MADITRACE

Final report supply chain mapping, requirements, elicitation, classification

Deliverable D3.8

Version N°4.1

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Summary

This deliverable (D3.8) contributes to the MaDiTraCe project's objective to enhance the traceability and transparency of critical raw material (CRM) supply chains. It focuses on four key commodities used in electric vehicle batteries and motors: cobalt, lithium, natural graphite, and neodymium. The report maps the supply chains of these materials, proposes criteria and an analysis for identifying leverage points in the supply chains, and identifies requirements, elicitation, and classification for digital product passports.

The report presents a comprehensive mapping of the supply chains, including extraction, processing, trade, recycling, secondary flows, and identifies key companies extracting and refining the case-study materials. Additionally, key intervention points, referred to as 'leverage points', are identified at which traceability technologies could have the greatest impact. These include changes in material composition, ownership, and geographic location. The analysis covers European stakeholders and high-risk regions, incorporating risk classifications from sources such as the Conflict-Affected and High-Risk Areas (CAHRAs) and the Financial Action Task Force (FATF). The report also defines the requirements for developing digital product passports (DPPs), including the needs of stakeholders, data structures, and alignment with existing standards such as CERA 4in1. A review of current traceability and control practices and technologies is also presented, providing insight into their implementation across the CRM sector.

Together, these data and insights contribute to the methodological basis for enabling the digital traceability and responsible sourcing of critical raw materials within complex global supply chains that are critical for the energy transition.

Keywords

EV batteries, cobalt, lithium, natural graphite, neodymium, rare earths, supply chain mapping, requirements elicitation

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Abbreviations and acronyms

BGR	German Federal Institute for Geosciences and Natural Resources
CAHRAs	Conflict-affected and high-risk areas
CCZ	Pacific Ocean's Clarion-Clipperton Zone
CoC	Chain of Custody
CRM	Critical Raw Material
DMP	Digital Material Passport
DPP	Digital Product Passport
EBR	European Business Register
ESG	Environmental, Social, and Governance (ESG) impacts
EU	European Union
EVs	Electric Vehicles
FATF	Financial Action Task Force
HHI	Herfindahl-Hirschman Index
IEA	International Energy Agency
IP	Identity preservation
LCA	Life Cycle Assessment
Li-ion	Lithium-ion
MFP	Material fingerprinting
REs	Rare earths

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1 Introduction

In the context of sustainable resource management and supply chain resilience, the sourcing and traceability of critical raw materials (CRMs) have gained attention, with a particular spotlight on materials crucial to electric vehicle (EV) batteries and motors. The responsible sourcing of materials, namely lithium, cobalt, and natural graphite for EV batteries, as well as neodymium for EV motors, has become a central concern for stakeholders across the supply chain (European Commission 2023a).

MaDiTraCe's main goal is to enlarge and integrate the portfolio of technological solutions, reinforcing the reliability of CRM tracking and the transparency of complex supply chains. The main objective of WP3 is to develop a methodological framework and key commodities that support the integration of existing identification, assessment, and tracing methods and tools, to enable digital material passport functionality.

This deliverable (D3.8) is focused on decentralized traceability of raw materials and comprises four main commodities. Firstly, it presents a comprehensive supply chain mapping - from extraction and primary production to encompassing trade flows and key stakeholders - for the selected CRMs: cobalt, lithium, natural graphite, and neodymium. Secondly, it provides an overview of leverage points, which are specific junctures in the supply chain where even small interventions using traceability technologies can lead to significant improvements. Thirdly, it defines the requirements, elicitation, and classification for the digital material passport. And finally, it outlines the state of practices of control methods and tracing solutions, see Figure 1. The deliverable builds on the findings and criteria proposed for determining the leverage point in Deliverable 3.1, incorporating insights from selected case studies and the collective expertise of the MaDiTraCe consortium.

