

Recreating and Extending the EU Critical Raw Material Assessment with a Transparent, Automated Tool

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Abstract

To support the Critical Raw Material (CRM) Act the European Commission (EC) published five CRM reports between 2011 and 2023 assessing what materials are critical. While the EC provides context for its assessments, it faces the same limitation as other CRM assessment methods: the inability to publish the underlying primary data. To improve the reproducibility in CRM assessments this work introduces a toolkit that processes primary data sources into a standardized database and uses it to calculate assessment results. While the tool can be employed for many assessment methods this work focuses on recreating the results of the EC's 2023 report. The supply risk was calculated for 78 of the 83 materials within the 2023 report. For these 78 materials the supply risk could be recreated to within a 0.2 mean deviation over all materials. The results of 63 materials could be recreated with less than or equal to 0.2 deviation. Of the remaining 15 materials, 12 deviate due to the lack of expert knowledge employed by the EC. To evaluate the results further the time frame of the 2023 report is extended by four years to represent a potential 2027 report. This ultimately shows that the toolkit can provide results before official reports while also enabling instant assessment calculation, easy updating of underlying data, and the documentation needed to assure reproducibility.

Keywords: criticality assessment, critical raw materials, database , supply risk, criticality assessment tool

1 Introduction

The European Commission (EC) demonstrated its commitment to mitigating risks of raw material supply shortages within the European Union's (EU's) economy with the introduction of the Critical Raw Materials (CRM) Act [1]. Its goal of increasing domestic production, refining and recycling of critical and strategic materials is a direct response to the increasing supply concentration of important materials within third party countries. To counteract this development the CRM Act proposes to keep the reliance on a single third party country below 65%. In turn, this increases the raw material supply chain resilience as the dependency of other countries is decreased.

With the CRM Act the EC also aims to cover 25% of the EU’s annual consumption of raw materials via recycling, which is an opportunity for the circular economy.

However, to achieve these goals it is important to first determine which materials already fulfill the goals set by the CRM Act and which need improvement. As some materials are more important to the EU than other materials, it is essential to concentrate not on the bulk materials but on the most important materials for the EU economy. To determine what materials are critical to the EU economy, due to overreliance on third party countries and to estimate the current status of domestic production, refining and recycling of these materials the EU regularly publishes updates on the status of CRMs in the EU. Currently there are five reports with the first being published in 2010 [2], then in 2014 [3], 2017 [4], 2020 [5] and the most recent being published in 2023 [6]. Within these reports the EC presents results of their criticality assessment. These assessments follow a product-centric approach as they focus on the technologies needed in the EU and follow their product life cycle, from mining to production. Therefore, the supply chain risk and the economic importance of a technology in the EU are one of the main messages of these reports.

The concept of determining material criticality through an assessment has a history of 20 years. First concepts of these assessments were established in 2008 by the National Research Council (NRC) of the US [7]. Whilst most resource shortages are often caused by natural disasters or military conflicts, an assessment of raw material criticality provides insight into the level of risk associated with raw material shortages. Today the shortages are present in most supply chains, and detailed analysis of existing CRM assessments already exists within the field. These range from general overviews [8], to sustainability based [9] to corporate focus [10].

While this work focuses on the EU’s CRM assessment as an example the presented approach to the assessment process can be adapted to any other assessment method. The presented approach aims to address multiple limitations in the process of the assessment. To highlight the current limitations in the field of criticality assessment the following chapter is a review of the documentation, data availability and assessment process of multiple assessment methods.

2 Criticality Assessment Landscape

Criticality assessments are often time intensive processes where experts are required to screen many different data sources with various data formats across multiple databases. The complexity of this task creates a need for a detailed documentation to ensure reproducibility. While the publication of the primary data used for the assessment would reduce the demand for source documentation significantly, this data is rarely published. This causes a large limit to the reproducibility of many assessment methods. This chapter investigates how the EC and other researchers deal with this limitation.

Starting with the first report in 2010 the EC started documenting the data sources they employed, listing every material and the used data source in the annex [2]. With the 2017 report [4] the methodology was revised and a document explaining the assessment method was published [11]. The report from 2017 is supported by multiple annex

documents that link materials to the data sources used, two factsheets listing facts for all critical and non-critical materials while citing the data sources, and another document providing a table of all used sources per data type and material. Starting with the 2020 report the SCRREEN project [12] was introduced as an expert network to support the creation of the EC’s reports. As a consequence the 2020 report [5] is missing data source documentation as the report itself states that the documentation can be found in the factsheets now created by the SCRREEN project. However, in the latest report in 2023 [6], an annex table was added including a list of data source citations. Unlike the document provided with the 2017 report most of these data sources cannot be linked to individual materials within the report. This link is provided in the SCRREEN2 factsheets [13].

In addition to the documentation provided by the SCRREEN projects, the Raw Materials Information System (RMIS) [14] was developed by the European Commission’s Joint Research Centre to provide comprehensive, structured knowledge on raw materials across their entire life cycle and value chains. It integrates data on supply, demand, sustainability, and risks, helping policymakers and stakeholders understand issues like critical raw materials, circularity, and resilience. RMIS supports EU policy (e.g., the Critical Raw Materials Act) by delivering coherent, high-quality information, foresight analyses, and timely insights in response to changing geopolitical and industrial needs. In essence, it acts as a central knowledge hub and interface connecting data, stakeholders, and policy decision-making in the raw materials domain. Together, the 2023 report, SCRREEN2 factsheets, and RMIS provide insight into the EC’s assessment process.

Other CRM assessment methods employ different forms of documentation to assure reproducibility. Some researchers outside the EC’s CRM assessment include insightful supplementary materials to their work. Often these are complex Excel files that contain meticulously collected data, but are missing calculation functionality. Experts spent much time collecting this data from individual public sources. Unfortunately this conventional method of assessment often is just a snapshot of criticality at the creation of these files and updating the results with new data often requires knowledge of the individual expert’s workflow. It is therefore a common issue that the data gathered in CRM assessments varies in data source, data format and data clarity. Many researchers are aware of these problems and within the literature active attempts to mitigate these problems can be found. One of these can be seen in the publications of the ESSENZ method. After introduction of the method by Bach et al. [15] regular updates have been published containing extensive supplementary material first in pdf format [16] and later on in detailed Excel tables [17]. Similar to the EU reports these updates include general results for the assessed materials not connected to specific use cases [18]. The ESSENZ methodology is an integrated assessment framework used to evaluate the criticality of raw materials at product level, combining supply risks, environmental, and social aspects across the full life cycle. ESSENZ defines multiple criticality categories (e.g., supply risk, market concentration, political stability), each quantified through specific indicators. These indicator values are compared to predefined target values using a “distance-to-target” (DtT) approach, which normalizes how critical a material is relative to acceptable thresholds. Criticality in ESSENZ reflects

both the likelihood of supply disruption (supply risk) and the importance of the material for the system, allowing comparison and prioritization of raw materials based on their overall risk profile. While the EU CRM Assessment is mainly addressing policy-makers and stakeholders, the ESSENZ method allows a company specific view.

