in higher latitudes (>45°). If the goal is absolute accuracy, a regional projection reference system is necessary (e.g. single UTM zones). This would require numerous reprojections of the mine sites since they are globally distributed.

At this stage of the sensitivity analysis, absolute accuracy is not necessary but distortions should be within limits. A good compromise is a reprojection of the mine sites into two projection reference systems (northern and southern hemisphere). Many equidistant projections have been tested. "North America Equidistant Conic" (ESPG: 102010) for the northern hemisphere and "South America Equidistant Conic" (ESPG: 102032) for southern hemisphere delivered the best results. Distortions range from 2 % to 4 %, and only in extreme cases 8 % in the horizontal extent (mines located >65° latitude).

Figure 10: Sensitivity of EHPs: changes in results by proximity analysis



Source: own visualisation, ifeu Institut

Two characteristics of proximity analysis were selected: 10 km and 25 km. Figure 10 summarises the results of the analysis for all evaluated mine sites. The indicators "water stress" and "desert area" remain stable for the 10 km analysis. A large shift can be observed for the 25 km buffer. The number of mine sites with low EHP is reduced to under 20 % (originally >50 %). Cases with a high EHP change from around 40 % to nearly 70 %. The group of cases with medium EHP increases in the 25 km buffer analysis, but remains the smallest group (about 14 %).

The proximity analysis for the indicators "protected areas" and "AZE sites" reflects a continuous increase along the 10 km and 25 km buffer. The number of mines with low EHP is reduced from nearly 80 % to under 40 % (25 km buffer). Cases with a high EHP change from around 5 % to nearly 30 % (10 km buffer) and nearly 40 % (25 km buffer). The cases with medium EHP increase from 15 % to around 20 % (10 km and 25 km buffer).

The reason for the different result patterns for the two indicators is the different spatial distribution and granularity of the EHP result maps. The map of the indicator "water stress and desert area" has rather large EHP areas, which are locally concentrated along the tropical/subtropical dry zones.

Furthermore, the majority of the areas are classified as high and low EHP. The map of the indicator "protected areas and AZE sites" consists of 250,000 single features and is globally distributed with high granularity (depending on the country). This characteristic leads to a more continuous increase in EHP distribution by adding different buffers.

The aspect of proximity of a mine site to potential areas with high EHP should be considered. This applies in particular to protected areas since a relevant change in results can be observed by considering even a rather small proximity of 10 km.

3.3.4 Findings from the application of the method

The OekoRess I project was mainly concerned with the following objectives: i) the development of the site-related evaluation method based on the research and preparation of 40 case studies (Dehoust et al. 2017a), and ii) the development of the raw material-related evaluation method (Dehoust et al. 2017b).

The site-related evaluation method was continuously developed during the course of the OekoRess I project using the experiences from the evaluation of the case studies. In particular, in the Geology and Technology levels, comprehensive measuring instructions and evaluation tools were compiled, and in some cases were only derived and developed within the scope of the project, e.g. regarding the deposit size, which enabled an evaluation even where the data situation was poor. In regard to the 'Ore grade' indicator, an evaluation tool was only available for the raw materials gold, copper, zinc, lead, nickel and diamond. As a general principle, the informative value of the evaluation increases with the quality of the available data at the specific site.

For the 'Natural environment' and 'Social environment' indicators, internet-based maps were used and analysis tools developed which, if the precise location and dimensions of the sites are available, enable a clear allocation.

It was evident that specialist knowledge in the fields of geology and mining is very helpful for the description and evaluation of mine sites, but is not an absolute prerequisite.

If at all possible, the description and evaluation of the sites should be done by the same party, and the description should be based as precisely as possible on the evaluation scheme. Through transparent documentation of the procedure, in particular in relation to the description of the data quality, combined description and evaluation reports constitute the best basis for an evaluation by third parties.

In the OekoRess III project, this previously established and refined site-related evaluation method was applied to a total of 100 mining operations extracting iron, copper and aluminium (bauxite) ores. In the framework of this project phase, the measuring instructions were also revised and updated again based on the findings from the application of the method. In this context, the evaluation tool for the 'Ore grade' indicator was also expanded once again to include the elements iron and aluminium, as well as tin, manganese and platinum group metals (PGM). Difficulties in assessing the individual indicators due to sometimes unclear specification of the EHP assessment categories or insufficient data were further addressed, and the measurement instructions were revised accordingly.

Not all of the suggested changes could be incorporated in the measurement instructions, however, as this would have exceeded the available resources of this project. These suggestions for future optimisation of the method are summarised in the following chapters. Further research work is needed to adequately incorporate them into the method.

In the course of gathering information on 100 mining operations, it became clear once again that access to publicly available and unbiased data is often limited. This remains a major design limitation of the method. Mining companies usually provide some basic information in their annual corporate reports, environmental management reports or on their homepages, but it has proven very difficult or even impossible to validate the data as further public information is often missing. Some companies publish their EIA reports, which are usually prepared by specialised consultancies and are therefore considered more independent and thus more trustworthy.

Depending on the location and history of a certain mining region, detailed information mainly relating to the mineral composition of a certain deposit and its ore grades can be derived from geo-scientific publications. However, as geological properties are likely to change spatially, e.g. with increasing depth an outer oxidized ore zone turns into a sulphidic inner zone, this information may already be outdated, especially if the data was published a long time ago.

The owners or operators of the respective mines were given the opportunity to comment on the EHP assessment results and to provide additional, up-to-date information about the conditions at their mining operations. Only a few companies responded to the project's request. However, due to the design of this method, adjustments to an EHP assessment are only permissible if they are based on publicly available data, in order to ensure general transparency and traceability.

Where available, other sources of information, e.g. local newspapers and reports from civil society organisations, were also evaluated, but these also have a tendency to be biased in one way or another.

The mining companies predominantly provide information in English, and depending on the location of the company's headquarters, also sometimes in French and Spanish. This also pertains to Chinese companies. However, searching for additional background/secondary information on Chinese mining operations and companies posed particular challenges for the authors due to language barriers. Similar experiences were had with some Russian mines.

Accessibility proved to be an issue in some cases. Sometimes information was publicly available in theory, but could not be accessed due to regional restrictions of the authorities (geo-blocking).

Overall, some of the indicators are easier to assess because information is published more frequently, while others must often be assessed based on information in the measuring instructions. In particular, the indicator "paragenesis with radioactive components" presented a challenge because in many cases no information was available.

As a broad generalisation, large western mining companies provide sufficient information in annual, sustainability and technical reports to enable a satisfactory assessment of the EHP of the mine.

A reoccurring difficulty is the correct identification of individual mine sites on satellite or aerial images. In particular, regions with a lot of mining activity and many pits complicate the differentiation of specific mines. Moreover, infrastructure as well plants and waste storage facilities often cannot be clearly attributed to a specific operation when many companies are operating close to each other. More transparency in this regard would be helpful: mining companies and authorities could provide better access to GIS data or information on mining locations. For applications of the site-related evaluation, users are therefore strongly recommended to follow the rules for the digitalisation of mining sites with satellite data, which are detailed in Section 3.3 “The site (surrounding) level” of the measurement instructions in Annex D.

4 Further development and recommendations for the site-related OekoRess evaluation method

Particular attention was paid to options for optimising the measurement instructions. Recommendations for optimisations are directly integrated into the measurement instructions (Annex D). Special attention was given to those aspects of the assessment matrix that could not be fully implemented within the framework of the OekoRess I project. Recommendations for further research are made if the subject of the recommendation goes beyond the scope of the project, with the specific aim of expanding and improving the database and research results on which the measurement instructions are based.

4.1 General adaptations of the measurement instructions

The introductory text of the measurement instructions has been updated. In the measurement instructions, the objectives were sharpened by introducing the targeted potential environmental impact for which the indicators are intended. These environmental goals were defined during the development of the evaluation system and listed in the tabular overview of the indicators and their systemic classification (Annex E). However, the goals were not considered further in the 1st edition of the measurement instructions. The current insertion is intended to give the reader a better overview of the reasons why the respective indicator has been taken into account in the system.

The evaluation system gives interested stakeholders a quick overview of potentials for environmental hazards. Based on this information further analyses can be carried out that address indicators with, for example, high EHP and thus enable users to focus on relevant aspects. The understanding and proper use of technical terminology is very important, therefore the project team has developed a glossary (Annex A) that will also be available in the online presentation of the results. Some of the indicators have been renamed to better reflect the content of the respective indicator. These indicators are:

Table 9: Renaming of indicators

New indicator name	Old indicator name	Justification
Ore grade	Specific ore grade	Specific ore grade is not a generally accepted term and has been adapted accordingly. Primarily, information on the ore grade of the proven reserve is used where available (cf. Section 3.1.3 of the measurement guidance in Annex D).
Mine type	Mining method	The evaluation system differentiates between three basic mine types but not between the large variety of mining methods that exist. Hence, the new term is more accurate.
Use of auxiliary substances	Extraction and processing method	Specification of the indicator name: During extraction and processing, differentiation is only based on the use of excipients or toxic auxiliaries. Other differences are not considered.
Mining waste	Mining waste management	The evaluation system aims to evaluate the size and nature of existing waste heaps, tailings etc., but not their management as such.

4.2 Geology

4.2.1 Preconditions for acid mine drainage (AMD)

There are measurement methods such as Acid Base Accounting, ABA, and Net Neutralizing Potential, or NNP Analyses, for measuring an acid formation potential. However, these methods are not completely comparable, and thus far a generally valid definition of class boundaries (low-medium-high) for the different methods is not feasible. Depending on the availability of information and the prior training of the user, these methods can be used to evaluate the potential for mine acid drainage. This information has been added to the measurement instructions. The ore itself may not be sulfidic but rather associated in the deposit with sulfidic minerals, for example oxidic weathering horizons over sulphidic ore bodies. A special case that shows that interpreting the results from such analysing methods requires sufficient background knowledge is the presence of carbonates, which can have a neutralising effect but, under certain circumstances, also add to the AMD.

4.2.2 Paragenesis with heavy metals

For this indicator no changes were made, apart from improving the goal definition.

4.2.3 Paragenesis with radioactive components

The first edition of the measurement instructions for the indicator paragenesis with radioactive components was ambiguous in that it did not specify when to use the general rule to assess the indicator with a medium EHP if no specific data is available, and when to use the results for Chinese deposits in Table 3-3. As an example, copper is assessed with a medium EHP following the general rule, while it is assessed with a low EHP when Table 3.3 is consulted (Annex D). Transferring the results for Chinese mines, meaning regional results, to the international context is problematic, because the geological settings for the same raw material can vary significantly. For this reason, the measurement instructions have been made more specific. It is recommended to use the general rules for ores if no more concrete information is available. However, if there are research results from the region, these results should be taken into account.

Accordingly, the results according to Table 3-3 can be used for Chinese mines. Furthermore, a reference to research results for natural radioactivity in Australian mines (Cooper 2005) is included in the measurement instructions. We propose further research for broadening the data basis of this indicator over time.

The measurement instructions follow a precautionary approach in the assessment of EHPs in the absence of concrete data for the mine site. Therefore, the assessment results may shift towards a lower EHP when concrete information becomes available. Hence, it would be a positive development if mining companies included activity concentrations for thorium (Th) and/or uranium (U) in their environmental and/or sustainability reports to improve the data situation. Currently, it seems that mining companies often do not publish such data if there are low to very low activity concentrations and no countermeasures need to be taken.

Proposal for future optimisation - Paragenesis with radioactive components
We propose further research for broadening the data basis of this indicator over time, with a view to regional data that can support the assessment if no site-specific data can be obtained.

4.2.4 Deposit size

The deposit size indicator aims to measure direct impacts on ecosystems. This is based on the hypothesis that mining larger deposits is likely to have a more severe impact on ecosystems than mining smaller deposits.

The site-related OekoRess methodology references the work of Petrov when classifying deposit sizes (Petrov et al. 2008). Petrov classified different raw materials into size categories. The information provided refers to a deposit's total valuable metal content and covers a wide range of metals. Petrov mostly uses four class divisions differentiating between small, medium, large and very large deposits. In some cases, an additional category "gigantic"is introduced (Petrov et al. 2008). During the work on the 100 case studies, the division into four classes proved to be useful. The class boundary allows a more precise classification of the mines and can help to verify qualitative information (e.g. statements from mine owners describing the mine as being the "largest" or "biggest") and underlined that some of the largest active mining projects have been selected.

The transfer of Petrov's results for deposit sizes of various raw materials based on Russian mines to other regions of the world can be justified in the absence of a better database but can nevertheless only be considered a temporary solution. There is a broader need for research to identify class boundaries based on global datasets of commodity-specific deposit sizes. However, such research is beyond the scope of this research project.

In the case of bauxite, Petrov differentiates three classes only (small, medium, large). Many of the bauxite mines are significantly larger than Petrov's class boundaries for the category "large". This might be because the data refers to Russian mines only, and the largest bauxite mines in the world are all situated outside Russia. In order to sharpen the class boundaries, especially "medium" to "large" to "very large", which are relevant to the project, a set of raw data on bauxite deposits provided by Professor Meyer from RWTH Aachen was used. The data was originally published in 2004 and represents a comprehensive set of data on bauxite reserves worldwide (Meyer 2004). Since the methodology Petrov used to determine the class boundaries was not accessible, a percentile approach is used[22]. The class boundaries have been set analogous to the OekoRess II methodology for the site-specific indicators as well as for cumulated energy demand and cumulated raw material demand. In OekoRess II, quartiles have been used to determine class boundaries (Dehoust et al. 2020). Similarly, quartiles are used to set class boundaries for bauxite deposits based on Meyer's data.

The smallest class represents values smaller than the 25th percentile, medium represents data between the 25th and 75th percentiles, and large deposits are greater than the 75th percentile. Deposits greater than the 90th percentile represent a fourth class of very large deposits. The large and very large classes both represent a high EHP (compare Table 10).

Table 10 EHP class boundaries for deposit size

	<25th Percentile	25th – 75th Percentile	75th – 90th Percentile	>90th Percentile
Class	small	medium	large	very large
EHP	Low EHP	Medium EHP	High EHP	High EHP

[22] The original reference is in Russian and not accessible online. Petrov's translated table with the class boundaries has been provided by the BGR.

In Table 11, Petrov's classes and the classes derived from Meyer's data are shown. Most significantly, a fourth class is added to the classes based on Meyer, allowing for a more accurate distinction of large mines. The medium class shifts to a broader range, also covering mines that would be classified as large according to Petrov's division. The large category starts at 200 Mt in the data based on Meyer, whereas Petrov's started at 100.

The same percentile class divisions are used for the set of 22 bauxite mines assessed in OekoRess III (compare Table 10). However, the results represent a set of data that is based only on the largest bauxite deposits worldwide, therefore the class division based on OekoRess III data is not suitable for determining class boundaries and can only be used for comparative considerations within the dataset used.

For comparison, both OekoRess III data and Meyer (2004) data were combined and thus all data points available were used to derive classes. Double-counting is excluded where identifiable. In cases where the same deposit appears twice, the more recent OekoRess III data is used. This approach still potentially includes double-counting as mines and deposits are sometimes known under different names, e.g. Worsley / Boddington.