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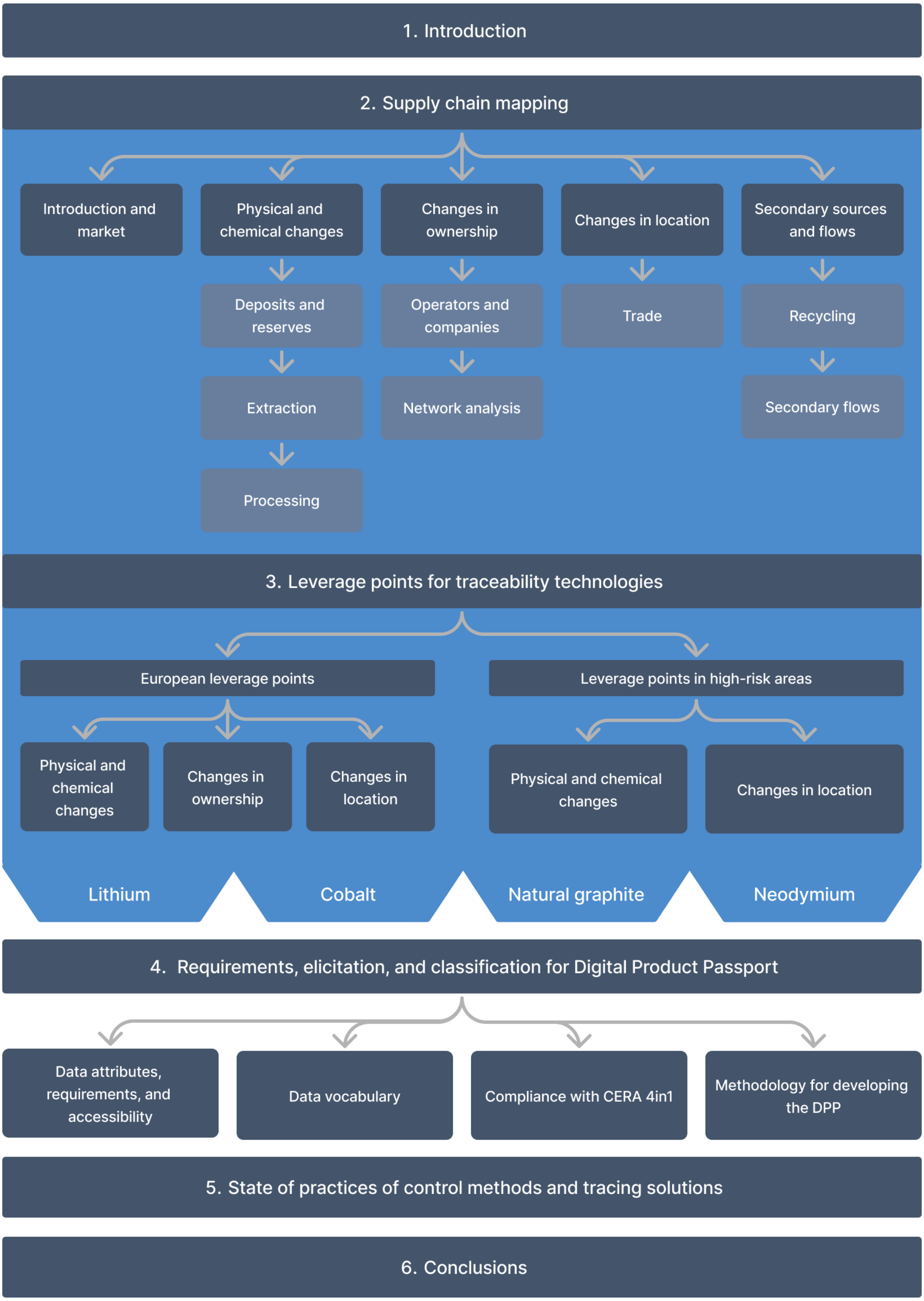

Figure 1: D3.8 report structure and its final deliverable

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Chapter 2 will focus on the supply chain mapping of raw materials for the selected CRMs: cobalt, lithium, natural graphite, and neodymium. The objective of the mapping is the identification of leverage points for traceability technologies. As mentioned, leverage points correspond to strategic intervention spots for traceability technology (Fischer and Riechers 2019; Gupta et al. 2025) . A set of three criteria was proposed in Deliverable 3.1 to identify these strategic points of the supply chain. The supply chain mapping of each material will be structured following these three criteria: transformations in material state and chemical modifications; changes in ownership (including a network analysis for the materials for which the required data was available); and changes in location (trade flows). In addition, the secondary sources and flows of each material are studied.