Another assessment method commonly referred to as the Augsburg Method receives regular updates tied to specific use cases. Publications of use cases employing this criticality assessment usually include detailed supplementary material containing interim result further breaking down the results presented in the initial work [19]. The Augsburg method is more flexible and research-driven in comparison to the EU method, allowing a broader set of indicators and adjustable weightings to specific scenarios or industries. As a result, the EU method provides clear, comparable rankings, while the Augsburg approach delivers more context-dependent criticality assessments. It is therefore suitable for comparing technologies and for forecast scenarios. Additionally, a recent publication by Hillenbrand et al. [20] includes a very detailed supplementary Python workflow [21], giving valuable insight into the assessment process.

A similar use case based approach is common for publications related to the GeoPolRisk method.[22] Additionally, there are publications specifically designed to develop the method further [23]. While unfortunately some of the GeoPolRisk publications are missing supplementary material, a supply risk assessment tool called GeoPolRisk-py was published. which provides the data and the calculations necessary to do the GeoPolRisk assessment [24]. The GeopolRisk method assesses raw material criticality by quantifying supply risk based on geopolitical stability of producing countries, weighting country-level governance indicators (e.g., political stability) by their share in global production. In contrast, EU criticality methodology evaluates materials using a broader framework, combining supply risk (including trade, substitution, and recycling factors) with economic importance to the EU economy. Thus, GeopolRisk is a narrow, geopolitics-focused supply risk indicator, while the EU approach is a multi-dimensional assessment integrating both risk and economic relevance.

While GeoPolRisk-py serves a similar function as the tool presented within this work, the presented has more advanced features. Users can choose from and combine multiple different datasources, while GeoPolRisk-py is reliant on the database provided within the tool. This database needs to be updated with every data release, while the presented toolkit is compatible with future data releases, as long as there is no major change in data format. Additionally, the toolkit aims to include multiple assessment methods and the existence of GeoPolRisk-py promises easy implementation of the GeoPolRisk method.

While GeoPolRisk-py is the only published tool comparable to the one presented in this work, frameworks for similar tools have been developed [25].

3 Methodology

To mitigate the problems found in the CRM assessment landscape this work presents a toolkit for an automatic, dynamic and transparent criticality assessment [26]. This tool will be evaluated through testing the reproducibility of the EC’s assessment. To better discuss the results of the toolkit, a brief summary of the EC’s methodology follows.

3.1 EU Criticality Method

Basis of the results published within the EU’s CRM reports is a methodology for material criticality assessment designed specifically for the EC. The newest CRM report itself does however not go into detail about the applied method. To recreate and understand the methodology and calculations other sources are required. First the EC itself published a supplementary work about the method [11], secondly the SCRREEN2 project [13] produced a working paper which highlights the effects of the parameters on the calculations [27].

To summarize, the EU Method is based on classical risk assessment including two dimensions: the likelihood of a disruption event to occur and the damage it would cause. [28] The EU uses two indicators for this, the risk of supply disruption of a material and the importance of the material to the EU economy, respectively. A material is deemed to be critical if it exceeds a threshold of both of these indicators.

In classical risk assessment the economic importance represents the impact a disruption would have on the EU economy. It is calculated by adding up the importance of the material in each EU manufacturing sector s . This is then corrected by the material’s overall sustainability represented by the substitution index (SI_{EI}).

$$EI = \sum_s (A_s \cdot Q_s) \cdot SI_{EI} \quad (1)$$

The sector-specific importance is calculated by the share of the end use of the raw material in that sector (A_s) and the added value of that sector (Q_s) according to NACE Rev.2.

The supply risk represents the likelihood of a disruption event to occur, which is the second factor in classical risk assessment. It is largely based on the Herfindahl-Hirschman Index (HHI), which represents concentration of countries producing a material. It ranges from 0 to 10000, where an HHI of 10000 indicates that 100% of a material is produced in a single country and the country therefore has a monopoly on the material’s production. A high HHI is therefore associated with a high risk of disruption.

To also consider the governance of the supplying countries the EU weights the share S_c of countries c with two additional factors. First is the World Governance Index (WGI) [29] which is an index that judges countries on six dimensions: Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption. As published these values are scaled from -2.5 to 2.5, with 2.5 being the best value for a stable country. However, for the calculation of the weighted HHI the EU adjusts these values to scale from 10 to 0 with 0 being the best achievable value. In addition to the rescaling of the values the EU uses a mean value of all six dimensions, resulting in the scaled WGI_c value used in the EU’s HHI calculation.

Ultimately, to reflect trade agreements and tariffs the share of each country is also modified by a trade parameter t_c . This trade parameter ranges from 0.8 to 1.5 where EU member countries are assigned a value of 0.8, countries with a beneficial trade agreement with the EU are assigned a value < 1 and countries with any tariffs or other

effects negatively affecting trade are assigned a value > 1 . Considering the nature of tariffs the trade parameter t_c is also dependent on the material that is considered. With the World Governance Index WGI_c and the trade parameter t_c modifying the share S_c of countries c producing a specific material the weighted HHI for the material is calculated as follows:

$$HHI_{WGI} = \sum_c (S_c)^2 WGI_c \cdot t_c \quad (2)$$

In the EU’s methodology the HHI is calculated for two scenarios: the global supply and the EU supply of the material. The global supply is represented by the total production of the material in every country of the world, while the EU supply is based on the total import to the EU market per country outside the EU and the total production of the material for EU member countries.

Both of these HHI values are then modified by the EU’s import reliance IR for the material. The reason for this is that if the EU is self sufficient the import reliance IR would be 0 and the global supply should not be considered in the supply risk calculation. However, if the EU is dependent on import and the reliance value is 1, the EU supply is still considered as it was chosen to scale the import reliance $IR/2$ to always consider at least 50% of the EU supply.

The last modifiers necessary for the supply risk calculation are the recycling of the material in form of the end-of-life recycling rate EoL_{RIR} , which is considered since a higher recycling rate causes less dependency on the supply of the production of the material and substitution factor SI_{SR} , describing how well the material can be substituted by other materials.