Table 11 Different deposit size class divisions for bauxite

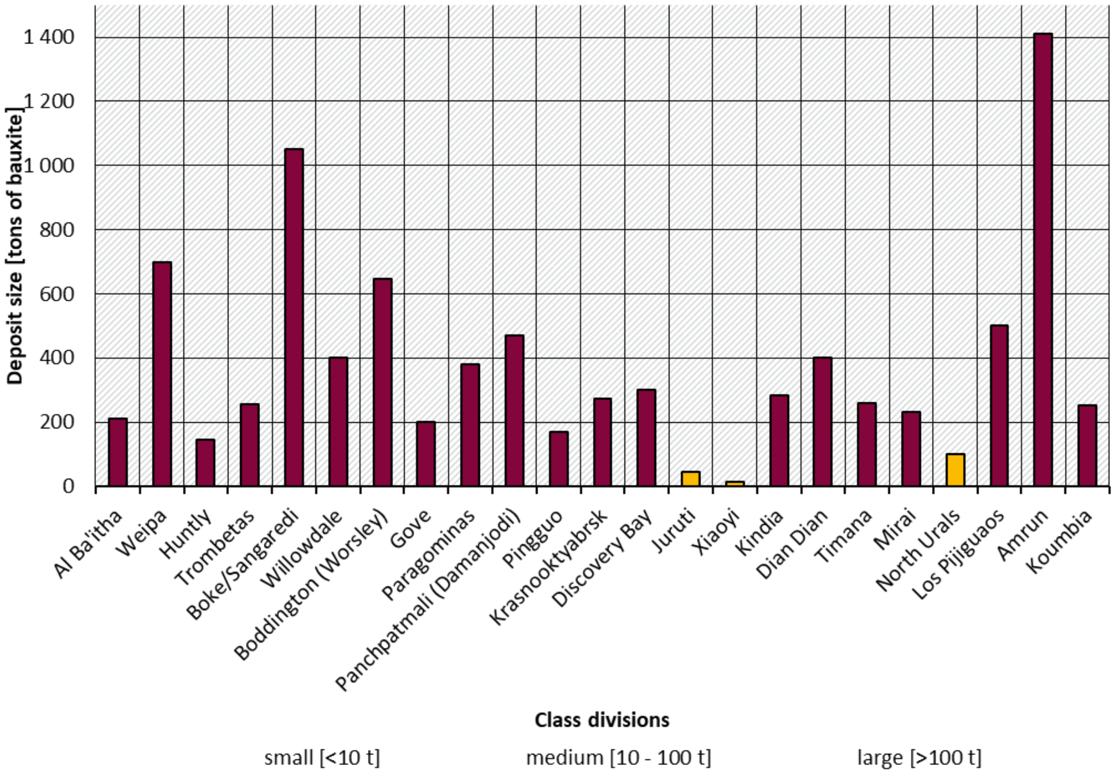
Data based on	Unit	Small	Medium	Large	Very Large
Petrov 2008	Mil. t ore	<10	10-100	>100	
Meyer 2004[23]	Mil. t ore	<15	15-200	200-500	>500
OekoRess III data	Mil. t ore	<200	200-400	400-650	>650
OekoRess III and Meyer	Mil. t ore	<20	20-250	250-570	>570

A merged dataset of OekoRess III data and Meyer (2004) is not used for several reasons: Firstly, the data is biased towards large deposits and therefore potentially overestimates the class boundaries. Secondly, the potential double-counting could lead to a distortion of the class divisions. Thirdly, the deposit size in the OekoRess evaluations includes historical figures and estimations as far as possible while Meyer (2004) solely looks at the deposit size at the time of data collection.

The data from Meyer was obtained late in the project and after the evaluation process was completed. Hence, Petrov's class division was used for the assessment of the bauxite mines in the OekoRess III project. Figure 11 shows the results for the bauxite mines assessed. 23 out of 24 mines were assessed, while no data was available for the Jamalco bauxite mine. Only three mines fall into the medium class division, while 20 mines are classified as large. The overall picture shows that the majority of all mines are large in terms of deposit size, which is in line with the premise of assessing the largest mines in the world (however, the selection was primarily based on annual production).

[23] The Petrov table is based on Russian mines and is the most complete database available to date. For bauxite, Meyer et al (2004) published information taking into account worldwide occurrences, which provides a better data basis and is therefore included.

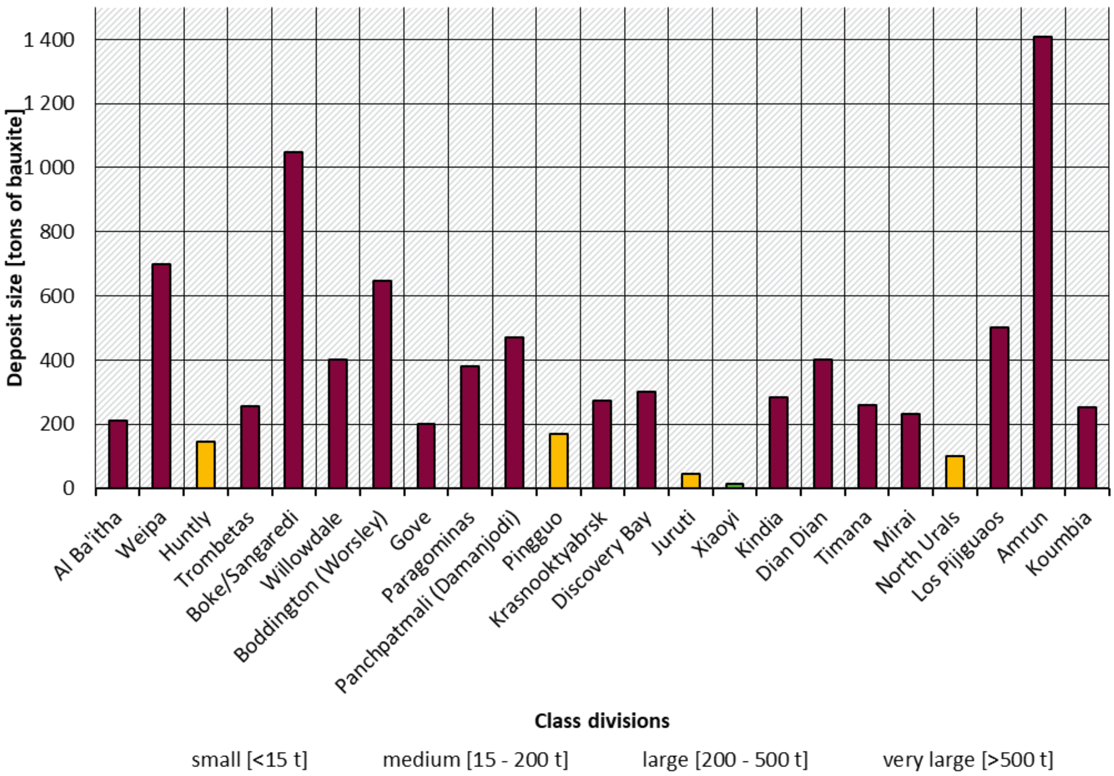
Figure 11: EHP of the deposit size according to Petrov's (2008) class divisions



Source: Own visualisation, Öko-Institut

Adjusting the EHP results using the class divisions based on Meyer, the picture looks slightly different. Figure 12 displays the results with adjusted class divisions. The overall variation is slightly higher. The mine with the smallest deposit in the OekoRess III database, Xiaoyi, is now classified as "small" and is therefore assigned a low EHP. More medium-sized deposits are the result of the new class boundaries. In total, four mines in the OekoRess database are now classified with a medium EHP. The remaining 18 deposits are classified with a high EHP. Due to the new class "very large", outliers that are significantly larger, such as Sangredi or Amrun, can be better incorporated into the classification.

Figure 12: EHP of the deposit size according to class divisions based on Meyer 2004



Source: Own visualisation based on data from Meyer (2004), Öko-Institut

However, the classes derived based on Meyer are only partially comparable to Petrov's. Petrov (2008) generally refers to total metal content (in the case of aluminium, it refers to the ore (bauxite)), meaning that material extracted in the past is taken into account as well as the current reserves. Data based on Meyer only represents the reserves and thus does not account for material already extracted. Considering this, it can be expected that Meyer's data should indicate overall smaller deposits because only the current reserves are represented. In contrast, the overall deposit sizes are larger based on the percentile classes. This could be explained by the fact that global data is used instead of only Russian deposits.

Both datasets have shortcomings. Petrov's data has a narrow geographic focus and is more than 10 years old. However, it is the best dataset on such a large number of metals. Meyer's data is even older but has a global focus and therefore covers more variation, both on smaller and larger deposits. Accordingly, the newly derived class divisions for bauxite based on Meyer allow for better differentiation of deposit sizes. Therefore, the measurement instructions have been updated, replacing Petrov's classes for bauxite with the classes derived from Meyer's data (see Annex D).

Proposal for future research – Deposit size

Future research should endeavour to derive more comprehensive class divisions for a large variety of resources based on global datasets. The transfer of results from one region of the world to another is problematic, as shown by the example of bauxite described above, and is currently only used here due to a lack of better available data. Furthermore, it should be borne in mind that Petrov's table refers to the entire metal content of the deposit, whereas for example

Meyer's data is based on reserves and therefore does not take into account quantities that have already been excavated. In addition, the data is very old and dates back to the late 1970s, while even the most recent data points refer to the years before 2003.

In an ideal scenario, a large and up-to-date dataset of global deposits with their total metal contents should be analysed, and class boundaries should be derived statistically.

Keeping in mind the large number of different mineral raw materials this proposal addresses, it is recommended to start with those raw materials which are currently the focus of the societal and political debate due to possible supply shortages and their importance to the German and EU industries. The regularly updated EU list of critical raw materials could provide a good basis for this approach[24]. -

The indicators "mine type" and "deposit size" aim to the goal "limiting the direct impact on ecosystems". This goal is strongly related to land use. During the project, the surface extension of the mines was determined based on latest available satellite imagery. Rules for the boundary demarcation in the satellite imagery were developed based on the 100 mine sites studied and their characteristics.

This is relevant to improving the evaluation of the site-surrounding indicators. It is also relevant at this point to bear in mind that the surface extension thus determined always only represents a snapshot in time.

Based on these developments, an indicator could be developed that provides direct information on current land use. Two approaches can be envisaged:

- Development of a specific indicator "area as a function of annual production" as the benchmark for mine sites of a specific raw material.
- Discussion of linkage to life cycle inventory data such as the evaluation of land use according to the hemeroby concept.

So far, however, no valid proposal has been developed according to which the temporal component can be adequately taken into account.

4.2.5 Ore grade

The ore grade indicator aims to capture the effort expended (e.g. energy consumption, rock mass moved, use of chemicals, and hence also water consumption) in extracting the raw material. The ore grade provides approximate information on the relative dimension of environmentally relevant parameters such as the amount of mining waste (waste rock, tailings), product-specific energy demand for extraction, transport, crushing, sorting and residue treatment, and the amount of auxiliary materials and reagents used in the processing of raw materials. Accordingly, lower ore grades entail a higher effort for extraction.

The second edition of the measurement instructions has been updated regarding the class divisions for several raw materials based on a new publication by Priester et al. (2019) that came out during the project.

[24] https://rmis.jrc.ec.europa.eu/?page=crm-list-2020-e294f6

The table below shows the new adjusted values:

Table 12: Grade categories for ore grades (based on Priester et al. 2019)

	Poor	Average	Rich
Gold (g/t)	<1.5	1.5-15	>15
Copper (%)	<0.5	0.5-3	>3
Iron (%)	<30	30-60	>60
Zinc (%)	<1.5	1.5-12	>12
Nickel (%)	<0.5	0.5-2	>2
PGM (g/t)	<1.5	1.5-6	>6
Tin (%)	<0.3	0.3-1.5	>1.5
Lead (%)	<1	1-15	>15
Manganese (%)	<20	20-45	>45
Diamond (g/t)	<0.01	0.01-0.5	>0.5

During the assessment of the bauxite mines in OekoRess III, it became evident that a class division for aluminium is necessary. As in the case of deposit size, both data provided by Meyer (2004) and the data created during the project was considered in deriving class divisions for poor, average and rich bauxite deposits. Using the same approach as Priester et al. (2019), the P10 value is used as a proxy for poor grades and the P90 value for rich grades. Values in between are considered average. The table below shows the classes derived. Moreover, two more publications by Mosier from the USGS have been included in the table as benchmarks (Mosier 1992a; b).

Table 13: Class divisions for bauxite ore grades

Based on	Unit	Poor	Average	Rich
Meyer 2004 based on mines (n=54)	% Al_2O_3	<39	39-52	>52
Own calculation with data from Meyer 2004 (n=66)	% Al_2O_3	<44	44-59	>59
OekoRess III (n=22)	% Al_2O_3	<32	32-52	>52
OekoRess III and Meyer (n=82)	% Al_2O_3	<41	41-59	>59
Laterite bauxite deposits (Mosier 1992a) (n=122)	% Al_2O_3	<35	35-55	>55
Karst bauxite deposits (Mosier 1992b) (n=41)	% Al_2O_3	<39	39-59	>59

In his publication "Availability of Bauxite Reserves", Meyer shows the distribution of ore grades in mines and prospects (Meyer 2004). He derives a median value of 45.6 % Al2O3 for mines. Based on the data in a graph in his publication, the P90 value is around 50 % Al2O3 and the P10 value is around 39 %.

Although the raw data was provided, it was not possible to derive exactly the same values. The derived classes generally show higher grades. The low grade class starts below 45 % and high grade at 59 %. This is probably because outliers were excluded from the analysis by Meyer, which becomes evident when comparing the graph to the raw data (Meyer 2004 pp. 169, Figure 10). Overall, most of the data points available refer to the late eighties and early nineties, being around thirty years old.

Contrary to the deposit size, the ore grade in OekoRess III data displays a wide variety. The selection of mines includes some of the lowest grades (27-30 % Al2O3) mined on a commercial scale in the Darling Range in Australia, and covers some of the highest-grade deposits (>60 % Al2O3) in the Shanxi province in China (Geoscience Australia 2013; Roskill 2019). Accordingly, the data provides an up-to-date overview of commonly mined grades. However, the low grade division class is significantly lower than in Meyer's and Mosier's data (compare Table 13).

Both datasets were also merged to derive class divisions (deleting mines that were present in both datasets). The results are very close to the classes derived from Meyer's raw data. Only differing in 3 % for the low grade class, while the high grade division is the same as in Meyer. The merging of both datasets is not recommended as potential undetected double-counting may occur. Also, the datasets are of significantly different ages.

In order to better interpret the results, publications by Mosier have been used for comparison. Mosier analysed laterite and karst bauxite deposits and derived P10 and P90 values for Al2O3 grades (Mosier 1992a; b). Overall laterite bauxite deposits have lower grades. The low grade for laterite deposits is below 35 %, and below 39 % for karst bauxite. The high grades for laterite bauxite start at 55 %, and for karst at 59 %.

Looking at the overall results it becomes clear that there is some variation between the datasets, particularly regarding the low grade division class. Both Meyer's and Mosier's data is not up to date and therefore might not reflect the current situation. OekoRess III on the other hand contains very recent data, but the sample is rather small. Deriving class divisions from around 20 data points is not sufficient to make a statistically valid generalisation for grade classes.

Comparing results of the EHP assessment using division classes based on Meyer 2004 and OekoRess III data, the differences are minimal (compare Table 14). Only one mine would be assessed differently. According to the OekoRess III data class division, Huntly would be attributed a medium EHP instead of a high EHP. The assessment should definitely be a high EHP since the grade mined in Huntly is among the lowest by global comparison.

Note that the grades referred to in this context are the grades of the reserves of a deposit. It is acknowledged that the ore grade may vary not only in terms of the time and location of the deposit, but also in terms of the reserve and the production.