Chapter 3 provides an overview of the identified leverage points for traceability technologies. The first part of the chapter lists all the identified leverage points in the European Union (EU). This includes all countries that are mining and processing the four materials, EU-based companies, and the countries that are importing materials into the EU. The second part of the chapter integrates the collected supply chain data and leverage points (on mining, processing and trade) with information on so-called ' high-risk countries' with regards to responsible sourcing, including countries listed on the 'Conflict-Affected and High-Risk Areas' (CAHRAs) as well as to countries listed on the 'grey' and 'black' list of the Financial Action Task Force (FATF) (Bellasio et al. 2023; Force 2019).

Chapter 4 outlines the requirements, elicitation, and classification necessary for developing a DPP, building on the groundwork laid in the previous chapters. In addition to outlining the theoretical foundations of the DPP, this chapter also presents an operationally feasible framework. From a data perspective, it first introduces the core data attributes, followed by a shared vocabulary that ensures consistency, accessibility, and supports data integration across stakeholders. The chapter then evaluates how the DPP framework aligns with the CERA 4in1 standard and the EU regulations. Finally, it presents a practical methodology for implementing the DPPs.

Finally, chapter 5 presents a state of practices of control methods and tracing solutions in relation to existing DPP initiatives and related data models. The chapter includes a description of the different chain of custody models (comprising both mixing and no-mixing approaches) that help traceability by tracking the journey of materials, using physical or electronic evidence.

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2 Supply chain mapping for leverage point identification

This chapter offers a comprehensive supply chain mapping for the selected CRMs: cobalt, lithium, natural graphite, and neodymium. The objective of the mapping is the identification of leverage points for traceability technologies. A set of three criteria was selected in Deliverable 3.1, to identify these strategic points of the supply chain. The supply chain mapping of each material will be structured following these three criteria: changes in location, transformations in material state, chemical modifications, and changes in ownership. In addition, the secondary sources and flows of each material are studied.

Each material case study will include:

- Market information, including:
    - The main applications, the total consumption, and the projected demand.
- Transformations in material state and chemical modifications, including:
    - Deposits and reserves: types of deposits and global reserves by country.
    - Extraction: mines, their locations, information on artisanal and small-scale mining, and forecasted production.
    - Processing (refining and smelting): the main processing steps, processing by country, overview of processing facilities (including production and/or capacity where available), global locations of refineries/smelters.
- Changes in ownership: an overview is provided of the companies that operate and own mines and processing facilities.
- Changes in location: the trade flows of the materials are mapped.
- In the section on secondary sources and flows, data is provided on the secondary supply, the main recycling companies (of Li-ion batteries primarily) and the waste flows are mapped.

The year 2022 is used as the base year to ensure consistency with Deliverable 3.1. In some of the case studies, there is additional information relevant to the leverage points, depending on the availability of information. For example, there is a network analysis in the cobalt and lithium case study that illustrates the links between mines, countries, owner companies, and operator companies. This information was not available for the other two materials.

2.1 Cobalt

This case study provides a comprehensive mapping of the global cobalt supply chain, with a specific focus on identifying leverage points for the application of traceability technologies (Tan and Keiding 2024).

2.1.1 Introduction and cobalt market

Cobalt is in high demand due to its diverse applications, primarily in chemical and metallurgical uses. In 2022, approximately 80% of cobalt demand stemmed from chemical uses, such as batteries and pigments, while metallurgical applications accounted for around 20%. Within the chemical sector, the predominant use of cobalt was in batteries, which represented almost 70% of total consumption. This includes electric vehicle batteries (34%), batteries for electronics (27%), and other types of batteries (7%), see Figure 2 (S&P Capital IQ (2024a)).