Ultimately, the supply risk according to the EU methodology can be calculated as follows:

$$SR = [(HHI_{WGI,t})_{GS} \cdot \frac{IR}{2} + (HHI_{WGI,t})_{EU} (1 - \frac{IR}{2})] \cdot (1 - EoL_{RIR}) \cdot SI_{SR} \quad (3)$$

3.2 Data Sources

The criticality assessment provided by the EC is build upon many different publicly available data sources and in specific cases expert knowledge. There is a inherent priority to the data used in the assessment with the following order: official EU data, EU member state data, international organisations and non-EU countries, and as a last resort industry data and expert knowledge. [11] The following chapter presents the public data used to reproduce the EC’s assessment in this work, which can also be seen summarized in Table 1.

Arguably the most important data for the assessment is that of material production per country. This data is reported by several institutions, one dataset is the World Mining Data (WMD) provided by the Austrian Federal Ministry of Finance (BMF) [30], which has a high priority in the assessment as it is provided by an EU member state. Other data also includes the British Geological Survey’s (BGS) World mineral statistics data [31] and the Unites States Geological Survey’s (USGS) Minerals Yearbook [32] and Commodity Summaries [33]. Each of these datasets reports different

Table 1 All data sources used in this work to recreate the EU assessment

Datatype	Used Sources
Material production	WMD [30], BGS [31], USGS [32, 33]
Material trade	Eurostat [34]
Governance indicators	World Bank [29]
Substitution, recycling and trade parameters	EC CRM Report [6]
Material specific source assignment	SCRREEN2 [13], RMIS [14]

materials, with substantial overlap among the most common materials. For the EC’s criticality assessment all three sources are required for different materials.

Almost as essential to the assessment is the international trade of materials. Within the EU CRM reports the main source for this data is the Eurostat database “EU trade since 1988 by HS2-4-6 and CN8 (DS-045409)” [34]. In this dataset the trade of products between a reporting EU member state and a partner country is provided. Within the dataset the products are categorized using the EU’s Combined Nomenclature (CN), which is an extension of the Harmonized System (HS) Code. Since these codes are primarily used for EU customs they are a lot more complex than the material list considered for the assessment. This causes some materials to be represented by multiple codes and other codes representing multiple materials, therefore these codes need to be linked to each material in the assessment.

Another important data source for the supply risk calculation are the World Governance Indicators (WGI) published by the World Bank [29]. The indicator used in the assessment is made up of multiple individual indicators published by the World Bank, which judge the governance of countries on six different dimensions: Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption. These values are reported for each country and require little pre-processing, or sorting.

Some data used in this work was acquired directly from the latest EU report. [6] This data includes many values that are not reported regularly including the end-of-life recycling rates and the substitution factors. But also values like the import reliance, the trade parameters, or the economic importance. While these values could technically be calculated, it was decided not to calculate them, to limit the scope of this work. While these values initially stem from other sources the EU report will be cited as they were modified by the EU experts.

Currently it is assumed that the EoL values of the materials stay consistent over the years as they were used in the EU report. However, this assumption is very dependent on the published EU reports. As a source for the EoL the report is using a report on metal recycling rates published in 2011 [35] and the EU’s own Material system analysis (MSA) reports [36]. The nature and the large effort put into these reports is out of scope for the application in the database. However, it could prove beneficial to explore extrapolation, or other methods to estimate these values for currently unknown time frames.

The substitutability of a material is a very complex value including every potential substitute material and their values like production, criticality and the share these materials have in each application where they could substitute the original material.

This makes the substitutability a very data intensive value to calculate. The scale of the required data to calculate the substitutability and its relatively small impact on the supply risk according to [27] has caused it to be deemed out of scope for this work and likely future database implementations.

As mentioned within chapter 2 the SCRREEN2 factsheets [13] and the documentation of RMIS [14] are essential for recreating the EU CRM assessment. They were employed to determine what data sources were used for which material within the report and to assign the CN8 trade codes to each material.

3.2.1 Missing Materials

Some materials present in the EU report are missing from the assessment performed in this work. These materials can be organized in two groups, one in which reproduction was not possible due to missing documentation and one in which materials are reliant on a material specific data source. The latter was not considered, in order to limit the scope of this work. All materials within these groups are explained in the following:

- **Noble Gases:** (Krypton, Neon, Xenon) The 2023 report references a publication from the Deutsche Rohstoffagentur (DERA) from 2018 [37]. However, there is no entry for noble gases in the RMIS documentation and there are no SCRREEN factsheets.
- **Wood:** (Natural teak wood, Roundwood, Sapele wood) the report cites expert knowledge and official EU data, which is not reproducible as this group of materials is missing in the RMIS documentation and SCRREEN factsheets.
- **Hydrogen:** Missing data, RMIS source is the Energy Institute [38]
- **Natural Cork:** Missing data, RMIS source is the Associação Portuguesa da Cortiça (APCOR)[39]
- **Natural Rubber:** Missing data, RMIS source is the Food and Agriculture Organization of the United Nations - FAOSTAT [40]

The above mentioned materials, are not yet supported in the presented tool due to missing data. However, it is possible to integrate new data, if available in the future. For all other materials of the EU CRM assessment data sources are available and the supply risk was calculated in this work.

4 Implementation

4.1 Data Processing

To create a tool that calculates the supply risk directly, it is necessary to bring the data sources into one standardized format. This was achieved by creating python scripts that can read the different source data files and standardize them in regard to units, material and country names, and structure.

The complexity of processing the source files highly depends on the publication format. While the BGS world mineral statistics data [31] can be downloaded in Excel format from their website, they also provide API access, making the data accessible for basic and advanced users. While not providing an API, the BMF provides the WMD releases

[30] in easy to read Excel format. The most processing is however required for the USGS mineral yearbook [32] data releases up to 2019. The format of the provided Excel files is not suitable for easy data extraction. Even worse, the USGS mineral commodity summaries [33] are only provided in pdf format up until 2021. However, the format for both USGS releases greatly improved beginning with the 2020 release of the mineral yearbook and the 2022 commodity summaries, which are now provided in well formatted Excel and csv files.

The remaining material trade and governance data are provided in useful formats. The data from Eurostat [34] comes in easy to read dat files, while the data from WorldBank [29] is provided in Excel format. Lastly, the data from the 2023 EU report [6] had to be extracted from the pdf release.

While processing the source data into a standardized format is an important task, the calculation of the supply risk also requires assignment of the correct source for each material. Additionally, the source data needs to be categorized either into the 'extraction' or 'processing' category as used in the EU report. Finally to use the trade data the CN codes need to be assigned to the correct materials and categories. While the data source for some materials can be inferred from the report, it lacks a detailed source or CN code assignment. However, the documentation of RMIS [14], and the material factsheets published by the SCRREEN2 project [13] closely match the EU report. Therefore they are used to determine the source and CN codes of each material within this work. Each material was checked for alignment with the report, and whether RMIS or the SCRREEN2 factsheets matched it, the best-matching source data was used.