Table 14: Comparison of EHP using different ore grade class divisions

Mine	% Al2O3	Class divisions based on Meyer 2004	Class divisions based on OekoRess III
Al Ba'itha Bauxite Mine	49.7	medium EHP	medium EHP
Weipa Bauxite Mine	50.6	medium EHP	medium EHP
Huntly Bauxite Mine	32.9	high EHP	medium EHP
Trombetas Bauxite Mine	49.9	medium EHP	medium EHP

Boke/Sangaredi Bauxite Mine	47.3	medium EHP	medium EHP
Willowdale Bauxite Mine	27.5	high EHP	high EHP
Boddington (Worsley) Bauxite Mine	27.8	high EHP	high EHP
Gove Bauxite Mine	49.5	medium EHP	medium EHP
Paragominas Bauxite Mine	49.5	medium EHP	medium EHP
Panchpatmali (Damanjodi) Bauxite Mine	45.0	medium EHP	medium EHP
Pingguo Bauxite Mine	53.5	low EHP	low EHP
Krasnooktyabrsk Bauxite Mine	43.1	medium EHP	medium EHP
Discovery Bay Bauxite Mine	45.0	medium EHP	medium EHP
Juruti Bauxite Mine	46.7	medium EHP	medium EHP
Xiaoyi Bauxite Mine	65.8	low EHP	low EHP
Kindia Bauxite Mine	45.3	medium EHP	medium EHP
Jamalco Bauxite Mine	45.2	medium EHP	medium EHP
Timana Bauxite Mine	44.5	medium EHP	medium EHP
Mirai	31.3	high EHP	high EHP
Los Pijiguaos Bauxite Mine	49.0	medium EHP	medium EHP
Amrun	52.3	high EHP	high EHP
Koumbia Bauxite Deposit	48.0	medium EHP	medium EHP

In summary, it is recommended to refer to Meyer's own data as it appeared in the publication. The dataset is somewhat younger than Mosier's and contains enough data points to derive statistically valid class divisions (n=54). Nonetheless, a more recent dataset with a large set of data points would be preferable as a basis for statistically derived class divisions.

The measurement instructions have been updated regarding possibilities of determining the ore grade. Possible sources of information are listed, and information as to which values are the most accurate is provided in the updated measurement instructions.

Proposal for future optimisation – Ore grades

Despite the newly introduced class boundaries for several commodities, a large number of commodities are still not covered by the instructions. It is recommended to broaden the database of the instructions by statistically analysing the ore contents of further commodities.

4.3 Technology

4.3.1 Mine type

The mine type gives an indication of the interventions on the earth's surface needed to extract the raw material. In the course of the project, the team found that in some cases, open pit and underground mining are carried out at the same site. Usually, one mine type prevails. Geological, economic or even environmental reasons can change the mine type over time, or new pits can be added to the site. In some cases, it is possible to split the mine site evaluation for this indicator to allow for a specific evaluation. Otherwise, the editor should consider the history of the mine and evaluate the dominant mine type at the site. It is recommended to highlight this specific characteristic in the explanation of the evaluation result (e.g. footnote or visual code).

Proposal for future optimisation – Mine type

The evaluation method differentiates between three mine types: underground mining (low EHP), solid rock open pit mining (medium EHP) and alluvial or unconsolidated sediment mining (high EHP). The reasoning is that underground mining has the lowest intervention rate on the earth's surface. Of course, every class boundary has borderline cases. However, an underground mine can have huge effects on the water balance, which leads to surface subsidence and other environmental impacts that may call into question the accuracy of this class boundary. The influence of underground mines on their environment can furthermore depend on various other factors, such as the rock stability, excavation and backfilling method, or lateral extent and depth, among others. For these reasons, and keeping in mind known cases of large-scale subsidence, not least in the Ruhr region, further investigations should be undertaken. There is a need to establish the influence of underground mines on the goal "Limiting the direct impacts on ecosystems", and to determine whether the class boundaries need to be modified based on the results.

4.3.2 Use of auxiliary substances

In the instructions, the drill and blast excavation method was previously evaluated with a medium EHP "use of auxiliary (non-toxic) substances" because of the explosives used. Drill and blast is the most common excavation method with usually very local effects of vibration and swath formation, with, of course, some extreme examples as well. Given that the effects are usually local and the auxiliary substance explosives usually confined to boreholes, and after the evaluation of 100 mine sites in addition to those evaluated in OekoRess I and II, a medium EHP does seem to overrate the impact on the defined goal "Limiting the direct impacts on ecosystems". The measurement instructions have therefore been adapted to include drill and blast in the category "no auxiliary substances" with a low EHP rating.

Furthermore, the instructions now specify that if the exact solvent used is known to be non-toxic, a medium EHP can be evaluated to avoid overrating the EHP if further information is at hand.

4.3.3 Mining waste

The indicator "mining waste" aims to measure the effort to minimise the risks caused by mining waste. Accordingly, safe storage practices such as backfilling are likely to have a lower environmental hazard potential than depositing the waste in stable, smaller tailing ponds or, worse, in unstable, high-volume or large-scale tailing ponds.

The instructions have been updated regarding the explanation to evaluate a medium or high EHP. Instead of the original term "structural dam height", the following definition of a large dam according to (ICOLD 2011) is used to evaluate a high EHP:

"A dam with a height of 15 meters or greater from lowest foundation to crest or a dam between 5 and 15 meters impounding more than three million cubic meters."

In addition, explanations are provided to determine the dam height, as well as options for determining the existence and size of tailing storage facilities if no direct information is available.

Proposal for future optimisation – Mining waste

The safety of industrial tailings management facilities (TMFs) is the subject of a study on behalf of the German Environment Agency (Vijgen and Nikolaieva 2016). The developed method aims to monitor and evaluate specific TMFs using a TMF Checklist and the developed Tailings Hazard Index (THI Method). The latter determines the specific risk of TMFs.

Depending on the available database, a basic or extended formula can be used. The elements of the extended formula are[25]:

- Capacity (size of the TMF)
- Toxicity (national hazard classes (for Germany, Ukraine))
- Management (if existent or not: active / abandoned / orphaned)
- Site (earthquake and flood risk)
- Dam (age, material, width[26])

The site-related evaluation method in OekoRess already includes elements of the THI Method. Toxicity is addressed by the four different indicators to measure the goal of avoiding pollution risks, and earthquake and flood are two of the four sub-indicators to evaluate the goal of avoiding natural accident hazards. To avoid double consideration and overvaluation, the THI Method as a whole is not suitable as a substitute for the evaluation for the indicator mining waste. However, the elements "capacity" and "dam" are relevant aspects for the OekoRess indicator mining waste, and provide a better assessment basis than the current explanation on dam height, which only distinguishes between medium and high EHP.

For future optimisation, the proposal is to use the two elements of the THI Method "capacity" and "dam" to evaluate the indicator mining waste. The THI capacity is evaluated based on the Log10 of the volume of tailing materials in m^3. In (Vijgen & Nikolaieva 2016) the range of values is given as 0 to 9, with 9 corresponding to a maximum value of 100,000,000 m^3. The THI dam consists of the elements age, material and width. The values for these elements are:

- Dam age: 0 for ≤ 30 years, 1 for > 30 years
- Dam material: 0 for hard rock, 1 for non-hard rock, soils
- Dam crest width: 0 for > 10 m, 1 for ≤ 10 m [27]

25 The basic formula only includes the elements capacity and toxicity.

26 Preferable to material and width is the "Factor of Safety" (FoS) if available.

27 The dam is assumed to be more stable if the width of the dam crest (and obviously, the dam basement) is sufficiently large to retain stored tails in the impoundment.

If no specific information is available, it is recommended to use the value 1 to evaluate the THI dam elements following the precautionary principle. In total (result THI capacity and THI dam) the range of values for the indicator mining waste would lie between 0 and 12.

To differentiate between a medium and a high EHP, a threshold value needs to be determined. This threshold value could be discussed in a stakeholder process.

The resulting new evaluation for the hazard potential relating to the long-term effect of mining waste materials could then be, for example:

- Low (green): (unchanged)

Safe storage/deposition of tailings in the deposit (backfilling of the mine in parallel to ongoing mining, backfill of waste materials to stabilise the mining plant)

- Medium (yellow):

Result of THI capacity and THI dam ≤ 6

- High (red):

Result of THI capacity and THI dam > 6

In addition to this proposed evaluation method, it is recommended to also apply the THI Method as a whole, given the availability of data. The THI Method is a recognised standard in all UNECE countries. The result should be reported separately as additional information on dam safety.

4.3.4 Remediation measures

For this indicator no changes were made, apart from improving the target definition.

4.4 Site (surroundings)

4.4.1 Accident hazard due to floods, earthquakes, storms, landslides

The hazard maps for riverine floods, earthquakes, tropical storms and landslides are based on the data of the Global Assessment Report on Disaster Risk Reduction (GAR). The last data update was downloaded from the GAR 2015. Since then, there have been two follow-up reports[28] in 2017 and 2019:

- GAR 2019: Global Assessment Report 2019
- GAR 2017: GAR Atlas - Unveiling Global Disaster Risk

Most of the spatial data on hazard and risk assessment is published by the UNDRR platform “PreventionWeb – The knowledge platform for disaster risk reduction”. After analysing the most recent dataset, it became obvious that no major updates have been conducted since 2015. However, some new models are available (e.g. GEM – Global Earthquake Model) and the state of the art should be reviewed with the next OekoRess methodology update.

It must be noted that between 2005 and 2015 the focus of UNDRR GAR activities was on improving risk information. For this reason, platforms with global data and standards were set up. In 2015 the “Sendai Framework for Disaster and Risk Reduction” was adopted, which focusses more on standards, targets and a legally-based instrument for disaster risk reduction.

[28] All reports can be downloaded at https://www.preventionweb.net/sendai-framework/gar (07.12.2020)

4.4.2 Water Stress Index (WSI) and desert areas

Proposal for future optimisation

The current method in all OekoRess projects to evaluate with the goal "Avoiding competition over water usage" is a combination of the water stress index developed by (Pfister et al. 2009) and defined desert regions (Olson et al. 2001).

A combination of two indicators was necessary because absolute water shortage in deserts - where water withdrawal was low - was not represented in the WSI indicator. However, this is an important aspect in the context of OekoRess, and the team decided on this integration of absolute aridity (Dehoust et al. 2017).

In recent years, a number of water footprint indicators have been developed due to better data availability and advanced method concepts. There have been many activities in the research field of water footprint and LCA methods[29]. Another push for method development arose from the update of the global freshwater model (WaterGAP[30]) to version 3. This model is the basis for most of the water footprint indicators and is widely used by UN und IPCC reports. The project team decided to review new indicators as potential candidates for an update of the OekoRess water indicator.

After a pre-screening the following indicators were reviewed:

- Water Depletion (Brauman et al. 2016)
- AWaRe (Boulay et al. 2018)
- WAVE+ (Berger et al. 2018)
- UBA: Konzeptionelle Weiterentwicklung des Wasserfußabdrucks (Conceptual advancement in the water footprint) (Berger et al. 2020)

The indicators are summarised briefly in tabular indicator profiles. These include a brief description, pro and contra arguments for the indictor, a comment on available spatial datasets, and the source.

Table 15: Indicator profile – Water Depletion

Description	A biophysical measure of the fraction of available renewable water consumed by human activities within a watershed. It directly addresses the question: "What share of renewable surface and groundwater in a watershed is being consumed seasonally, annually, or in dry years, and is thereby not available for other uses?"
Pro	▪ Easily interpretable indicator ▪ WaterGAP3 ▪ Takes seasons and dry year into account ▪ High resolution ▪ Thresholds defined
Contra	▪ No adjustment to arid regions (deserts)

[29] A good overview of different concepts, standards, tools, databases, datasets and impact assessment methods relating to water footprinting is available on the online platform "Water Footprint Toolbox" hosted by TU Berlin: https://wf-tools.see.tu-berlin.de/wf-tools/waterfootprint-toolbox/ (02.12.2020)

[30] Developed at the University of Kassel/Frankfurt. Update version 3 (Eisner 2016).

Spatial datasets	Available in GeoTiff. No regional aggregations
Source	Brauman, K. A.; Richter, B. D.; Postel, S.; Malsy, M.; Flörke, M. (2016): Water depletion: An improved metric for incorporating seasonal and dry-year water scarcity into water risk assessments. In: *Elementa: Science of the Anthropocene*. Vol. 4, S. 000083.

Table 16: Indicator profile – Available Water Remaining [AWaRe]

Description	The AWaRe indicator can be interpreted as a proxy for the potential of water consumption to deprive other users of water. It is based on the demand-to-availability (DTA) concept: Inverse of water availability minus water demand associated with environmental water requirements and human water consumption (DTA). Values are normalised against the global average in the range of 0.1 and 100.
Pro	▪ Approved LCA method developed by an international working group (WULCA) ▪ Normalisation to the global average considers desert regions ▪ Potential impacts on ecosystems integrated via environmental water demand
Contra	▪ No thresholds defined ▪ WaterGAP2
Spatial datasets	Spatial datasets for AWaRe are provided by WULCA (2016) for individual sub-watersheds, divided into agricultural and non-agricultural water.
Source	Boulay, A.-M.; Bare, J.; Benini, L.; Berger, M.; Lathuillière, M. J.; Manzardo, A.; Margni, M.; Motoshita, M.; Núñez, M.; Pastor, A. V.; Ridoutt, B.; Oki, T.; Worbe, S.; Pfister, S. (2018): The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). In: The International Journal of Life Cycle Assessment. Vol. 23, No.2, S. 368–378.

Table 17: Indicator profile – Water Accounting and Vulnerability Evaluation [WAVE+]

Description	WAVE+ analyses the vulnerability of basins to freshwater depletion based on local blue water scarcity. The indicator initially covers two steps of calculation: 1) Water Accounting (effective water consumption) 2) Vulnerability Evaluation (relative water scarcity and absolute water shortage). Water accounting consideres basin-internal evaporation recycling (BIER). This represents the share of evapo(transpi)ration that is returned to the originating basin via precipitation. The vulnerability evaluation uses the integrated water deprivation index (WDI).
Pro	▪ Ground and surface water stocks are considered in the scarcity assessment ▪ WDI combines relative water scarcity and absolute water shortage ▪ Updated on WaterGAP3 model (no. of basins, higher resolution, data 1981-2010) ▪ WAVE+ or WDI can be used on an annual or monthly basis
Contra	▪ No thresholds defined

Spatial datasets	On the level of basin, county, region. Temporal resolution annually or monthly. Agricultural and non-agricultural water. Separate indicator components BIER/WDI/WAVE+
Source	Berger, M.; Eisner, S.; van der Ent, R.; Flörke, M.; Link, A.; Poligkeit, J.; Bach, V.; Finkbeiner, M. (2018): Enhancing the Water Accounting and Vulnerability Evaluation Model: WAVE+. In: Environmental Science & Technology. Vol. 52, No.18, S. 10757–10766.

Table 18: Indicator profile – Conceptual further development of the water footprint taking into account the concept of planetary boundaries

Description	For the calculation, environmentally induced regional water flow requirements are subtracted from the natural water supply. The difference here is a carrying capacity limit within which sustainable water consumption is possible. The determined carrying capacity limits are set against the total human water consumption.
Pro	▪ Up-to-date data ▪ Integration of popular concept of planetary boundaries ▪ Connectivity to UBA methodologies
Contra	▪ No consideration of absolute water shortage in desert regions ▪ No thresholds defined
Spatial datasets	On the level of basin, county, region. Annual/monthly.
Source	TU Berlin ongoing project FKZ 3719 31 201 0

The Water Depletion indicator (Braumann et al. 2016) is easy to interpret and straightforward in design with defined thresholds, but absolute water shortage in desert regions is not well represented. This is why it has not been further investigated for the current update of the site-related OekoRess evaluation method. The Available Water Remaining [AWaRe] indicator (Boulay et al. 2018) was developed by an international working group (UNEP/Society for Environmental Toxicology and Chemistry, SETAC) to enhance the evaluation of freshwater use in LCA.

The indicator is well recognised, especially by the LCA and water footprint community. The concept of the indicator fits the scope of the OekoRess water indicator well, but it still relies on WaterGAP2 and there is no information available if the indicator is soon to be updated. If an update is to be integrated in future, it would also be a suitable candidate for the OekoRess update.

The WAVE indicator fits best the scope of the OekoRess measuring goal for the water indicator. It was developed by TU Berlin (Berger et al. 2014) and updated to WAVE+ in 2018 (Berger et al. 2018). The indicator combines a water accounting model with a vulnerability evaluation model. The special characteristic of the indicator is the integration of the “basin internal evaporation recycling” (BIER) ratio. It represents the share of evapotranspiration, which is returned to the originating basin via precipitation and is the most important component of the water accounting model.