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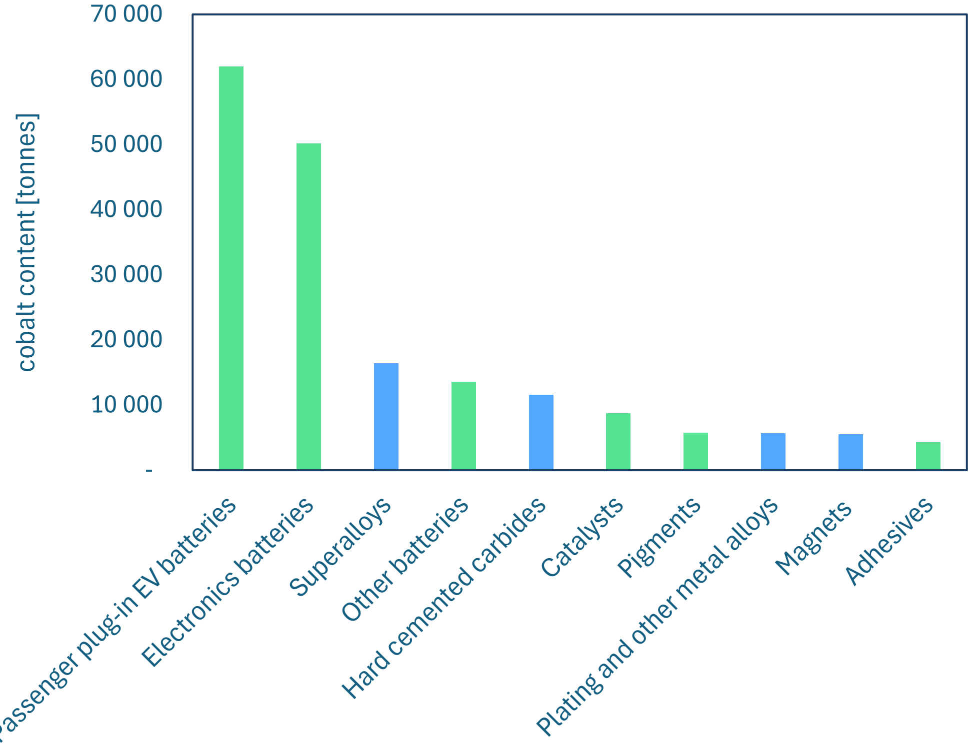

Figure 2: Cobalt consumption 2022 by product.
Chemical demand is illustrated in green and metallurgical demand in blue (S&P Capital IQ 2024a).

The International Energy Agency (IEA) projects that global cobalt demand will increase by 190%, rising from 181kt in 2021 to 344kt by 2030. The expected mine supply from announced projects will exceed 300 kt by 2030 (IEA 2024a).

2.1.2 Transformations in material state and chemical modifications

2.1.2.1 Deposits and reserves

Cobalt is extracted as one of several by-products in the following types of deposits:

- Stratiform Sediment-Hosted Copper-Cobalt (SSHC) Deposits: SSHC deposits are considered the leading global source of cobalt, contributing to 63% of worldwide cobalt mine production in 2017 (Petavratzi, Gunn, and Kresse 2019). These deposits are typically formed through sedimentary processes and are known for their rich cobalt content.
- Nickel-Cobalt Laterite Deposits: Laterite deposits are primarily mined for their nickel content but may also contain significant cobalt concentrations, often up to 0.22% cobalt (Berger et al. 2011; Schulz et al. 2017).
- In some cases, cobalt is extracted as a by-product during the mining of other metals such as silver, lead, or zinc.

While these are the most significant sources, other deposit types also contain notable cobalt concentrations, some of which currently produce cobalt or have done so historically.

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The distribution and concentration of cobalt are influenced by factors like the mineralogy of the host rocks, climate conditions, and the metal extraction processes (Horn et al. 2021).

Global cobalt reserves were estimated at 11 million tonnes. Most of these reserves are in the Democratic Republic of the Congo (DRC[1]) (6 million tonnes) and Australia (1.7 million tonnes). Estimates of reserves in other individual countries are at 0.5 million tonnes or lower, as shown in Figure 3 (USGS 2024).