4.2 Database Design

After processing a local SQLite database is created with the source data. SQLite was selected to keep the toolkit flexible and lightweight. Within this work calculations of the supply risk were performed using SQL scripts. Alternatively a python script for calculating the supply risk is included in the public release of the toolkit [26]. The SQLite database can also be connected to an API using NodeJS, which enables the database to be used in other applications, as previously demonstrated for prototypes combining the database with life cycle assessment results [41] or repairability analysis [42].

The basis of this database are the *material*, *country* and *source* tables, which include basic information like the standardized names and an assigned id. Compared to the *material* and *country* table, the *source* table is more complex as it includes a direct link to the data source and the correct citation of the source.

With these three base tables it is possible to build the rest of the database, where tables always combine a material and/or country id with the source id, which is always included. This results in the table structures seen in Figure 1 that covers all data sources.

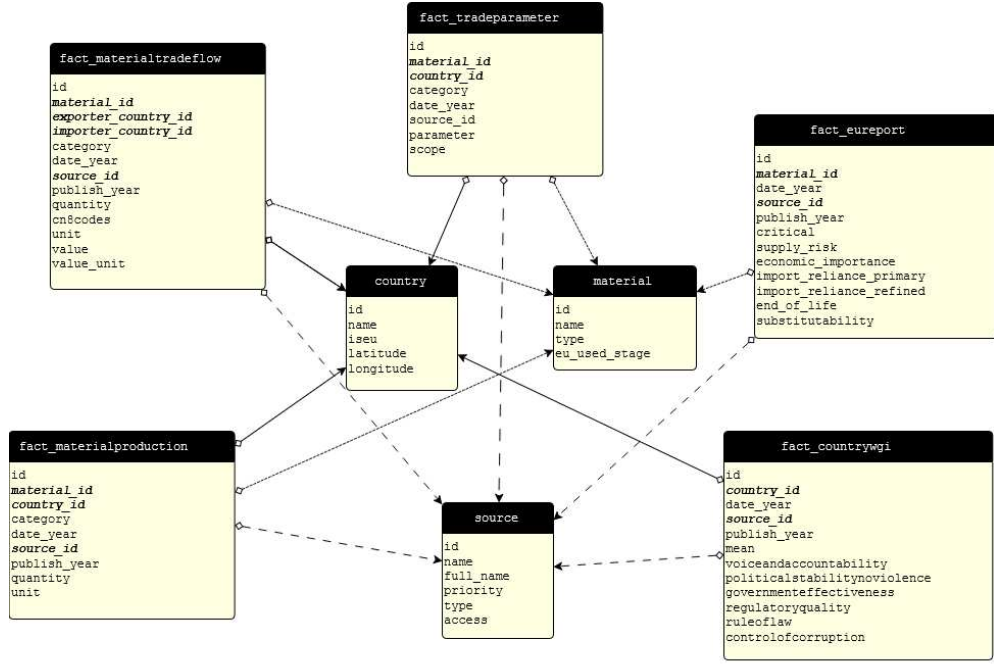


Fig. 1 Database shema showing the base *country*, *material* and *source* tables in the center, surrounded by the fact tables

In total five additional tables are integrated into the database for the supply risk calculation. Least complicated are the *countrywgi* and *eureport* tables. While the governance indicators in the *countrywgi* table are only dependent on a country, a reporting year and a publication year, the general material information found in *eureport* switches the country dependency for a material dependency. The more complicated tables start with the *materialproduction* table, which includes WMD [30], BGS [31] and USGS [32, 33] data. All these data sources share the same pattern with each production value being dependent on a material, producing country, production category, year of production, the source itself, and the year of publication. Similar behavior can be found in the *materialtrade* table, where Eurostat data [34] is stored. The trade data within this table shares the same dependencies as the production data, but changes the one country dependency to a two country dependency in the form of exporter and importer country. Lastly, the database also includes a *tradeparameters* table, whose data also stems from the EU report [34], but adds a production category and partner country dependence compared to the *eureport* table.

In addition to the different tables listed above, the database also includes multiple views. One of which is the *tradeparameter_permaterial* view. This view enables efficient storage of the tradeparameter values in the main *tradeparameter* table. Thanks

to the view the main table only includes parameters that diverge from the value 1 for non-EU countries, or 0.8 for EU member states. The view itself generates any missing trade parameters, by assigning missing EU members the value 0.8, and any other countries the value 1. Another essential view in the database is that of the *material-supply*. This view represents the EU supply of each material as used in the supply risk calculation. Ultimately, this view combines EU imports from non EU countries found within the *materialtrade* table and the production of EU countries found in the *materialproduction* table to determine the EU supply.

5 Results

The aforementioned dynamic nature of the database enables many different assessment outputs within seconds. For this work the toolkit is evaluated by reproducing the EU’s 2023 assessment. To achieve this the supply risk is calculated for the time frame 2016-2020, matching the report’s range. The mean difference in supply risk between the report and this work was found to be 0.2 ± 0.3 . Of all 78 materials analysed in this work a total of 63 materials have a supply risk difference ≤ 0.2 . To visualize the difference between the supply risk results of this work and the EU report, the former is plotted against the latter in the following Figure 2.

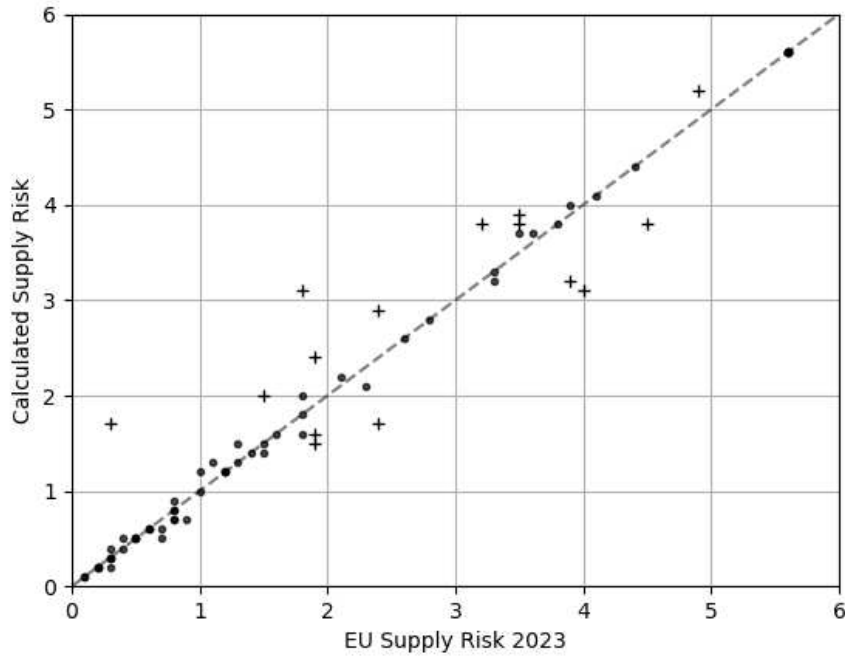


Fig. 2 Calculated supply risk compared to that published within the 2023 EU report. Materials with a difference in supply risk bigger than the mean difference (> 0.2) are highlighted (+)

5.1 Deviation Analysis

Within this work only 15 of the 78 analysed materials deviate from the EU assessment by more than 0.2 in the supply risk value. All of these materials are highlighted in Figure 2. Of these 15 materials six are Rare Earth Elements (REE) and two are Platinum Group Metals (PGM). Only the material tellurium has a different criticality status in this work than in the EU's report. All deviating materials can be seen in Figure 3. Each of these deviating materials is discussed further below.