The use of BIER is especially relevant if analysed processes have a dominant evapotranspiration characteristic (e.g. crop production). Otherwise, the vulnerability evaluation model, which depicts the integrated water deprivation index (WDI), can be applied solely.

Although evaporation is an important component of process water in mining (e.g. evaporation in tailing storage facilities), it is not the main characteristic of process water if mining is considered in general. Depending on the climatic preconditions of a region and the techniques of tailing management, water can be returned to the basin, released to another basin, or stored for long periods. For this reason it was decided that basin internal evaporation recycling does not have an overall dominant role, and the BIER ratio of WAVE+ is not considered.

The WDI is the underlying index for the vulnerability evaluation model and considers relative freshwater scarcity as well as absolute water shortage. The relative freshwater scarcity uses the concept of consumption to availability (CTA), which is a further development of the withdrawal to availability (WTA) concept. Water consumption is defined as the fraction of water withdrawal that has become unavailable for the originating river basin users due to evapo(transpi)ration, product integration, or discharge into other basins and the sea. Additionally, CTA has been enhanced to create a more meaningful water scarcity indicator by adding surface water stocks and integrating an adjustment factor for the availability of groundwater stocks.

The absolute water shortage represents aridity thresholds classified by UN Environment (ratio of evapotranspiration to precipitation). It should be noted that this setting represents a model choice to acknowledge that absolute water shortage can influence the vulnerability of a basin to freshwater deprivation and, thus, the potential to deprive other users when consuming water in this basin (Berger et al. 2018). Many water footprint indicators do not consider this characteristic. In the context of OekoRess this is important because mining sites can be relevant freshwater consumers and have the potential to change the background data for freshwater modelling in arid regions.

Besides the choice of using the complete WAVE+ indicator or only the WDI, the indicator offers a choice for (non-)agricultural applications and a monthly/annual resolution. Since mining is a non-agricultural process and operations are not subject to high seasonality (apart from mining in high altitudes), the non-agricultural annual dataset on river basin level is used. The vulnerability evaluation model suggests indirectly thresholds for low, medium and high scarcity ranges by fitting CTA values to the logistic function of WDI. Table 19 considers the definition of WDI values and suggests a fitting to the OekoRess EHP evaluation.

Table 19: EHP Evaluation for the "Water Deprivation Index" (WDI)

WDI value	OekoRess EHP evaluation
0 – 0.1	Low EHP
> 0.1 – 0.5	Medium EHP
> 0.9	High EHP

The authors of the WAVE+ indicator are also developing an new indicator in the ongoing UBA project "Konzeptionelle Weiterentwicklung des Wasserfußabdrucks unter Berücksichtigung des Konzeptes der planetaren Grenzen (Conceptual advancement in the water footprint Taking into account the concept of planetary boundaries)(FKZ 3719 31 201 0)" (Berger et al. 2020). It appears that a regional vulnerability to water scarcity describes the situation before the defined regional ecological capacity boundaries are crossed. Additionally, the indicator does not consider absolute water shortage. Thus, the global distribution of ecological capacity boundaries is significantly different to the original evaluation in OekoRess. Nevertheless, connectivity to OekoRess should be checked again at the end of the project (FKZ 3719 31 201 0).

4.4.3 Protected areas and AZE sites

For the OekoRess III evaluation, the WDPA and AZE dataset was updated in December 2019 (see updated instructions for site-related evaluation in Annex D). Beyond the officially designated protected areas, the indicator considers Alliance for Zero Extinction (AZE) sites with a medium EHP in order to take highly threatened species (from extinction) into account.

The evaluation results of OekoRess showed a low impact on the general evaluation. In the dataset of OekoRess III mining sites, none of the few intersections with AZE sites were determining the result. This is due to the fact that 57 % of AZE sites are already protected, and in a lot of cases the AZE site lies within a designated but low-protected area (e.g. low or no IUCN category). The overall evaluation impact would change if AZE sites were rated with a high EHP.

Proposal for future optimisation – Protected areas and AZE sites

Besides the global dataset of already protected areas, there is a continuously growing global data coverage of areas with high environmental importance. A widely used and respected concept is the Key Biodiversity Areas (KBA) programme. Nature is declining globally at rates unprecedented in human history (Brondizio et al. 2019). This biodiversity crisis, along with the climate crisis, presents a great challenge to global society. There is now a greater focus on biodiversity, and areas with high biodiversity value should be treated with higher priority.

The KBA Programme reviews proposals of KBAs using defined criteria during a standardised identification process, and adds the sites to the World Database of Key Biodiversity Areas (IUCN 2016). To date, the programme has mapped more than 16,000 KBAs worldwide, safeguarding important populations of more than 13,100 species for which conservation is a concern[31]. KBAs cover larger regions than IBAs (Important Bird Areas) or AZE sites, and usually incorporate these.

The following options are recommended as an update of the OekoRess indicator:

1. Evaluate AZE sites with high EHP
2. Add KBA sites to the indicator. It should be analysed in a future optimisation of the method whether KBAs are rated with medium or high EHP. If rated with high EHP, the separate evaluation of AZE sites can be dismissed since it is a subset of KBA.

[31] http://www.keybiodiversityareas.org/about-kbas (07/12/2020).

4.4.4 Conflict potential with local population

It is widely acknowledged that there can be a connection between mineral deposits and conflicts, but that the existence of a conflict is not negative *per se*. It must be evaluated how these conflicts are resolved.

In the first version of the measurement instructions, the use of two World Governance Indicators (WGIs) "Voice and Accountability" and "Control of Corruption" was promoted to approximate the notion of: (1) freedom of speech and (2) low corruption in a country, assuming that environmentally induced conflicts connected to resource extraction can generally be peacefully negotiated.

Given that the WGIs are derived at country level, the applicability at local level and thus the evaluation of the EHP on a local scale is not appropriate. The derivation from two sub-indicators of the WGI is also disputable.

However, the relevance of environmentally induced conflict potentials with the local population is high. But the EHP should be evaluated based on a suitable site-specific indicator, which is currently not available on a global level. Instead of using country-specific indicators as an approximation, the authors recommend not evaluating the EHP for the time being, but rather qualitatively taking into account general context information about environmental governance.

For example, see suitable context information on environmental governance on the next page:

Indicators or legal framework information at country/state level:

- Environmental Performance Indicator (EPI)[32]. The EPI was identified in OekoRess II as the most useful indicator for mapping environmental governance at country level. However, the indicator does not represent conflict (potential) and is also located at country level. It does, however, give an indication of whether it can be assumed that all necessary/announced measures are being adequately implemented.
- World Governance Indicators[33]
- EITI membership[34]
- Mining Laws and Regulations

Voluntary standards or indices at company level:

- Responsible Mining Index (RMI)[35]
- Initiative for Responsible Mining Assurance (IRMA)[36]
- International Council of Mining & Metals (ICMM)[37]

4.5 Summary of the need for further research and proposals for future optimisation of the measurement instructions

The authors certainly see the need for further research, in particular to improve the available data for applying the method, and in individual cases also to supplement the evaluation tools. For the “Ore grade” indicator, for example, the classes for evaluation should be created for as many other raw materials as possible. So far, evaluation classes are only available for gold, copper, iron, zinc, lead, nickel, diamonds, PGM, tin, manganese and aluminium.

However, at the present stage, the method is certainly sound. Ideally, further development should take place within the context of frequent and extensive use of the method. Then, for example, the values collected could be merged in a database, enabling the evaluation tools to be reviewed and developed further. In addition, by analysing the experience of using the existing evaluation system, it is possible to identify which indicators are hard to back up with data. From these findings, the following aspects can be derived:

- How the evaluation tools need to be refined
- In which instances the evaluation tools lead to false positive or false negative results
- Which exceptional circumstances should be taken into account

Within the framework of the OekoRess III project, some improvements have been proposed and even already implemented, as detailed in the course of this chapter. However, additional work on the method is needed in order to optimise it in the long run. A summary of concrete proposals for future optimisation sorted by indicator is presented below:

Indicator - Paragenesis with radioactive components: The evaluation of this indicator often proves difficult or impossible, as mining companies rarely provide information on activity concentrations and/or uranium and thorium concentrations in their environmental and/or sustainability reports.

[32] https://epi.yale.edu

[33] www.govindicators.org

[34] https://eiti.org/countries

[35] https://responsibleminingindex.org/en/companies

[36] https://responsiblemining.net/what-we-do/responsible-mining-map

[37] https://www.icmm.com/en-gb/members/member-companies

In this context, it is recommended that companies be obliged to disclose this data as part of the official annual reporting, which would improve the respective company transparency as well as the data situation. In follow-up projects, the measuring instructions could be expanded to include tables indicating the tendency of paragenesis with radioactive components based on the raw material and/or the geographic region, similar to the table addressing activity concentrations in Chinese mines, which is already included.

Indicator - *Deposit size*: Future research should endeavour to derive more comprehensive classifications for all resources based on global datasets, as the transfer of results from one region of the world to another is problematic and is currently only used here due to the more optimal data situation. Furthermore, it should be borne in mind that Petrov's table refers to the entire metal content of the deposit, whereas Meyer's data is based on reserves and therefore does not take into account quantities that have already been excavated. In addition, the data is very old and goes back to the late 1970s, with even the most recent data points referring to the years before 2003. In an ideal scenario, a large and up-to-date dataset of global deposits with their total metal contents should be analysed, and classification thresholds should be derived statistically.

Indicator - *Ore grade*: It is recommended to further expand the available database in order to be able to classify the ore contents of more raw materials than those specified at the time of publication of this report. With regard to the bauxite ore grades, it is recommended to thoroughly validate the values if significant uncertainties remain after initial evaluation according to the OekoRess method.

Indicator - *Mining waste*: The safety of industrial tailings management facilities (TMF) is the subject of a study on behalf of the German Environment Agency (Vijgen & Nikolaieva, 2016). The developed method aims to monitor and evaluate specific TMFs using a TMF checklist and the developed Tailings Hazard Index (THI Method). The latter determines the specific risk of TMFs (cf. Section 4.4.3). Depending on the available database, a basic or an extended formula can be used.

For future optimisation, the proposal is to use the two elements of the THI Method "capacity" and "dam" to evaluate the indicator mining waste. The THI capacity is evaluated based on the Log10 of the volume of tailing materials in m^3.

If no specific information is available, it is recommended to use the value 1 to evaluate the THI dam elements following the precautionary principle. In total (result THI capacity and THI dam) the range of values for the indicator mining waste would lie between 0 and 12. To differentiate between a medium and a high EHP, a threshold value needs to be determined. This threshold value could be discussed in a stakeholder process.

The resulting new evaluation for the hazard potential relating to the long-term effect of mining waste materials could then be, for example:

- Low (green) (unchanged to current evaluation): Safe storage/deposition of tailings in the deposit (backfilling of the mine in parallel to ongoing mining, backfill of waste materials to stabilise the mining plant)
- Medium (yellow): Result of THI capacity and THI dam ≤ 6
- High (red): Result of THI capacity and THI dam > 6

In addition to this proposed integration in the OekoRess evaluation method it is recommended to also apply the THI Method as a whole, given the availability of data. The THI Method is a recognised standard in all UNECE countries. The results should be reported separately as additional information on dam safety.

At the 'Site (surroundings)' level: The newly established spatial assessment of the area expansion, which constitutes the data basis for the corresponding 'Site'-related indicators, could be further developed. For instance, the ratio area expansion / production volume as a new specific indicator could serve as a benchmark for mine sites extracting specific commodities. In addition, life cycle inventory data could also be derived, which could furthermore be included in the assessment of land use according to the hemeroby concept. For this, an approach needs to be developed as to how the time-dependent component of land use can be taken into account.

Indicator - Water Stress Index (WSI) and desert areas: The current method in the OekoRess projects to evaluate with the goal "Avoiding competition over water usage" is a combination of the water stress index (WSI) developed by (Pfister et al. 2009) and defined desert regions (Olson et al. 2001). A combination of two indicators was necessary because absolute water shortage in deserts - where water withdrawal was low - was not represented in the WSI indicator.

However, this is an important aspect and was therefore included in the OekoRess indicator. In recent years, a number of further models have been developed due to better data availability and advanced method concepts.

The most relevant methods in the OekoRess context are described in the OekoRess III report. From this, the "Water Deprivation Index" (WDI), an integrated part of the WAVE+ indicator 2018 from (Berger et al. 2018), is recommended for future optimisation. Therefore, the non-agricultural annual dataset on river basin level should be used. A possible evaluation for the hazard potential based on the WDI value is described in the OekoRess III report.

Indicator – Protected area and AZE sites: Besides the global dataset of already protected areas, there is a continuously growing global data coverage of areas with high environmental importance. The most relevant databases are described in the OekoRess III report.

As an update of the OekoRess indicator, the following options are recommended:

- Evaluate AZE sites with high EHP.
- Add Key Biodiversity Area (KBA) sites to the indicator. It should be analysed in a future optimisation of the method whether KBAs are rated with medium or high EHP. If rated with high EHP, the separate evaluation of AZE sites can be dismissed since it is a subset of KBA.

Indicator - Conflict potential with local population: For future optimisations, an attempt should be made to find an indicator that is suitable for indicating potentials for environmentally induced conflicts with the local population. One future approach could be to include this aspect in an existing and recognized voluntary standard. However, such a standard would need to be widely applied worldwide and be applicable to a large number of raw materials. To date, no standard meets these requirements. Another possibility could be to research and evaluate court decisions in which mining companies are defendants.

4.6 Recommendations for application and action

With the site-related evaluation, a system exists for mining and processing sites that takes into account the deposit-specific, technical and geographical parameters, and permits a multifactorial, reproducible, reliable and transparent evaluation of environmental hazard potentials. The range of applications is diverse:

- Site-related decisions – whether for the (co-)financing of mining projects, the acquisition of ores and concentrates from remote mining projects, or the independent assessments of as yet unrecorded impacts and risks – require a sound scientific basis which, however, can only be established in many cases with substantial financial and logistical efforts. For many stakeholders in industry, finance and civil society, drafting such comprehensive assessments only comes into question when projects become concreteor initial reports on environmental problems become known. This gap can be filled by the method presented here for the estimation of environmental hazard potentials of individual mining projects, supplemented by the method for the estimation of mining residues (Priester and Dolega 2015). Indeed, these methods cannot and should not replace any comprehensive environmental impact assessment, but can facilitate robust initial assessments for companies, financial institutions and civil society groups, and can be used as an initial "hazard radar" for environmental issues.

- A further field of application for such a hazard radar is the remit of government authorities involved in permitting and supervising mines in developing countries. While as a general rule the relevant committees and authorities have very limited personnel and financial resources, the task of inspecting contract awards and mining operations in terms of their environmental impacts and providing, if applicable, relevant restrictions and conditions/obligations is nevertheless incumbent upon them. Indeed, even here the site-related evaluation method presented cannot be a substitute for well-developed environmental impact assessments, but it still provides a good approach for providing robust initial assessments and to planning further investigations at comparatively low expense. In addition, this initial assessment can provide support with reviewing environmental impact studies, e.g. in licensing procedures.
- Using the results from the evaluations of several sites in a developing country, it would be possible, within the scope of policy consultation, to derive recommendations and suggestions for supportive capacity building as regards the handling of environmental conflict potentials, and for focusses on licensing, permitting and monitoring in the respective countries.
- In addition, information can be derived from the results as to where reporting obligations for mining companies should be intensified.
- Finally, the evaluation system and its results may be helpful for individual sites when it comes to further developing standards and guidelines or agreeing these in a binding manner, whether through governments, financial institutions and mining initiatives or along supply chains in commercial and business relationships (BMUB/UBA 2017). The individual environmental hazard potentials have a bearing on existing guidelines, for example in relation to:
- Acid Mine Drainage: GARD (Global Acid Rock Drainage Guide), which was developed under the auspices of the International Network for Acid Prevention (INAP) with funding from the Global Alliance through Golder Associates, and constitutes a framework for acidic mine drainage water and its formation and prevention. See also the UmSoRess Steckbriefe[38] from the UFOPLAN project UmSoRess.
- Auxiliary substances/reagents: The Cyanide Code (ICMI – International Cyanide Management Institute) was developed as a multi-stakeholder initiative under the guidance of the United Nations Environmental Programme (UNEP) and the International Council on Metals and the Environment (ICME), and represents a standard for the safe management of cyanide in gold and silver mining. See also the UmSoRess Steckbrief on ICMC[39].

[38] https://www.umweltbundesamt.de/umweltfragen-umsoress

[39] https://www.umweltbundesamt.de/sites/default/files/medien/378/dokumente/umsoress_kurzsteckbrief_icmc_final.pdf

- Hazardous incidents: The following initiatives, among others, have produced standards on safe mining practice:
- ICMM (International Council on Mining & Metals) within the framework of the 10 principles for sustainable development in the mining and metals industry and as a position statement on tailings dams. See also the UmSoRess Steckbrief on ICMM[40].
- ICOLD (International Commission on Large Dams) has published best practice standards on the safe design of mining dams and on dams and the environment.
- TSM (Towards Sustainable Mining), an initiative of the Mining Association of Canada, sets internationally recognised standards for sustainable mining practice. Additional standards have been developed on topics such as mining waste management, crisis situations and communication, and mine closure and water management, and are updated based on current events (e.g. after the collapse of a dam in 2014). See also the UmSoRess Steckbrief on TSM[41].
- Global Tailings Review, the joint commitment of the International Council on Mining and Metals (ICMM), the United Nations Environment Programme (UNEP) and the Principles for Responsible Investment (PRI) to the adoption of global best practices on tailings storage facilities and the establishment of an international standard.
- Mining waste management: EU Mining Waste BREF – the Reference Document on Best Available Techniques for Management of Waste from extractive industries issued by the EU to support the implementation of the EU Mining Waste Directive.
- IRMA (Initiative for Responsible Mining Assurance)[42] has developed a standard for responsible mining which defines good practices for responsible mining on the industrial scale. The requirements of the standard include the four principles: business integrity, planning for positive legacies, social responsibility, and environmental responsibility.
- Protected areas: ICMM Good Practice Guidance for Mining and Biodiversity and Position Statement on Mining and Protected Areas
- Governance: EITI[43], possibly also the National Resource Charter or Africa Mining Vision

Many of the application cases referred to above call for international agreements. In this context, this publication has been produced in English. Furthermore, a discussion at the European level on a corresponding higher-level initiative is indispensable.

40 https://www.umweltbundesamt.de/sites/default/files/medien/378/dokumente/umsoress_kurzsteckbrief_icmm_final_aktualisiert.pdf

41 https://www.umweltbundesamt.de/dokument/umsoress-steckbrief-towards-sustainable-mining-tsm

42 https://www.umweltbundesamt.de/sites/default/files/medien/378/dokumente/umsoress_steckbrief_irma_final.pdf

43 https://www.umweltbundesamt.de/dokument/umsoress-steckbrief-initiative-fuer-transparenz-im

5 Results presentation on an interactive map

The information compiled in each factsheet represents a comprehensive dataset that will be of interest to many user groups working in the environment, social and governance (ESG) in the industrial mining sector. The target groups are governmental agencies, policy advisors and consultants, researchers, NGOs, and private companies along the value chain of each individual commodity. To make the project results easily accessible, the results for each mine are made publicly available on the interactive online map. The map can be accessed with a standard internet browser, builds on the ESRI ArcGIS software, and is hosted on the UBA web servers. To contribute to the German as well as the EU-wide debate on the security of raw material supply that must go hand in hand with a globally understood responsibility for environmental footprints, the results published in the online map are in English.

The online map displays the location and surface extension of all 100 mine site evaluated in the course of the project. Users can filter general and specific information, such as indicators and assessment results. In addition to standard map tools such as base maps, thematic layers and a distance meter, the map also contains several info boxes. These provide background information on the OekoRess III project, the applied site-related EHP evaluation method, and further links. The map also includes a glossary and a disclaimer. When the user clicks on the map symbol of each mine site displayed, a drop-down list appears that contains further site-specific information of the respective mine site. Within this drop-down list, there is a link for downloading the complete factsheet for each mine as a PDF file.

Due to the spatial presentation of the mine sites and the variety of filter and layer functions included, each user group can easily select and extract the information most relevant to their work. In general, the user can obtain specific information on individual mine sites, but also derive geographical trends and comparisons of certain indicators between locations.

The aspect of open-data conformity and, hence, the option to transfer referenced data to other online portals such as govdata.de are duly considered.

Although at present only mine sites are displayed at which copper ore, iron ore and bauxite are extracted, the database can in principle be extended to any other mineral commodity of interest. This applies not only to the online map but also to the factsheet database.

5.1 Features of the online map

The aim of the online map is clear presentation as well as simple and intuitive handling. Therefore, the underlying ArcGIS attribute table only comprises a selection of entries from the factsheets. Based on this selection, mining operations can be searched for quickly and compared easily. Via a link in the respective drop-down list, opened by clicking on the map symbol, the user can download each individual factsheet for a mine of interest and thus the complete site-specific information as a PDF file. The screenshot (Figure 13) shows an overview of the online map.

Figure 13: Overview of the online map

Presentation of own spatial data, map layout adapted by Projekt-Consult, ifeu Institut, Öko-Institut; Map source: Earthstar Geographics | Esri, FAO, NOAA (powered by Ersi)

The online map contains the following tools and functions, which are presented in detail below:

- Welcome window
- Standard map tools
- Attribute table as drop-down list incl. download link
- Info boxes
- Base maps gallery
- Legend containing overview of active layers
- Thematic layers with EHP assessment result
- Glossary
- Filter tool
- Distance and area meter

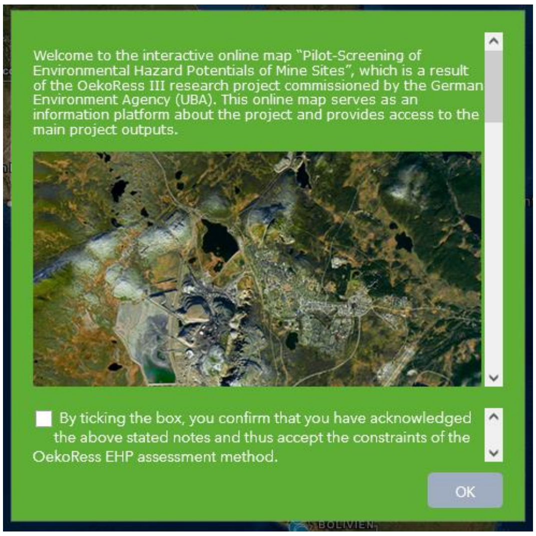
Welcome window:

When the online map is opened, a pop-up window (Figure 14) appears that shows a welcome message, outlines the purpose of the online map, and provides a short description of the OekoRess III project and the contact details of the Client and the Contractor, general notes on initial assumptions, the known limitations of the EHP method, and the data sources. By setting a checkmark the user agrees to the general terms of use.

Standard map tools:

- Via "+/-" buttons the user can easily zoom-in/out to a certain map section
- By holding the left mouse button the map can be moved to the desired position
- A scale bar enables a rough estimation of the dimensions
- A coordinate bar always shows the coordinates at the current location of the cursor. After activating the coordinate bar, the longitude and latitude of a selected point can be taken, which is then marked by a green symbol pointing downwards
- Clicking on the "house" symbol returns the online map to the overview display (entire world by default)
- By clicking on the "crosshairs" symbol, the current location of the user is displayed
- A search function can be used to search for addresses and places, which are then displayed on the map
- Zooming in the map makes more and more details visible. At a certain zoom level, the map symbols (points) of the mining operations are labelled with the respective name, and the visible outlines of the operation are shown. Note that the point symbol is usually placed in the middle of the open pit. The areas (polygons) where mining, heaps and processing plants are located are determined via satellite images (cf. EHP instructions). These areas form the basis for certain spatial indicators

Figure 14: Welcome window of the online map



Source: Map source: NASA satellite image (nasa.gov), online map function Projekt-Consult;

Attribute table as drop-down list incl. download link:

Clicking on the map symbol opens a drop-down list containing all entries of the attribute table for the respective location (Figure 15). The selected attributes and the respective entries are consistent with the factsheet database. The attribute table comprises the following attributes:

Figure 15: Attribute table

Source: Display online map function, Projekt-Consult

- Name of mine
- Main commodity
- Factsheet (download link)
- Operator
- Principal owner
- Country
- By-products
- Annual production (in million tons)
- Precondition for acid mine drainage
- Paragenesis with heavy metals
- Paragenesis with radioactive components
- Deposit size
- Ore grade
- Mine type
- Use of auxiliary substances
- Mining waste
- Remediation measures
- Accident hazard
- Water stress
- Protected areas and AZE sites

The user can download the complete factsheet of the selected mine site as a PDF file via the link indicated in the attribute "Factsheet".

Info box:

The info box contains more detailed and background information on the project:

- OekoRess III project description
- Further links to UBA publications related to this project
- External links, e.g. to WGI, ILO, EITI, ASI etc.
- Imprint, including the contact details of the Client and Contractor

Base maps:

The user can choose between up to six base maps:

- OpenStreetMap
- Satellite imagery
- Satellite imagery with captions
- "National Geographic" style map
- Topographic map
- Imagery hybrid map

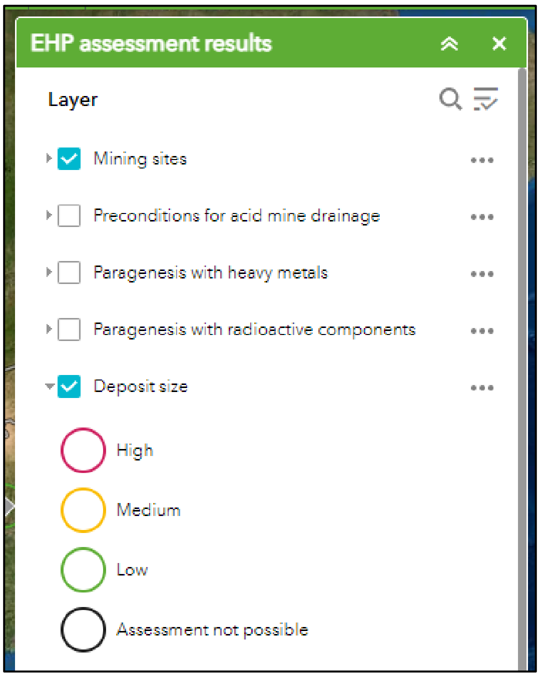
Legend containing overview of active layers:

The legend contains all the active layers that are currently displayed on the online map. The map symbols for the mine sites, which differ in shape and colour depending on the commodity extracted, are always activated by default.

Thematic layers with EHP assessment result:

The user can add up to 12 pre-defined layers to the map view. These thematic layers correspond to the EHP indicators (Figure 16). They are classified as “high”, “medium”, “low” and “assessment not possible” according to their respective EHP assessment result. They are accordingly displayed as coloured rings. In addition to the layer “Commodities”, only one further layer can be selected at a time. The following layers can be selected:

Figure 16: Visualisation of EHP assessment results



- Geology
- Paragenesis with heavy metals
- Paragenesis with radioactive components
- Deposit size
- Ore grade
- Technology
- Mine type
- Use of auxiliary substances
- Mining waste
- Remediation measures
- Framework conditions natural environment
- Accident hazard
- Water stress
- Protected areas and AZE sites

Source: Display online map functions, Projekt-Consult

Glossary:

The glossary contains explanations of the most important abbreviations and describes the EHP indicators and associated criteria that lead to the low, medium or high EHP assessment results.

Filter tool

This tool enables the user to set specific filter criteria for each category. Only the mine sites that fulfil the filter criteria are displayed on the map. The following four categories can be added individually: General Information, Geology, Technology and Natural Environment. Clicking on the small, grey arrows on the left of the categories’ names opens a list containing the respective EHP indicators and a selection of filter options.

Distance and area meter:

This tool is also integrated into in the toolbar. It can be used to measure distances between any points, e.g. two mine sites, or an area, such as the surface area of a mining heap.

The online map offers a wide range of options for displaying the information collected in the project and filtering it according to the user’s interests. It thus offers interested members of the public the opportunity to use all the results of the project.

6 Conclusion

During the project, the team analysed a large number of mine sites with respect to their annual production and reserves to determine 100 large mine sites for the site-related OekoRess evaluation and subsequent creation of factsheets. The mine sites were selected in such a way as to ensure the highest coverage of global annual production and high coverage of global reserves for all three commodities (bauxite, copper ore and iron ore), while giving annual production a slightly higher priority. Information on governance and CSR was gathered to provide context information.

The results were subjected to a 2-step validation process and transferred to an Access database. Comments and suggestions for optimisation were discussed and incorporated if reasonable. Additional information provided by mine owners that could give a different evaluation result was included if a quotable source is listed.

The method provides a good tool for an initial overview of EHPs at mine level for lay people, interested government officials, mine evaluators in remote areas with low human resource capacities.

The site-related OekoRess evaluation system is designed in such a way that the analysis of the indicators can be performed without on-site surveys, and by professionals without specific background experience related to mining, geology or environmental assessment. If direct site-specific information is available for the indicators, the evaluation takes this information into account. However, if no direct data is available, the evaluation system can carry out the assessment on the basis of rules established in the measurements instructions that take into account raw material-related scientific results and expert knowledge.

The indicators of the "site (surrounding)" level can be determined using the geographical coordinates. Nonetheless, the following limitations must be taken into account:

- The results are only meaningful as environmental hazard potentials for a specific site. The results always constitute initial estimations, which on no account can or should be a substitute for an Environmental Impact Assessment (EIA).
- Information on specific levels of damage in the event of accidents or the release of harmful substances occurring during normal operation cannot be represented using the methods.
- The results from the site-related evaluation do not provide any indication of a company's environmental management, and therefore do not constitute an evaluation of the mine operator. They only provide information about site-, deposit-, technology- and governance-specific hazard potentials.
- For concrete estimations such as investment decisions, the planning of measures etc., the results must always be complemented by on-site surveys, e.g. an EIA. The evaluation can, however, provide qualified estimations as to which sub-aspects should be examined in particular detail.
- Having evaluation results from several sites tends to lead to the comparison of (mine) sites with each other. This is not the intention, nor does it always produce meaningful results, since the evaluation is performed qualitatively without reference to a basis of comparison. Instead, each evaluation result should be considered individually and, as such, provides information about hazards intrinsic to the site or waste material and possible hotspots in terms of duties of care, licensing requirements, environmental impact assessments etc.
- Despite the lack of a basis of comparison and qualitative evaluation, the evaluation results from possible sites can be used as a first step towards, or as part of, a site comparison which, however, needs to be supplemented by specific on-site analyses.

- The authors recommend dispensing with an aggregation of the results of the individual indicators and instead using the results matrix as an end result, which still enables identification of all the facts from the individual evaluations. Consequently, the connections between individual indicators that exist in practice (interdependencies), which can intensify or inhibit the potentials to different degrees, have not been addressed.

Most impacts can be countered with various management structures and tools. For example, the impact on the surrounding rock, or on the surrounding area, can be greatly improved in the long term through backfilling, reforestation and water recycling. Appropriate design, use and maintenance of TSFs can lead to adequate safety even if a high EHP is determined. Such measures need to be evaluated by experts according to the respective national legislation and safety standards. The method shows which points deserve increased attention, but is not a substitute for a more extensive EIA. A strong recommendation for the future is therefore to discuss a possible 2-step process in which the OekoRess evaluation forms the first step, and in the second step other methods evaluate the management and safety performance, or alternatively the actual impacts (as suggested by the DPSIR framework[44]), depending on the goal of the analysis. Based on discussions during the project it became clear how important it is to convey the possibilities but also the limits of the evaluations system, in order to avoid incorrect or over-interpretation of the results.