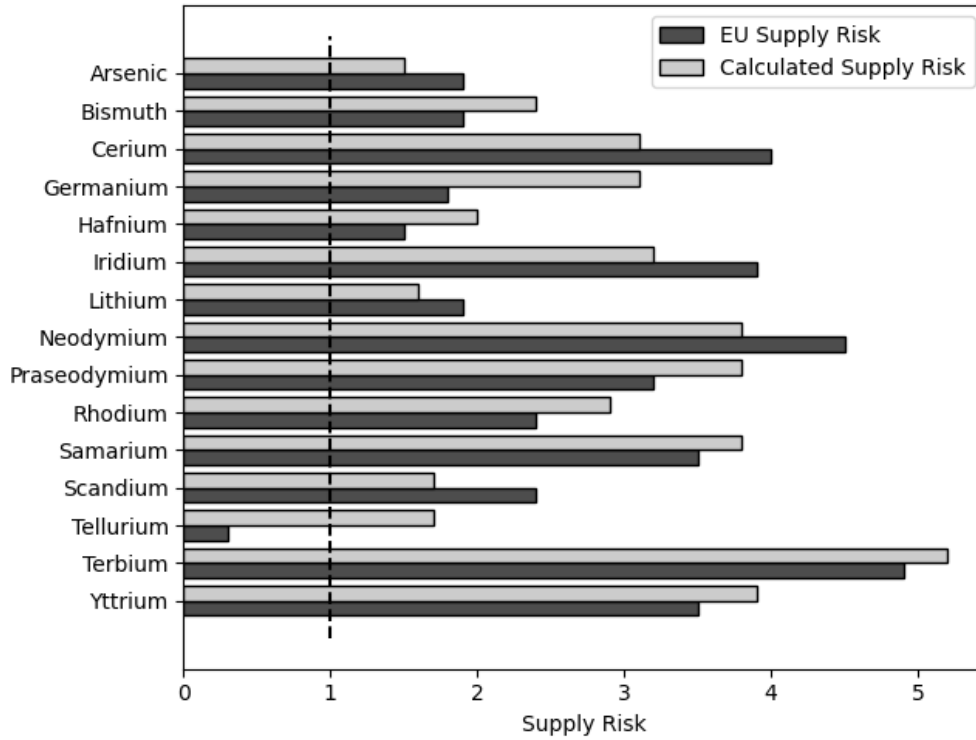


Fig. 3 Comparison of official EU supply risk and that calculated within this work, for materials deviating by more than 0.2 between the two

5.1.1 Arsenic

The supply risk calculated for arsenic within this work is 0.4 below the EU's. This is caused by a difference in the EU supply of arsenic metal. While the EU report, the SCRREEN2 factsheets and this work identify Belgium as the major supplier within the EU, the Belgian contribution is inconsistent. The EU report and the SCRREEN2 factsheets both report 59%. However, both show inconsistencies. Within Annex 8 the United Kingdom is reported as the main supplier of the EU with 44%, while a paragraph in the demand section of the factsheet reports Belgium with a contribution of 67% citing Eurostat [34] and WMD [30]. Within this work the contribution of Belgium was found to be 65% employing the same sources as stated in the demand section.

5.1.2 Bismuth

Within this report the supply risk of bismuth is 0.6 higher than the one reported by the EU. The report cites the source for bismuth data as a combination of WMD [30], USGS [32, 33] and expert knowledge from one of their workshops. The data for bismuth is reported inconsistently within the report. The results of this work match

the EU supply provided in Table 6 and Annex 1, but Annex 8 reports a different EU supply. Annex 8 includes a contribution of Belgium of 26% which causes the difference in supply risk. However, the data for Belgium is a result of expert knowledge and therefore was not reproducible in this work.

5.1.3 Germanium

The supply risk of germanium calculated within this work is bigger by 1.3 compared to the EU’s report. Similar to bismuth in section 5.1.2 the EU report cites the data for germanium as a combination of WMD [30] and expert knowledge for countries Germany and Belgium. These countries make up a combined contribution of 41% to the EU supply. [6] The lack of this data within this work causes the major difference in calculated supply risk. All used production sources within this work are missing European production of germanium. Like seen with bismuth the supply added by the experts for Germany and Belgium are reported in Annex 1, but are missing from Annex 8. The supply distributions within Annex 8 are very similar to the one within this work.

5.1.4 Hafnium

Compared to the EU report the supply risk within this work is higher by 0.5. Like bismuth 5.1.2 and germanium 5.1.3 the EU relies on expert knowledge for domestic production. The major supplier of the EU is reported to be France with a contribution of 76%. Within the production data used in this work there is no European production of hafnium. Unlike observed with bismuth and germanium, the supply distribution of hafnium reported in Annex 1 and Annex 8 matches, however, within Annex 1 global and EU supply have been swapped by mistake.

5.1.5 Lithium

Within this work the supply risk of lithium is 0.3 lower than the one reported by the EU. The cause of the difference is a lack of data on lithium processing within the data sources used in this work. The report cites the source of lithium processing as a combination of extraction data from WMD [30] and processing data from experts.

5.1.6 Platinum Group Metals

While the results of this work match the supply risk of the EU report for platinum (0.1 difference), palladium (exact match) and ruthenium (exact match), the results of the other Platinum Group Metals (PGMs), namely iridium (0.7 lower than EU) and rhodium (0.7 higher than EU) deviate from the report. The aggregation of production data for the PGMs differs between data sources. WMD [30] reports on palladium, platinum and rhodium, while USGS [32, 33] reports on platinum and palladium, however since 2018 BGS [31] reports on platinum, palladium, rhodium, ruthenium and iridium. Therefore WMD was used for palladium, platinum and rhodium, while BGS was selected as a source for ruthenium and iridium PGM data.