Optimisation proposals for the instructions are included directly in the instructions and are detailed in Chapter 4 of this report for each of the respective indicators. Where such optimisations affect the evaluation results, they are also included in the factsheet database. Where adaptations were made only after all factsheets had been finalised (new deposit size estimation for bauxite mines), the changes could no longer be applied to the dataset. All changes due to optimisations along the project were given special attention during the final quality control. Further proposals to refine the method mainly address the need to enhance the database, for example performing more research on ore grade statistics for further raw materials.

The method is based on numerous existing scientific analyses and results, but still constitutes an innovation in terms of its methodological approach. It was developed in an iterative process as an evaluation approach for environmental hazard potentials of mining sites, and was adapted and validated using practical examples. Despite a deliberate restriction to only a few indicators, the systems reflect the range of the geological, technical and site conditions, and demonstrate the diversity of the possible environmental effects resulting from mining.

[44] https://www.umweltbundesamt.de/publikationen/comparative-analysis-of-case-studies-for-mining

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7 Annex

A Nomenclature

Table 20: Nomenclature of technical terms in the fields of mining method, processing and waste management

Glossary of relevant technical terms	
Drill and blast	An excavation method used in mining and quarrying as much as in tunnelling. Holes are drilled in a pre-designed pattern in order to create optimal fracture patterns for the specific use. Explosives are placed in the holes. After detonation and collapse of the rock, the rubble is removed and the steps are repeated[45].
Dry stacking	Dewatering tailings to higher degrees than paste produces a filtered wet (saturated) and dry (unsaturated) cake that can no longer be transported. These filtered tailings are normally [...] compacted to form an unsaturated tailings deposit. This type of tailings storage produces a stable deposit usually requiring no retention bundling and is referred to as 'dry stack'. [...] Some low throughput alumina operations filter their tailings to produce a wet cake and thus 'dry stack' the tailings[46].
Dump Synonyms that should be avoided to achieve better harmonisation: heap, pile.	"A pile of broken rock or ore on surface.[47]" More specifically: oiling up of non-marketable products (gangue, mine waste, waste rock, overburden, residues), which occur, for example, when uncovering the deposit or during the mining process. If there is a lack of sales, also stockpiling of coal, coke, ore and other mineral raw materials.[48]
Gangue	The part of an ore that is not economically desirable but cannot be avoided in

[45] RPM Drilling (2019): Blast Hole Drilling - The Basics, https://www.rpmdrilling.co.za/blast-hole-drilling-process/ (retrieved 05.11.2019)

[46] Engles (2012): Dry Stacking of Tailings, (Filtered Tailings), Website: Tailings.info, http://www.tailings.info/disposal/drystack.htm citing Davies and Rice (2001) (retrieved 05.11.2019)

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[48] Bischoff, W. und Bramann, H. (1981): Westfälische Berggewerkschaftskasse Bochum: Das kleine Bergbaulexikon. Essen (Verlag Glückauf); ISBN 3-7739-0501-7

Glossary of relevant technical terms	
	mining[49]
Heap	A pile of dry mining waste that is stored above surface level and without natural or artificial boundaries.
Mine waste	"Mining wastes include waste generated during the extraction, beneficiation, and processing of minerals."[50] Thus, an umbrella term for overburden, waste rock and tailings.
Open-cast mining	"A mining method consisting of removing the overlying strata or overburden, extracting the coal (team´s note: or other commodities), and then replacing the overburden. When the overlying material consists of earth or clay it can be removed directly by scrapers or excavators, but where rock is encountered it is necessary to resort to blasting to prepare the material into suitable form for handling by the excavators.[51]"
Open-pit mining	"a. A form of operation designed to extract minerals that lie near the surface. Waste, or overburden, is first removed, and the mineral is broken and loaded, as in a stone quarry. Important chiefly in the mining of ores of iron and copper. b. The mining of metalliferous ores by surface-mining methods is commonly designated as open-pit mining as distinguished from the strip mining of coal and the quarrying of other non-metallic materials such as limestone, building stone, etc.[52]"

[49] JRC Science for Policy Report (2018): Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries (MWEI BREF), Publications Office of the European Union, https://publications.jrc.ec.europa.eu/repository/handle/JRC109657

[50] US Environmental Protection Agency, https://archive.epa.gov/epawaste/nonhaz/industrial/special/web/html/index-5.html

[51] Hacettepe University Department of Mining Engineering (2009): Dictionary of Mining, Mineral, and Related Terms, http://www.abdurrahmanince.net/ (retrieved 05.11.2019)

[52] Op. Cit.

Glossary of relevant technical terms	
Overburden	The material that extractive operations move during the process of accessing an ore or mineral body, including during the pre-production development stage: layer of natural soil or massive rock on top of an orebody[53]
Pile (of mining waste)	A pile of dry mining waste that is stored above surface level and without natural or artificial boundaries. Equivalent to a waste heap.
Strip mine	"An open-pit mine, usually a coal mine, operated by removing overburden, excavating the coal seam, then returning the overburden.[54]"
Tailings	"Material rejected from a mill after most of the recoverable valuable minerals have been extracted.[55]"
Tailings dam	"A tailings dam is a tailings embankment or a tailings disposal dam. The term "tailings dam" encompasses embankments, dam walls or other impounding structures, designed to enable the tailings to settle and to retain tailings and process water, which are constructed in a controlled manner.[56]"
Tailings impoundment	"A tailings impoundment is the storage space/volume created by the tailings dam or dams where tailings are deposited and stored. The boundaries of the impoundment are given by the tailings dams and/or natural boundaries.[57]"

[53] JRC Science for Policy Report (2018): Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries (MWEI BREF), Publications Office of the European Union, https://publications.jrc.ec.europa.eu/repository/handle/JRC109657

[54] US Security and Exchange Commission (n.y.): Glossary of Mining Terms, https://www.sec.gov/Archives/edgar/data/1165780/000116578003000001/glossary.htm (retrieved 05.11.2019)

[55] Op. Cit.

[56] United Nations Economic Commission for Europe (2014): Safety guidelines and good practices for tailings management facilities, Geneva, GE.13-26665-April2014-696-ECE/CP.TEIA/26

[57] Op. Cit.

Glossary of relevant technical terms

Tailings Pond Synonyms that should be avoided to achieve better harmonisation: clarification or settling pond	"A low-lying depression used to confine tailings, the prime function of which is to allow enough time for heavy metals to settle out or for cyanide to be destroyed before water is discharged into the local watershed.[58]"
Tailings management facility	"… a tailings management facility (TMF) is intended to encompass the whole set of structures required for the handling of tailings including the tailings storage facility, tailings dam(s), tailings impoundment, clarification ponds, delivery pipelines, etc.[59]"
Tailings storage facility	"A tailings storage facility is a facility used to contain tailings. This can include a tailings dam (impoundment and pond), decant structures and spillways. A tailings storage facility can also be open pits, dry stacking, lakes or underground storages.[60]"
Waste rock (= mining waste rock)	"Waste rock is classed as ores that are below the economic cut-off grade.[61]" (Roche et al. 2017) "Barren or submarginal rock or ore that has been mined, but is not of sufficient value to warrant treatment and is therefore removed ahead of the milling processes.[62]"

[58] US Security and Exchange Commission (n.y.): Glossary of Mining Terms, https://www.sec.gov/Archives/edgar/data/1165780/000116578003000001/glossary.htm (retrieved 05.11.2019)

[59] United Nations Economic Commission for Europe (2014): Safety guidelines and good practices for tailings management facilities, Geneva, GE.13-26665-April2014-696-ECE/CP.TEIA/26

[60] Op.Cit.

[61] Roche, C., Thygesen, K., Baker, E. (Eds.) 2017. Mine Tailings Storage: Safety Is No Accident. A UNEP Rapid Response Assessment. United Nations Environment Programme and GRID-Arendal, Nairobi and Arendal, www.grida.no, ISBN: 978-82-7701-170-7

[62] Hacettepe University Department of Mining Engineering (2009): Dictionary of Mining, Mineral, and Related Terms http://www.abdurrahmanince.net/ (retrieved 05.11.2019)

B Lists of mine sites for the selection process

B.1 Bauxite mines

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
1	Australia	Weipa Bauxite Mine	Operating	26.34	8.8%	1500	52.8	5.4%
2	Australia	Huntly Bauxite Mine	Operating	23.00	7.7%	144.6	32.9	0.5%
3	Brazil	Trombetas Bauxite Mine	Operating	15.73	5.3%	257.5	49.8	0.9%
4	Guinea	Boke/Sangaredi Bauxite Mine	Operating	15.44	5.2%	53.1	50.5	0.2%
5	Australia	Willowdale Bauxite Mine	Operating	10.00	3.4%	144.6	32.9	0.5%
6	Australia	Boddington (Worsley) Bauxite Mine	Operating	8.50	2.9%	312	30.3	1.1%
7	Australia	Gove Bauxite Mine	Operating	8.03	2.7%	201	45.3	0.7%
8	Brazil	Paragominas Bauxite Mine	Operating	7.57	2.5%	878	49.5	3.1%
9	India	Panchpatmali (Damanjodi) Bauxite Mine	Operating	6.30	2.1%	81	43	0.3%

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
10	China	Pingguo Bauxite Mine	Operating	6.13	2.1%	86.4	46	0.3%
11	Kazakhstan	Krasnooktyabrsk Bauxite Mine	Operating	5.50	1.8%	89.5	41.3	0.3%
12	Jamaica	Discovery Bay Bauxite Mine	Operating	4.71	1.6%	120	47.5	0.4%
13	Brazil	Juruti Bauxite Mine	Operating	3.90	1.3%	700	49.5	2.5%
14	China	Xiaoyi Bauxite Mine	Operating	3.57	1.2%	n/a	n/a	0.0%
15	Guinea	Kindia Bauxite Mine	Operating	3.33	1.1%	153	45.3	0.5%
16	Jamaica	May Pen Bauxite Mine	Operating	3.30	1.1%	n/a	45.2	0.0%
17	Guinea	Dian Dian Bauxite Deposit	Operating (seit Juni 2018)	3-6 (expected)	60%	564	n/a	0%
18	Russia	Timana Bauxite Mine	Operating	2.82	0.9%	260	44.5	0.9%
19	Brazil	Pocos de Caldas (CBA) Bauxite Mines	Operating	2.50	0.8%	34.7	46.4	0.1%
20	Russia	Severouralsk (North Ural) Bauxite Mines	Operating	2.50	0.8%	42	n/a	0.2%

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
21	Venezuela	Los Pijiguaos Bauxite Mine	Operating	2.50	0.8%	570	47.4	2.0%
22	Jamaica	Kirkvine (Windalco) Bauxite Mine	Operating	2.01	0.7%	n/a	n/a	0.0%
23	Greece	S & B Bauxite Mines	Operating	2.00	0.7%	n/a	n/a	0.0%
24	Guyana	Aroaima Mining Co Bauxite Mine	Operating	1.51	0.5%	96	51.9	0.3%
25	Suriname	Onverdacht Bauxite Mines	Operating	1.50	0.5%	200	45	0.7%
26	Suriname	Moengo (Coermotibo) Bauxite Mine	Operating	1.20	0.4%	18	n/a	0.1%
27	China	Guizhou Bauxite Mines	Operating	1.08	0.4%	n/a	n/a	0.0%
28	Greece	Delfi-Distomon Bauxite Mine	Operating	1.00	0.3%	n/a	n/a	0.0%
29	India	Hindalco Industries Ltd	Operating	1.00	0.3%	n/a	n/a	0.0%
30	China	Nanchuan (Chalco) Bauxite Mine	Operating	0.99	0.3%	n/a	n/a	0.0%
31	China	Gongyi Bauxite Mine	Operating	0.88	0.3%	n/a	n/a	0.0%

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
32	China	Xiaoguan Bauxite Mine	Operating	0.81	0.3%	n/a	n/a	0.0%
33	Brazil	Alcoa Pocos de Caldas Bauxite Mines	Operating	0.80	0.3%	1.1	39.5	0.0%
34	China	Huaxing Bauxite Mine	Operating	0.76	0.3%	n/a	n/a	0.0%
35	Saudi Arabia	Al Ba'itha Bauxite Mine	Operating	0.88	0.3%	220	49.5	0.8%
36	Australia	Amrun	Construction	22.5	8%	1409	52.4	5%
37	Guinea	Koumbia Bauxite Deposit	Construction	n/a	0%	695.9	n/a	2%
38	Laos	Bolaven Plateau Bauxite Project	?	n/a	0%	226	n/a	1%
39	Guinea	Bel Air Bauxite Project	Construction	n/a	0%	n/a	n/a	0%
40	Australia	Skardon River Bauxite Project	Construction	n/a	0%	n/a	n/a	0%

Source. Own research

B.2 Copper mines

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
1	Chile	Escondida Copper Mine	Operating.	886.20	4.80	7080	0.6	5.38
2	Peru	Antamina Copper/Zinc Mine	Operating	461.10	2.50	744	1.065	1.00
3	Peru	Las Bambas Copper Mine	Operating	453.75 (in 2017)	2.46 (in terms of global production 2013)	952 (6.9 - 7.71 Mt copper content)	0.71-0.73	0.04
4	Chile	El Teniente Copper Mine	Operating.	450.40	2.44	1538	0.99	1.93
5	Papua New Guinea	Grasberg/ Ertsberg Copper/Gold Mine	Operating	436.30	2.36	2341	1.09	3.23
6	Chile	Collahuasi Copper Mine	Operating	416.10	2.26	3143	0.9	3.58
7	Chile	Los Pelambres (OP) Copper Mine	Operating	405.30	2.20	1488	0.65	1.22
8	Chile	Radomiro Tomic Copper (SX-EW) Mine	Operating	379.60	2.06	2567	0.59	1.92
9	Chile	Los Bronces Copper Mine	Operating	378.00	2.05	2117	0.62	1.66

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
10	Chile	Escondida Copper (SX-EW) Mine	Operating	305.30	1.65	152	n/a	n/a
11	Chile	Andina Copper Mine	Operating	236.70	1.28	2551	n/a	n/a
12	Iran	Sar-Cheshmeh Copper Mine	Operating	220.00	1.19	1200	0.7	1.06
13	Chile	Chuquicamata Copper Mine	Operating	220.00	1.19	1057	0.7	0.94
14	Peru	Cerro Verde Copper Mine	Operating	214.00	1.16	4373	0.4	2.21
15	USA	Bingham Canyon Copper Mine	Operating	211.00	1.14	784	0.47	0.47
16	USA	Morenci Copper (SX-EW) Mine	Operating	210.00	1.14	3094	0.27	1.06
17	DR Congo	Tenke Fungurume Copper/Cobalt (SX-EW) Mine	Operating	209.80	1.14	144	2.6	0.47
18	Poland	Rudna Copper Mine	Operating	195.00	1.06	347	1.78	0.78
19	Zambia	Sentinel	Operating	190.6 (Prod. 2017)	1.03 (in terms of global	n/a	0.5	n/a

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
					production in 2013)			
20	Russia	Oktyabrsky Nickel/Copper Mine	Operating	190.00	1.03	98	n/a	n/a
21	Peru	Toromocho Copper Mine	Operating	182.28 (Prod. in 2015)	0.99 (in terms of global production in 2013)	1526	0.48	0.93
22	Poland	Polkowice-Sieroszowice Copper Mine	Operating	180.00	0.98	278	2.65	0.93
23	Chile	Esperanza (Antofagasta) Copper Mine	Operating	174.90	0.95	732	0.54	0.50
24	Australia	Olympic Dam Copper/Gold Mine	Operating	174.40	0.95	552	1.2	0.84
25	Peru	Cuajone (SPCC) Copper Mine	Operating	168.60	0.91	2285	0.67	1.94
26	Chile	La Candelaria Copper/Gold Mine	Operating	168.00	0.91	315	0.95	0.38

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
27	DR Congo	Kamoto Copper/Cobalt Mines	Operating	160.60	0.87	27	4.21	0.14
28	Chile	El Abra Copper (SX-EW) Mine	Operating	155.60	0.84	725	n/a	n/a
29	Chile	Spence Copper (SX-EW)Mine	Operating	151.60	0.82	311	1.24	0.49
30	Zambia	Kansanshi Copper Mine	Operating	151.00	0.82	726	0.82	0.75
31	DR Congo	Mutanda Copper/Cobalt (SX-EW) Mine	Operating	150.60	0.82	48	n/a	n/a
32	Kazakhstan	Zhezkazgan Copper Mines	Operating	145.00	0.79	344	n/a	n/a
33	Peru	Antapaccay Copper Mine	Operating	139.00	0.75	540	0.59	0.40
34	Australia	Mount Isa Copper Mine	Operating	130.40	0.71	53	3.3	0.22
35	Chile	Gabriela Mistral Copper (SX-EW) Mine	Operating	128.20	0.69	535	n/a	

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
36	Chile	Zaldivar Copper (SX-EW) Mine	Operating	126.50	0.69	552	n/a	
37	Mongolia	Erdenet Copper Mine	Operating	121.00	0.66	1540	0.51	0.99
38	Zambia	Kansanshi Copper (SXEW) Mine	Operating	120.00	0.65	726	n/a	n/a
39	Brazil	Sossego Copper Mine	Operating	119.00	0.64	151	n/a	n/a
40	Mexico	Buenavista del Cobre Copper Mine	Operating	115.80	0.63	6120	0.69	5.35
41	Zambia	Lumwana Copper Mine	Operating	115.00	0.62	526	n/a	n/a
42	Canada	Highland Valley Copper Mine	Operating	113.20	0.61	673	n/a	n/a
43	Peru	Toquepala (SPCC) Copper Mine	Operating	110.70	0.60	3371	0.61	2.60
44	Argentina	Alumbrera Gold/Copper Mine	Operating	109.60	0.59	81	n/a	n/a
45	Papua New Guinea	Ok Tedi Copper/Gold Mine	Operating	105.50	0.57	129	n/a	n/a

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
46	Canada	Manitoba and Ontario Nickel/Copper Mines	Operating	105.00	0.57	124	n/a	n/a
47	Chile	El Tesoro Copper (SX-EW) Mine	Operating	102.60	0.56	222	n/a	n/a
48	Chile	Chuquicamata Copper (SX-EW) Mine	Operating	100.00	0.54	1700	n/a	n/a
49	Mexico	La Caridad Copper Mine	Operating	96.90	0.53	4651	n/a	n/a
50	Chile	Sierra Gorda Copper Mine	Operating	94 (Prod. in 2016)	0.51 (in terms of global production in 2013	1275	0.4	0.65
51	USA	Morenci Copper Mine	Operating	90.00	0.49	596	n/a	n/a
52	Russia	Taimyrsky Nickel/Copper Mine	Operating	90.00	0.49	80	n/a	n/a
53	Laos	Sepon (Khanong) Copper (SX-EW) Mine	Operating	90.00	0.49	17	n/a	n/a
54	Russia	Gaisky Copper/Zink Mines	Operating	86.00	0.47	0	n/a	n/a

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
55	Mongolia	Oyu Tolgoi (Turquoise Hill) Copper/Gold Mine	Operating	76.70	0.42	1540	1.66	3.24
56	Russia	Uchalinsky Copper Mines	Operating	69.00	0.37	1940	1.05	2.58
57	Mexico	Buenavista del Cobre (SX-EW) Mine	Operating	66.40	0.36	1981	n/a	n/a
58	Brazil	Salobo Copper Mine	Operating	65.00	0.35	1123	0.68	0.97
59	USA	Sierrita Copper Mine	Operating	65.00	0.35	1588	0.26	0.52
60	Uzbekistan	Kalmakyr Copper Mine	Operating	65.00	0.35	1400	n/a	n/a
61	Chile	Salvador Copper Mines	Operating	44.00	0.24	812	n/a	n/a
62	Australia	Ridgeway Deeps Gold Mine	Operating	40.60	0.22	1700	0.38	0.82
63	Armenia	Kajaran Copper/Molybdenum Mine	Operating	32.00	0.17	1800	n/a	n/a

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
64	Australia	Boddington Gold Mine	Operating	29.90	0.16	956	n/a	n/a
65	USA	Newmont Nevada Mines	Operating	13.50	0.07	854	n/a	n/a
66	Australia	Cadia East Gold/Copper Mine	Operating	9.40	0.05	1500	0.26	0.49
67	South Africa	Mogalakwena (Platreef) PGM Mine	Operating	7.20	0.04	1009	n/a	n/a
68	Chile	Quebrada Blanca Copper (primary) Deposit	Operating	n/a	n/a	1478	0.58	1.09
69	Kazakhstan	Aktogay Copper Deposit	Operating	n/a	n/a	1614	0.37	0.76
70	Canada	Red Chris Gold Mine	Operating	n/a	n/a	302	0.36	0.14
71	Chile	Antucoya Copper Deposit	Operating	n/a	n/a	642	n/a	n/a
72	Chile	Santo Domingo Sur Copper/Iron Ore/Gold Deposit	Operating	n/a	n/a	418	n/a	n/a

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
73	Peru	Constancia Copper Mine	Operating	n/a	n/a	372	n/a	n/a
74	Kazakhstan	Bozshakol Copper Mine	Operating	n/a	n/a	186	n/a	n/a
75	DR Congo	Kolwezi Copper Tailings Mine	Operating	n/a	n/a	113	n/a	n/a
76	Panama	Cobre Panamá Copper/Gold Mine	Construction	320 (expected for 2019)	1.73 (in terms of global production in 2013)	3058	0.38	1.47
77	Russia	Mikheevskoye Copper/Gold Mine	Construction	n/a	n/a	469	n/a	n/a
78	Mongolia	Wunugetushan Copper/Molybdenum Mine	Construction	n/a	n/a	370	n/a	n/a
79	USA	Pumpkin Hollow Copper Deposit	Construction	n/a	n/a	368	0.47	0.22
80	Peru	Mina Justa (Marcona) Copper Deposit	Construction	n/a	0.54	163	0.71	0.15

Source: Own research

B.3 Iron ore mines

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
1	Australia	Hamersley Iron Ore Mines	Operating	133.30	6.63	1804.50	61.7	1.06
2	Brazil	Vale Northern System (Carajas) Iron Ore Mines	Operating.	104.89	5.22	7183.90	66.7	4.23
3	Australia	Chichester Range Iron Ore Mines	Operating.	94.70	4.71	1471.00	57.4	0.87
4	Australia	Yandi Iron Ore Mine	Operating	77.19	3.84	866.00	57.1	0.51
5	Australia	Solomon Hub	Operating (since 2014)	75 (Prod. 2014)	3.73	674	29.6	1.40
6	Australia	Mount Newman Iron Ore Mines	Operating	68.22	3.39	1281.00	62.8	0.75
7	Australia	Robe River Iron Mines	Operating	62.40	3.10	502.00	59.3	0.30
8	Australia	Area C Iron Ore Mine	Operating	54.98	2.73	760.00	62.1	0.45
9	Brazil	Minas Centrais Iron Ore Complex	Operating	37.75	1.88	200.00	49.0	0.12
10	Brazil	Mariana Iron Ore Complex	Operating	37.70	1.87	535.40	45.5	0.31

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
11	Brazil	Itabira Iron Ore Complex	Operating	34.00	1.69	767.10	53.6	0.45
12	Australia	Hope Downs Iron Ore Mine	Operating	33.79	1.68	250.00	61.6	0.15
13	Brazil	Minas Itabirito Iron Ore Complex	Operating	30.97	1.54	467.70	56.6	0.28
14	South Africa	Sishen Iron Ore Mine	Operating.	30.94	1.54	983.90	59.1	0.58
15	Russia	Lebedinsky Iron Ore Mine	Operating	29.16	1.45	4589.90	34.0	2.70
16	Brazil	Paraopeba Iron Ore Complex	Operating	26.04	1.29	85.50	62.5	0.05
17	Brazil	Vargem Grande Iron Ore Complex	Operating.	21.94	1.09	100.60	50.5	0.06
18	Brazil	Germano Iron Ore Mine (Alegria)	Operating	21.74	1.08	624.00	44.7	0.37
19	Canada	Mont Wright Iron Ore Mine	Operating	18.10	0.90	2197.00	30.2	1.29
20	Russia	Mikhailovsky Iron Ore Mine	Operating	18.00	0.90	11000.00	40.0	6.47
21	Sweden	Kiruna Iron Ore Mine	Operating	17.10	0.85	684.00	48.2	0.40

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
22	Brazil	Casa de Pedra Iron Ore Mine	Operating	15.40	0.77	1471.00	47.8	0.87
23	Canada	Carol Iron Ore Mines	Operating	15.37	0.76	592.00	65.0	0.35
24	Russia	Stoylensky Iron Ore Mine	Operating	15.14	0.75	4939.00	0.0	2.91
25	Ukraine	Severny (Krivoi Rog) Iron Ore Mine	Operating	15.00	0.75	713.00	0.0	0.42
26	USA	Minntac Iron Ore Mine	Operating	14.60	0.73	573.00	0.0	0.34
27	Ukraine	Inguletsky Iron Ore Mine	Operating	13.62	0.68	444.00	0.0	0.26
28	Russia	Gusevogorskoye Vanadium/Iron Ore Mine	Operating	13.60	0.68	2704.70	16.3	1.59
29	Ukraine	Poltavskaya Iron Ore Mines	Operating	13.20	0.66	1440.00	31.4	0.85
30	South Africa	Khumani Iron Ore Mine	Operating	13.17	0.65	488.70	64.5	0.29
31	Sierra Leone	Tonkolili Iron Ore Mine	Operating	13.10	0.65	1280.00	0.0	0.75

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
32	India	Bailadila 14 Iron Ore Mine	Operating	11.20	0.56	161.80	67.0	0.10
33	Australia	Koolyanobbing Iron Ore Mine	Operating	11.10	0.55	78.10	60.9	0.05
34	Australia	Channar Iron Ore Mine	Operating	11.05	0.55	53.00	62.9	0.03
35	South Africa	Kolomela (Sishen South) Iron Ore Mine	Operating	10.81	0.54	203.40	64.7	0.12
36	India	Bailadila 5 Iron Ore Mine	Operating	10.30	0.51	225.60	66.5	0.13
37	Australia	Eastern Range Iron Ore Mine	Operating	10.05	0.50	47.00	62.7	0.03
38	Iran	Gole Gohar Iron Ore Mine	Operating	10.00	0.50	1345.00	0.0	0.79
39	Iran	Chadormalou Iron Ore Mine	Operating	10.00	0.50	398.90	55.0	0.23
40	Venezuela	San Isidro Iron Ore Mine	Operating	10.00	0.50	225.00	65.6	0.13
41	Sweden	Malmberget Iron Ore Mine	Operating	8.20	0.41	336.00	41.9	0.20

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
42	USA	Hibbing Iron Ore Mine	Operating	7.70	0.38	321.00	19.1	0.19
43	USA	Tilden Iron Ore Mine	Operating	7.50	0.37	714.20	0.0	0.42
44	Australia	Whyalla (Middleback Range) Iron Ore Mine	Operating	6.88	0.34	125.00	45.5	0.07
45	Peru	Marcona Iron Ore Mine	Operating	6.68	0.33	300.00	57.0	0.18
46	India	Donimalai Iron Ore Mine	Operating	6.64	0.33	80.60	0.0	0.05
47	Ukraine	Central (Krivoi Rog) Iron Ore Mines	Operating	6.58	0.33	396.20	0.0	0.23
48	Chile	Los Colorados Iron Ore Mine	Operating	6.57	0.33	243.70	46.4	0.14
49	Brazil	Usiminas Iron Ore Mines	Operating	6.50	0.32	260.00	0.0	0.15
50	Iran	Chogart Iron Ore Mine	Operating	5.50	0.27	1500.00	55.0	0.88
51	Mauritania	Guelb el Rhein Iron Ore Mine	Operating	5.50	0.27	550.00	37.0	0.32

No.	Country	Name	Status	Production 2013 (Mt)	% global production 2013	Reserve (Mt)	Ore grade in reserve (%)	% global reserve
52	China	Baima Iron Ore Mine	Operating	4.60	0.23	612.00	0.0	0.36
53	USA	Northshore (Babbitt) Iron Ore Mine	Operating	3.90	0.19	1063.10	25.0	0.63
54	Sierra Leone	Marampa (London Mining) Iron Ore Mines	Operating	3.39	0.17	531.60	31.2	0.31
55	China	An-qian Iron Ore Mine	Operating	3.00	0.15	1100.00	28.4	0.65
56	Brazil	Serra Sul Iron Ore Mine	Construction	90.00 (expected)	4.48 (expected)	4239.60	66.0	2.49
57	Ukraine	Yeristovskoye Iron Ore Mine	Construction	30.00 (expected)	1.49 (expected)	632.00	32.0	0.37
58	Australia	Marillana Iron Ore Deposit	Construction	17 (expected)	0.85 (expected)	1049.5		

Source. Own research

C Matrices of EHP evaluation results by commodity

C.1 Bauxite

Name of mining operation	Principal mine owner	Country	Preconditions for	Paragenesis with heavy metals	Paragenesis with radioactive componenns	Deposit size	Ore grade	Mine type	Use of auxiliary substances	Mining waste	Remediation measures	Accident hazard	Water Stress Index	Protected areas and AZE sites
Huntly Bauxite Mine	Alcoa Mining	Australia	Low	Medium	Medium	High	High	High	Medium	Medium	Low	High	Low	Low
Willowdale	Alcoa Mining	Australia	Low	Medium	Medium	High	High	High	High	High	Low	High	Low	High
Weipa bauxite mine	Rio Tinto	Australia	Low	Medium	Medium	High	Low	High	Low	High	Low	High	Low	Low
Gove Operations Bauxite Mine	Rio Tinto	Australia	Low	High	Low	High	Medium	High	Low	High	Low	Low	Low	Medium
Amrun	Rio Tinto	Australia	Low	Low	Medium	High	Low	High	Low	High	Low	Low	Low	Low
Boddington (Worsley)	South 32	Australia	Low	Medium	Medium	High	High	High	High	High	Low	High	Low	Low
Juruti Bauxite Mine	AWAC – Alcoa World Alumina and Chemicals	Brazil	Low	High	Low	Medium	Low	High	Low	Medium	Medium	High	Low	Low
Miraí Bauxite Mine	Companhia Brasileira de Aluminio (CBA)	Brazil	Low	Medium	Medium	Medium	High	Medium	Low	High	Low	Low	Low	Low

Paragominas Mine	Norsk Hydro	Brazil	Low	Medium	Medium	High	Low	High	Low	Low	Low	High	Low	Low
Trombetas Bauxite Mine	Vale S.A.	Brazil	Low	Medium	Medium	High	Low	High	Low	Low	Low	Medium	Low	Medium
Pingguo	Aluminium Corp. of China Ltd (CHALCO)	China	Low	Medium	Medium	High	Low	High	High	High	Low	High	Low	Low
Xiaoyi Bauxite Mine	Chalco	China	Low	Medium	Medium	Low	Low	Medium		High	High			
Koumbia Bauxite Deposit	Alliance Mining Commodities (AMC)	Guinea	Low	Medium	Medium	High	Low	Medium	Low			Medium	Low	Low
Sangaredi	Halco Mining Inc	Guinea	Low	Medium	Medium	High	Low	Medium	Low	High	High	High	Low	Low
Kindia Bauxite Mine	RUSAL	Guinea	Low	Medium	Medium	Medium	Low	High	Low	Medium	Low	Medium	Low	Medium
Dian Dian Bauxite Deposit	RUSAL	Guinea	Low	Medium	Medium	High	Medium	High		Medium	Medium	Medium	Low	Low
Panchpatmali	National Aluminium Co. Ltd (NALCO)	India	Low	Medium	Medium	High	Medium	High	Low	High	Low	Low	High	Low
Discovery Bay	New Day Aluminum LLC	Jamaica	Low	Medium	Medium	High	Medium	High	Low	High	Low	Medium	Low	Low
Jamalco/May Pen Bauxite Mine	Noble Group	Jamaica	Low	Medium	Medium		Low	High	Low	Low	Low	High	Low	Medium