Iridium global processing production within Annex 7 matches that of ruthenium reported by the BGS, if the supply of iridium would be replaced by that of ruthenium,

the supply risk would match to within 0.1. Rhodium global processing production within Annex 7 of the report matches the data used in this work. All other used parameters match with those within the report. The cause of the deviation is unknown.

5.1.7 Rare Earth Elements

The calculation of the rare earth supply risk has the most limitations of any material within this work. Data is sparse and when available aggregated for the groups of Rare Earth Elements (REEs), Light Rare Earth Elements (LREEs) or Heavy Rare Earth Elements (HREEs) as a whole. In terms of production data all sources used in this work report REE data. While the USGS [32, 33] reports mine production data, both WMD [30] and BGS [31] report Rare earth oxides data. Within the EU report all REEs share the same extraction data as reported in WMD for oxides. However, the supply risk calculation of the EU is based on the processing data for REEs. The data reported for world wide processing of REEs could not be reproduced with the data sources within this work. The documentation of RMIS [14] suggests that the report used expert knowledge for the determination of world wide processing of all REEs. Therefore the processing data is not reproducible in this work. To mitigate this it was chosen to use the WMD source, which reports on rare earth oxides as an estimate for LREE processing. For HREE processing the world supply is set to stem 100% from China, which is also used in the report. The lack of world processing data is however not the only limitation. While multiple CN trade codes exist for REEs most are highly aggregated. Within the EU report it is stated that trade codes had to be split based on expert advice. The limitations on processing data for world wide production and the EU supply cause almost all REE supply risk calculations within this work to deviate from the EU report.

5.1.8 Scandium

The supply risk of scandium within this work is lower than the EU report by 0.7. None of the data sources used in this work report on the production of scandium. The EU report itself does provide processing production data, but states that expert estimates were used. While this work uses trade data to calculate the supply risk, the EU report states that trade data for scandium is unreliable and therefore only uses the aforementioned expert data. Therefore the supply risk score for scandium is not reproducible in this work.

5.1.9 Tellurium

Within this work the supply risk of tellurium is 1.4 higher than in the EU report. The report states that the EU is self sufficient and therefore the supply risk calculation is only dependent on the EU supply. However the EU supply of Tellurium was not reproducible within this work. The primary data sources used within this work do not report on all tellurium production within the EU. For example, a note in the BGS [31] data release states that data from Germany and Belgium is not included. Additionally, the documentation of RMIS [14] states that the tradecodes of tellurium are highly aggregated and require splitting by experts.

5.2 Temporal Extension

After comparison to the EU assessment (2016-2020) other time frames were calculated to visualize the potential developments in material criticality. To investigate the results of the temporal extension the five materials with the biggest change relative to the 2023 report timeframe (2016-2020), excluding materials previously discussed in chapter 5.1, are displayed in Figure 4 and discussed in the following.

No material was found to cross the threshold of criticality within the analysed timeframes. The material getting closest to a change in criticality status is phosphate rock. Within the 2020-2024 timeframe the material reaches the supply risk threshold value of 1. The cause of the decline is a decrease of EU trade with the biggest suppliers Morocco and Russia by 5% and 4% respectively, while the biggest global Supplier China also decreased by 3%. Directly related to phosphate rock is the processed phosphorus, which already had the highest supply risk in the 2016-2020 timeframe. In the following timeframes this supply risk increased further since Kazakhstan, the biggest EU supplier of phosphorus, raised its share from 70% to 78%.

A different development can be observed with manganese. While phosphate rock and manganese have the same supply risk value in the 2023 report timeframe, the supply risk of manganese increases in the temporal extension of the report. The change for manganese is caused by a shift in the EU's biggest supplier, which changed from South Africa with 42% to Gabon with 48%. While this already increases the share of the main supplier, the lower WGI score of Gabon increases supply risk even further. While remaining consistent over most timeframes the supply risk of coking coal increases in the last timeframe. This is caused by the global supply of coking coal remaining constant with a 52% share supplied by China. However, a decrease of Russian supply to the EU from 9% to 5% made the EU supply less diversified.

Another material for which the supply risk decreased within the temporal extension is kaolin clay. While kaolin clay is not critical in the 2023 report its supply risk was decreased further by a drop in the share of the EU's main supplier, Ukraine, from 45% to 33%. The missing share was, however, not replaced by a single supplier, resulting in a diversification of the supply and a lower supply risk.

One material with already high supply risk in the 2023 report whose supply risk increased further is cobalt. The DR Congo, the major global supplier of cobalt increased its share from 63% to 69%.

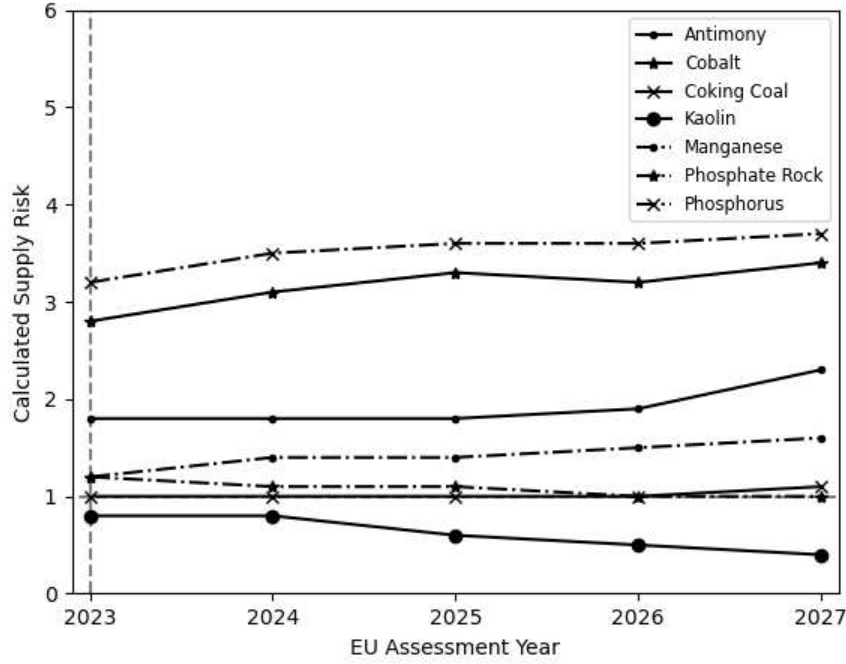


Fig. 4 The five materials with the largest change in supply risk relative to the 2023 report timeframe (2016–2020), extended through the equivalent of a 2027 report (2020–2024)

6 Conclusion and Future Work

Analysis of the CRM assessment landscape shows that assessment reproducibility in the field is limited by the infrequent publication of primary data and insufficient source documentation. It has become essential for researchers to meticulously document the exact data sources for each assessment to assure reproducibility. To assist researchers with this task this work presents an automated, transparent and dynamic assessment tool and evaluates its usefulness on the EU’s CRM assessment.