Krasnooktyabrsk Bauxite Mine	Eurasian Resources Group (ERG)	Kazakhstan	Low	Medium	Low	High	Low	Medium	High	High	Low	Low	Low	Low
Middle Timana Bauxite Mine	RUSAL	Russia	Low	Medium	Low	High	Medium	High	Low	Low	Medium	Low	Low	High
North Urals Bauxite Mine	RUSAL	Russia	Low	Medium	Low	High	Medium	Low	Low	High	High	Low	Low	Low
Al' Ba'itha	Ma'aden	Saudi Arabia	Low	Medium	Medium	High	Low	High	Low	Medium	Medium	Low	High	Low
Los Pijiguaos bauxite mine	Venezuelan government	Venezuela	Low	Medium	Low	High	Medium	High	Low	Low	Low	High	Low	Low

C.2 Copper ore

Name of mining operation	Principal mine owner	Country	Preconditions for acid mine drainage	Paragenesis with heavy metals	Paragenesis with radioactive components	Deposit size	Ore grade	Mine type	Use of auxiliary substances	Mining waste	Remediation measures	Accident hazard	Water Stress Index	Protected areas and AZE sites
Alumbrera	Glencore	Argentina	High	High	Medium	High	High	Medium	High	Medium	Medium	Medium	Medium	Low
Olympic Dam	BHP Billiton	Australia	High	High	High	High	Medium	Low	High	High	Low	Medium	High	Low
Mount ISA Copper	Glencore	Australia	High	High	Medium	High	Medium	Low	High	High	Medium	Low	Low	Low
Sossego Copper Mine	Vale S.A.	Brazil	High	High	Medium	Medium	Medium	Medium	High	High	Medium	High	Low	Low
Highland Valley	Teck Resources	Canada	High	High	Medium	High	High	Medium	High	High	Low	Medium	Low	Low
Collahuasi	Anglo American	Chile	High	High	Low	High	Medium	Medium	High	High	Low	High	High	Low
Los Bronces	Anglo American	Chile	High	High	Medium	High	Medium	Medium	High	High	Low	High	High	Low
Centinela (Esperanza)	Antofagasta	Chile	High	High	Medium	High	High	Medium	High	Medium	Medium	High	High	Low

Los Pelambres	Antofagasta	Chile	High	High	Medium	High	Medium	Medium	High	High	Low	High	High	Low
Zaldívar	Antofagasta/Barrick Gold	Chile	Low	High	Medium	High	High	Medium	High	Medium	Low	High	High	Low
Escondida	BHP Billiton	Chile	High	High	Medium	High	Medium	Medium	High	Medium	Medium	High	High	Low
Spence (Pampa Norte)	BHP Billiton	Chile	High	High	Medium	High	High	Medium	High	High	Low	High	High	Low
Andina Copper Mine	Codelco	Chile	High	High	Medium	High	Medium	Medium	High	High	Medium	High	High	Low
Chuquicamata Copper Mine	Codelco	Chile	High	High	Medium	High	Medium	Medium	High	High	Medium	High	High	Low
El Teniente	Codelco	Chile	High	High	Medium	High	Medium	Low	High	High	Low	High	High	Low
Gabriela Mistral	Codelco	Chile	Low	High	Medium	Medium	High	Medium	High	High	Low	High	High	Low
Radomiro Tomic	Codelco	Chile	Low	High	Medium	High	High	Medium	High	Medium	Low	High	High	Low
El Abra	Freeport-McMoran	Chile	High	High	Medium	High	Medium	Medium	High	High	Low	High	High	Low
Candelaria Copper Mining Complex	Lundin Mining	Chile	High	High	Medium	High	Medium	Medium	High	High	Medium	High	High	Low

Tenke Fungurume	China Molybdenum Co., LTD.	DRC	High	High	Medium	High	Medium	Medium	High	High	Medium	Low	Low	Low
Mutanda	Glencore	DRC	Low	High	Medium	High	Medium	Medium	High	High	Medium	Low	Low	Low
Kamoto Mine	Katanga Mining Limited	DRC	High	High	High	High	Low	Low	High	High	Medium	Low	Low	Low
Grasberg	Freeport McMoran	Indonesia	High	High	Medium	High	Medium	Medium	High	High	Medium	High	Low	High
Sar-Cheshmeh	National Iranian Copper Industries Co. (NICICO)	Iran	High	High	Medium	High	Medium	Medium	High	High	High	High	High	Low
Zhezkazgan Copper Mine	KAZ Minerals	Kazakhstan	High	High	Medium	Medium	Low	Low	High	High	Low	Low	High	Low
Buenavista del Cobre	Grupo Mexico	Mexico	High	High	Medium	High	High	Medium	High	High	High	Low	High	Medium
La Caridad Copper Mine	Southern Copper Corporation	Mexico	High	High	Medium	High	High	Medium	High	High	High	Low	High	Low
Erdenet Copper Mine	State of Mongolia/Erdenet	Mongolia	High	High	Medium	High	High	Medium	High	High	Low	Medium	Low	Low

Cobre Panamá	First Quantum Minerals	Panama	High	High	Medium	High	High	Medium	High	Medium	Medium	High	Low	Medium
Toromocho Copper Mine	Aluminium Corp of China Ltd (CHALCO)	Peru	High	High	Medium	High	Medium	Medium	High	High	Medium	High	High	Low
Cerro Verde	Freeport-McMoRan	Peru	High	High	Medium	High	High	Medium	High	Low	Low	High	High	Low
Antamina	Glencore	Peru	High	High	Medium	High	Medium	Medium	High	High	Low	High	Low	Low
Antapaccay Copper Mine	Glencore	Peru	High	High	Medium	High	High	Medium	High	High	Low	Medium	Low	Low
Toquepala Copper	Grupo Mexico	Peru	High	High	Medium	High	Medium	Medium	High	High	Medium	High	High	Low
Las Bambas	MMG	Peru	High	High	Medium	High	Medium	Medium	High	High	Low	High	Low	Low
Cuajone	Southern Copper (Grupo Mexico)	Peru	High	High	Medium	High	Medium	Medium	High	High	Low	High	High	Low
Polkowice-Sieroszowice	KGHM Polska Miedź S.A.	Poland	High	High	Low	High	Medium	Low	High	High	Low	Low	Low	Low
Rudna	KGHM Polska Miedź S.A.	Poland	High	High	Low	High	Medium	Low	High	High	Low	Low	Low	Low
Norilsk-1 Deposit and	Nornickel	Russia	High	High	Medium	High	Medium	Low	High	High	High	Medium	Low	Low

Talnakh Ore Field														
Morenci Copper Mine	Freeport-McMoRan	USA	High	High	Medium	High	High	Medium	High	High	Low	High	High	Low
Bingham Canyon Mine	Rio Tinto	USA	High	High	Medium	High	Medium	Medium	High	Medium	Medium	High	High	Medium
Lumwana	Barrick Gold Corporation	Zambia	High	High	High	High	Medium	Medium	High	High	Low	Low	Low	Medium
Kansanshi	First Quantum	Zambia	Medium	High	Medium	High	Medium	Medium	High	High	Low	High	Low	Low
Sentinel	First Quantum	Zambia	High	High	Low	High	Medium	Medium	High	High	Medium	Low	Low	Low

C.3 Iron ore

Name of mining operation	Principal mine owner	Country	Preconditions for acid mine drainage	Paragenesis with heavy metals	Paragenesis with radioactive components	Deposit size	Ore grade	Mine type	Use of auxiliary substances	Mining waste	Remediation measures	Accident hazard	Water Stress Index	Protected areas and AZE sites
Yandi Iron Ore Mine	BHP Billiton	Australia	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	High	Low
Mount Newman Mine	BHP Billiton	Australia	Medium	Medium	Medium	High	Low	Medium	Medium	High	Low	Medium	High	Low
Area C	BHP Billiton	Australia	Medium	Medium	Medium	High	Low	Medium	Medium	Low	Low	Medium	High	Low
Marillana	Brockman Mining Limited	Australia	Medium	High	Medium	Medium	Medium	Medium	Medium	High	Low	Medium	High	Low
Chichester Range Iron Ore Mines	Fortescue Metals Group Ltd.	Australia	Medium	Medium	Medium	High	Medium	Medium	High	Low	Low	Medium	High	Low
Solomon Hub	Fortescue Metals Group Ltd.	Australia	Medium	Medium	Medium	Medium	Medium	Medium	High	High	Low	High	High	Low
Hamersley Iron Ore Mines	Rio Tinto	Australia	Medium	Medium	Medium	High	Low	Medium	Low	High	Low	High	High	High
Robe River Iron Ore Mines	Rio Tinto	Australia	Medium	Medium	Medium	Medium	Medium	Medium	Medium	High	Low	High	High	Low

Hope Downs Iron Ore Mine	Rio Tinto	Australia	Low	Medium	Medium	Medium	Low	Medium	Medium	High	Low	Medium	High	Low
Casa de Pedra	CSN	Brazil	Medium	Medium	Low	High	Medium	Medium	High	High	Medium	High	Low	Low
Northern System Carajas	Vale S.A.	Brazil	Low	Medium	Medium	High	Low	Medium	Low	Low	Low	Medium	Low	Medium
Minas Centrais Complex	Vale S.A.	Brazil	Medium	Medium	Medium	Medium	Medium	Medium	High	High	Medium	High	Low	Medium
Mariana Iron Ore Complex	Vale S.A.	Brazil	Medium	Medium	Medium	High	Medium	Medium	High	High	Medium	Medium	Low	High
Itabira Iron Ore Complex	Vale S.A.	Brazil	Medium	Medium	Medium	High	Medium	Medium	High	High	High	Medium	Low	Low
Minas Itabirito Iron Ore Complex	Vale S.A.	Brazil	Medium	Medium	Medium	High	Medium	Medium	High	High	High	Medium	Low	Medium
Paraopeba Iron Ore Complex	Vale S.A.	Brazil	Medium	Medium	Medium	Medium	Medium	Medium	High	High	High	Medium	Low	High
Vargem Grande Iron Ore Complex	Vale S.A.	Brazil	Medium	Medium	Medium	Medium	Medium	Medium	High	High	High	Medium	Low	Medium
Mont-Wright mine	ArcelorMittal	Canada	Medium	Medium	Medium	Medium	Medium	Medium	Medium	High	Low	Low	Low	Low
Carol Lake	Rio Tinto	Canada	Medium	Medium	Medium	High	Low	Medium	Low	High	Low	High	Low	Low

Gole Gohar	Golgohar Mining & Industrial Co.	Iran	Medium	High	Medium	Medium	Medium	Medium	Medium	High	High	High	High	Medium
Chogart	National Iranian Steel Co. (NISCO)	Iran	Medium	Medium	Low	Medium	Medium	Medium	Low	High	High	High	High	Medium
Guelb el Gheïn Iron Ore Mine	SNIM	Mauretania	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	High	Low	High	Low
Lebedinsky	Metalloinvest	Russia	Low	Medium	High	High	Medium	Medium	Low	Medium	Medium	High	Medium	High
Mikhailovsky	Metalloinvest	Russia	Low	Medium	Medium	High	Medium	Medium	Low	Low	Medium	High	Low	Low
Stoilensky	NLMK	Russia	Low	Medium	Medium	High	Medium	Medium	Low	High	Low	High	Medium	Low
Sishen	Anglo American	South Africa	Low	Low	Medium	High	Low	Medium	Medium	High	Medium	High	High	Low
Kiruna	Swedish State	Sweden	Medium	Medium	Medium	High	Low	Low	Low	High	Low	Medium	Low	Low
Yeristovo	Ferrexpo Yeristovo Mining (FYM)	Ukraine	Low	Medium	Medium	Low	Medium	Medium	Low	Low	Medium	High	Low	Low
Ingulets	Metinvest (Smart N.V.)	Ukraine	Low	Medium	Medium	Medium	Medium	Medium	High	Low	Low	High	Low	Low
ArcelorMittal Ukrainian Mines	PJSC ArcelorMittal Kryvyi Rih	Ukraine	Medium	Medium	Medium	Medium	Medium	Medium	Medium	High	Low	High	Low	Low

Tilden	Cleveland Cliffs Inc.	USA	Medium	High	Medium	Medium	Medium	Medium	High	High	Medium	High	Low	Medium
Minntac	United States Steel	USA	Medium	Medium	Medium	Medium	High	Medium	High	High	High	High	Low	Low

D Revised measurement instructions

A revised edition of the measurement instructions for the site-related OekoRess evaluation method is provided as a separate document.

E Evaluation scheme for potential environmental impacts from mining – site-related evaluation

	Field	Goal	Indicator	Evaluation of environmental hazard potential		
				Low	Medium	High
Geology	Raw material-specific	Avoiding pollution risks	Preconditions for acid mine drainage (AMD)	Geochemical preconditions for AMD do not exist	Geochemical preconditions for AMD exist in part	Geochemical preconditions for AMD exist
			Paragenesis with heavy metals	The deposit has no elevated heavy metal concentrations	The deposit has slightly elevated heavy metal concentrations	The deposit has strongly elevated heavy metal concentrations
			Paragenesis with radioactive components	The deposit has low uranium and/or thorium concentrations	The deposit has slightly elevated uranium and/or thorium concentrations	The deposit has elevated uranium and/or thorium concentrations
	Deposit-specific	Limiting the direct impacts on ecosystems	Deposit size	Small	Medium	Large
		Limiting the effort for extraction	Ore grade	Rich	Medium	Poor
Technology	Mining-specific	Limiting the direct impacts on ecosystems	Mine type	Underground mining	Solid rock open pit mining	Alluvial or unconsolidated sediment mining
	Processing-specific	Avoiding pollution risks	Use of auxiliary substances	Without auxiliary substances	With auxiliary substances	With toxic reagents

	Field	Goal	Indicator	Evaluation of environmental hazard potential		
				Low	Medium	High
	Management-specific	Minimising risks from mining waste	Mining waste	Safe storage/deposition of tailings in the deposit	Among others, stable mine heaps, marketing of mine residues	Risky deposition, unstable tailings ponds, no tailings management system
		Minimising longevity of impacts	Remediation measures	Process-parallel rehabilitation	Financial accruals for rehabilitation	No provisions
Site (framework conditions)	Natural environment	Avoiding natural accident hazards	Accident hazard due to floods, earthquakes, storms, landslides	All sub-indicators exhibit a low accident hazard (green)	At least one sub-indicator exhibits a medium accident hazard (yellow), none a high accident hazard*	At least one sub-indicator exhibits a high accident hazard (red)
		Avoiding competition over water usage	Water Stress Index (WSI) and desert areas	Low water stress	Moderate water stress	Severe water stress or desert region
		Protecting/preserving valuable ecosystems	Protected areas and AZE sites	No relation to protected areas or AZE sites	AZE site or protected area (e.g. IUCN Cat. V-VI, national reserve)	Highly protected area (e.g. World Heritage Site, IUCN Cat. I-IV)
	Social environment	Avoiding environment-related conflicts in resource usage	Previous ‘conflict potential with local population’ indicator (2 Worldwide Governance Indicators) has been withdrawn and should be replaced by a site-specific			

	Field	Goal	Indicator	Evaluation of environmental hazard potential		
				Low	Medium	High
			indicator, which is currently not available			

* Natural accident hazards for the Arctic are generally evaluated conservatively with yellow (medium potential) due to lack of hazard maps
Green = low EHP; yellow = medium EHP; red = high EHP, Source: modified matrix based on Dehoust et al. (2017), modifications by Projekt-Consult, ifeu Institut and Öko-Institut.