The performed assessment demonstrates that the tool is able to reproduce the supply risk calculation of the EU criticality assessment methodology exceptionally well. Only 15 of the 78 materials analysed within this work deviate more than 0.2 from the official EU supply risk value. Of these materials six belong to the group of rare earth elements and two are platinum group metals. To evaluate the cause of deviation all 15 materials were analysed. For 12 of the materials the missing expert knowledge employed by the EC could be identified as the main cause of deviation. Expert knowledge was used by the EC to add, or modify the production source data, or to split

trade codes that are reporting on multiple materials. While the true reason for deviation of the remaining three materials is unknown, all show inconsistencies in the report and SCREEN2 factsheets. The data reported for Iridium within the report matches the data of Ruthenium. The Rhodium data used in this work matches the report's, yet the supply risk result could not be reproduced.

The recreation of the supply risk calculation and deviation analysis prove the accuracy of the processed data and database. Future implementations of the database could therefore be employed to perform other criticality assessments. Researchers employing the presented database and workflow can improve the reproducibility of results and benefit from fast and easy updating of assessment results.

Additionally, the temporal extension of the 2023 report data shows the potential of predicting future publications of the EC. While the results show that no analysed material changes its criticality status within the analysed years general trends could be observed. For example, the observed decline in supply risk for phosphate rock could be affected by the war in Ukraine, as sanctions against Russia, which are not considered in the trade parameters used in this work could have an effect on the supply risk of the material. However, future research would benefit from reviewing the assumptions made to limit scope within this work. The temporal extension of the EU methodology would benefit from updating the trade parameters. As the trade parameters have little effect on most materials, but a small number of materials are strongly affected by them. In the near future, further assessment methods, such as ESSENZ, the Augsburg method, or GeoPolRisk, can be integrated into the tool. In addition, newly published material data will be incorporated to ensure that the dataset remains up to date.

Data Availability

The primary data used in this work cannot be shared freely as part of this work due to the rights of the original data providers. However, all data is publicly available and can be accessed from the original providers cited in this work. The supply risk results of this work, along with documentation of which primary data was used, are provided in the supplementary material. The results of this work can be reproduced using the toolkit [26] with the primary data identified in the supplementary material.

Supplementary Material

The presented toolkit is publicly available [26].

Supplementary data to this article can be found online at ...

References

- [1] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL Establishing a Framework for Ensuring a Secure and Sustainable Supply of Critical Raw Materials and Amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0160> Accessed 2025-07-15

- [2] European Commission: Critical Raw Materials for the EU: Report of the Ad-hoc Working Group on Defining Critical Raw Materials
- [3] European Commission: Report on Critical Raw Materials for the EU: Report of the Ad-hoc Working Group on Defining Critical Raw Materials
- [4] European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, British Geological Survey, Deloitte Sustainability, TNO, Bureau de Recherches Géologiques et Minières: Study on the Review of the List of Critical Raw Materials – Final Report. <https://doi.org/10.2873/876644>
- [5] European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Blengini, G.A., El Latunussa, C., Eynard, U., Torres De Matos, C., Wittmer, D., Georgitzikis, K., Pavel, C., Carrara, S., Mancini, L., Unguru, M., Blagoeva, D., Mathieux, F., Pennington, D.: Study on the EU’s List of Critical Raw Materials (2020) – Final Report. Publications Office of the European Union. <https://doi.org/10.2873/11619>
- [6] European Commission. Directorate General for Internal Market, Industry, Entrepreneurship and SMEs.: Study on the Critical Raw Materials for the EU 2023: Final Report. Publications Office. <https://doi.org/10.2873/725585>
- [7] Economy, Committee on Critical Mineral Impacts of the U.S: Minerals, Critical Minerals, and the U.S. Economy. National Academy Press, Washington (2008)
- [8] Schrijvers, D., Hool, A., Blengini, G.A., Chen, W.-Q., Dewulf, J., Eggert, R., van Ellen, L., Gauss, R., Goddin, J., Habib, K., Hagelüken, C., Hirohata, A., Hofmann-Amttenbrink, M., Kosmol, J., Le Gleuher, M., Grohol, M., Ku, A., Lee, M.-H., Liu, G., Nansai, K., Nuss, P., Peck, D., Reller, A., Sonnemann, G., Tercero, L., Thorenz, A., Wäger, P.A.: A review of methods and data to determine raw material criticality. *Resources, Conservation and Recycling* **155**, 104617 (2020) <https://doi.org/10.1016/j.resconrec.2019.104617>
- [9] Perossa, D., Rosa, P., Terzi, S.: A systematic literature review of existing methods and tools for the criticality assessment of raw materials: A focus on the relations between the concepts of criticality and environmental sustainability. *Resources* **13**(9), 131 <https://doi.org/10.3390/resources13090131>
- [10] Otterbach, N., Fröhling, M.: Raw material criticality assessments as decision-making support for corporate circular economy strategies – A systematic review. *Resources, Conservation and Recycling* **219**, 108299 (2025) <https://doi.org/10.1016/j.resconrec.2025.108299>
- [11] European Commission. Directorate General for Internal Market, Industry, Entrepreneurship and SMEs.: Methodology for Establishing the EU List of Critical Raw Materials: Guidelines. Publications Office. <https://doi.org/10.2873/769526>

- [12] Solutions for CRITICAL Raw Materials - a European Expert Network — SCRREEN — Project — Fact Sheet — H2020. CORDIS — European Commission. <https://cordis.europa.eu/project/id/730227>
- [13] Solutions for CRITICAL Raw Materials - a European Expert Network 2 — SCRREEN2 — Projekt — Fact Sheet — H2020. CORDIS — European Commission. <https://cordis.europa.eu/project/id/958211>
- [14] Manfredi, S., Pennington, D., D’elia, E., Georgitzikis, K., Unguru, M., Perpetuo, C.F., Ciuta, T., Garbossa, E.: Raw Materials Information System (RMIS): Current Status & 2024 Roadmap. <https://publications.jrc.ec.europa.eu/repository/handle/JRC134030> Accessed 2025-07-15
- [15] Bach, V., Berger, M., Henßler, M., Kirchner, M., Leiser, S., Mohr, L., Rother, E., Ruhland, K., Schneider, L., Tikana, L., Volkhausen, W., Walachowicz, F., Finkbeiner, M.: Integrated method to assess resource efficiency – ESSENZ. *Journal of Cleaner Production* **137**, 118–130 <https://doi.org/10.1016/j.jclepro.2016.07.077>
- [16] Bach, V., Berger, M., Finogenova, N., Finkbeiner, M.: Analyzing Changes in Supply Risks for Abiotic Resources over Time with the ESSENZ Method—A Data Update and Critical Reflection. *Resources* **8**(2), 83 <https://doi.org/10.3390/resources8020083>
- [17] Bach, V., Marinova, S., Finkbeiner, M.: Updated data and characterization factors of the criticality assessment for the integrated method to assess resource efficiency (ESSENZ and ESSENZ+). *Discover Sustainability* **5**(1) <https://doi.org/10.1007/s43621-024-00513-x>
- [18] Yavor, K.M., Bach, V., Finkbeiner, M.: Adapting the ESSENZ Method to Assess Company-Specific Criticality Aspects. *Resources* **10**(6), 56 <https://doi.org/10.3390/resources10060056> . Accessed 2026-04-14
- [19] Helbig, C., Bradshaw, A.M., Thorenz, A., Tuma, A.: Supply Risk Considerations for the Elements in Nickel-Based Superalloys. *Resources* **9**(9), 106 <https://doi.org/10.3390/resources9090106>
- [20] Hillenbrand, M., Helbig, C., Marschall, R.: Supply risk considerations for photoelectrochemical water splitting materials. *Energy & Environmental Science* **17**(7), 2369–2380 <https://doi.org/10.1039/d3ee04369j>
- [21] Hillenbrand, M., Helbig, C., Marschall, R.: Supply Risk Considerations for Photoelectrochemical Water Splitting Materials. <https://doi.org/10.17605/OSF.IO/D9E8X> . <https://osf.io/d9e8x/> Accessed 2026-01-09
- [22] Cimprich, A., Young, S.B., Helbig, C., Gemechu, E.D., Thorenz, A., Tuma,

- A., Sonnemann, G.: Extension of geopolitical supply risk methodology: Characterization model applied to conventional and electric vehicles. *Journal of Cleaner Production* **162**, 754–763 <https://doi.org/10.1016/j.jclepro.2017.06.063> . Accessed 2025-09-16
- [23] Gemechu, E.D., Helbig, C., Sonnemann, G., Thorenz, A., Tuma, A.: Import-based Indicator for the Geopolitical Supply Risk of Raw Materials in Life Cycle Sustainability Assessments. *Journal of Industrial Ecology* **20**(1), 154–165 <https://doi.org/10.1111/jiec.12279> . Accessed 2026-03-30
 - [24] Koyamparambath, A., Schraml, T., Helbig, C., Sonnemann, G.: Geopolrisk-py: A Python-Based Library to Operationalize the Geopolitical Supply Risk Method for use in Life Cycle Assessment and Comparative Risk Assessment. *Journal of Open Source Software* **11**(118), 9600 <https://doi.org/10.21105/joss.09600> . Accessed 2026-04-21
 - [25] Perossa, D., Rosa, P., Terzi, S.: Corporate raw materials criticality assessment: A novel tool for car electronics value chains developed with design science research methodology. *Journal of Environmental Management* **398**, 128555 (2026) <https://doi.org/10.1016/j.jenvman.2026.128555>
 - [26] Anonymous [Author name redacted for double-blind review]: Critical Material Toolkit. Software referenced in this manuscript. Repository details redacted for double-blind review.
 - [27] Tercero Espinoza, L.: Understanding the methodology behind the EU list of critical raw materials <https://doi.org/10.24406/publica-2455> . Accessed 2025-05-28
 - [28] Glöser, S., Tercero Espinoza, L., Gandenberger, C., Faulstich, M.: Raw material criticality in the context of classical risk assessment. *Resources policy* **44**, 35–46 <https://doi.org/10.1016/j.resourpol.2014.12.003>
 - [29] World Bank: Worldwide Governance Indicators. <https://www.worldbank.org/en/publication/worldwide-governance-indicators> Accessed 2025-07-30
 - [30] Austrian Federal Ministry of Finance (BMF): World Mining Data - Mineral Raw Materials. https://www.world-mining-data.info/?World_Mining_Data___Mineral_Raw_Materials Accessed 2025-07-30
 - [31] British Geological Survey (BGS): World mineral statistics archive. <https://www.bgs.ac.uk/mineralsuk/statistics/world-mineral-statistics/world-mineral-statistics-archive/> Accessed 2025-07-30
 - [32] U.S. Geological Survey (USGS): Minerals Yearbook. <https://www.usgs.gov/centers/national-minerals-information-center/minerals-yearbook-metals-and-minerals> Accessed 2025-07-30

- [33] U.S. Geological Survey (USGS): Mineral Commodity Summaries. <https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries> Accessed 2025-07-30
- [34] European Commission: EU trade since 1988 by HS2-4-6 and CN8 (DS-045409). <https://ec.europa.eu/eurostat/web/products-datasets/-/ds-045409> Accessed 2025-07-30
- [35] Graedel, T.E., Allwood, J., Birat, J.-P., Reck, B.K., Sibley, S.F., Sonnemann, G., Buchert, M., Hagelüken, C.: Recycling Rates of Metals – A Status Report. A Report of the Working Group on Global Metal Flows to the International Resource Panel. UNEP (2011)
- [36] Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission), ifeu, In Extenso Innovation Croissance, Ökoinstitut e.V, Ighilahriz, M.: Update of the 2015 Material System Analyses: Final Report. Publications Office of the European Union, ??? (2024). <https://data.europa.eu/doi/10.2873/440874> Accessed 2025-08-06
- [37] Elsner, H., Liedtke, M., Meßner, J., Blumenberg, M., Warstat, J.: Edelhase - Versorgung Wirklich Kritisch? DERA Rohstoffinformationen, vol. 39. DERA
- [38] Energy Institute: Statistical Review of World Energy 2024. Available online. <https://www.energyinst.org/statistical-review/home>
- [39] De Castro, A., Avillez, F., Rodrigues, V., Silva, F.G., Santos, F., Rebelo, F., Jorge, M.N., Aires, N.: The Cork Sector: From the Forest to the Consumer: Final Report – Extended Summary. <https://www.corkinov.com/uploads/Media/Estudo-Sectorial-Floresta-Consumidor/APCOR-Extended-Summary-Feb-2020-BX.pdf>
- [40] Food and Agriculture Organization of the United Nations: Production Statistics on Natural Rubber: Crops and Livestock Products. FAOSTAT database. <https://www.fao.org/faostat/en/#data/QCL>
- [41] Anonymous [Author name redacted for double-blind review]: Combining a criticality assessment database with life cycle assessment results. Reference redacted for double-blind review. Full citation will be provided upon acceptance. (2025)
- [42] Anonymous [Author name redacted for double-blind review]: Integrating a criticality assessment database with repairability analysis. Reference redacted for double-blind review. Full citation will be provided upon acceptance. (2026)

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