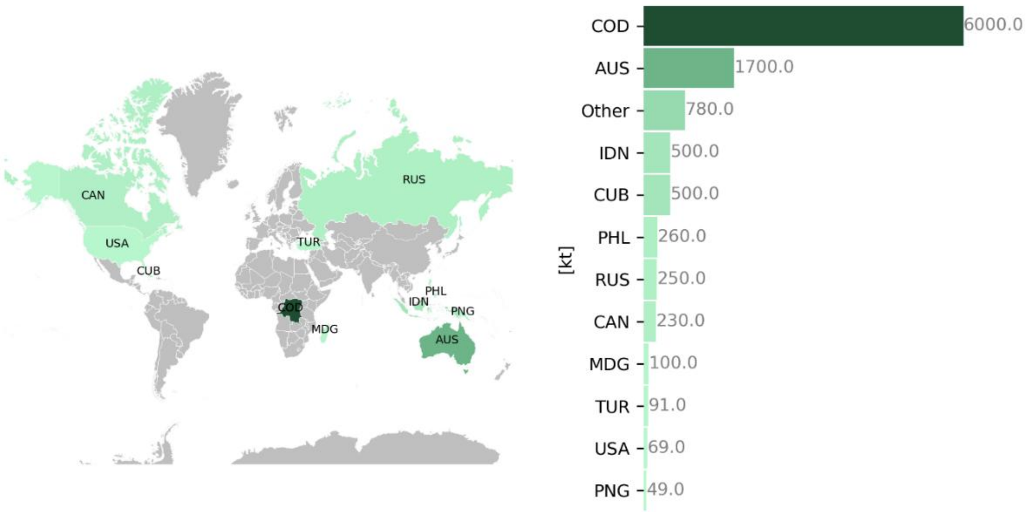

Figure 3: Cobalt reserves per country in 2022 in kilotonnes (kt) (USGS 2024).

2.1.2.2 Extraction

Cobalt mines

In 2022, 60 operational cobalt mine projects produced an estimated 164 kt of cobalt, out of a total global production of approximately 200 kt (Mining Technology 2024; S&P Capital IQ 2024c). The majority–69%–of this production came from the DRC, while other countries, such as Australia, contributed 5% or less, see Figure 4 and Figure 5.

[1] COD is used in the figures that use ISO 3166-3 nomenclature for countries.

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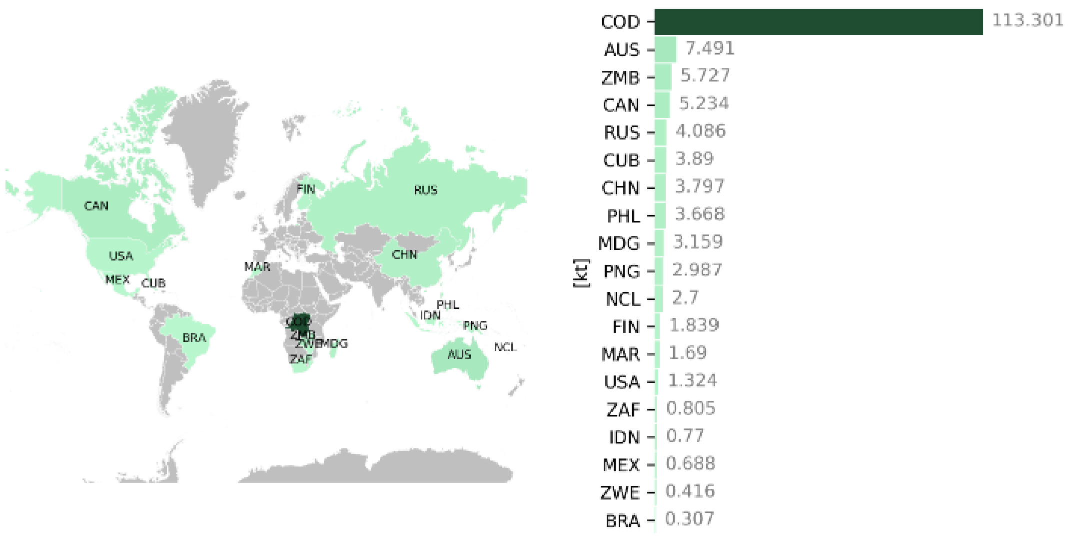

Figure 4: Cobalt mined per country in 2022 in kilotonnes (kt).
Based on S&P Global mining projects data (van den Brink et al. 2020; S&P Capital IQ 2024c).

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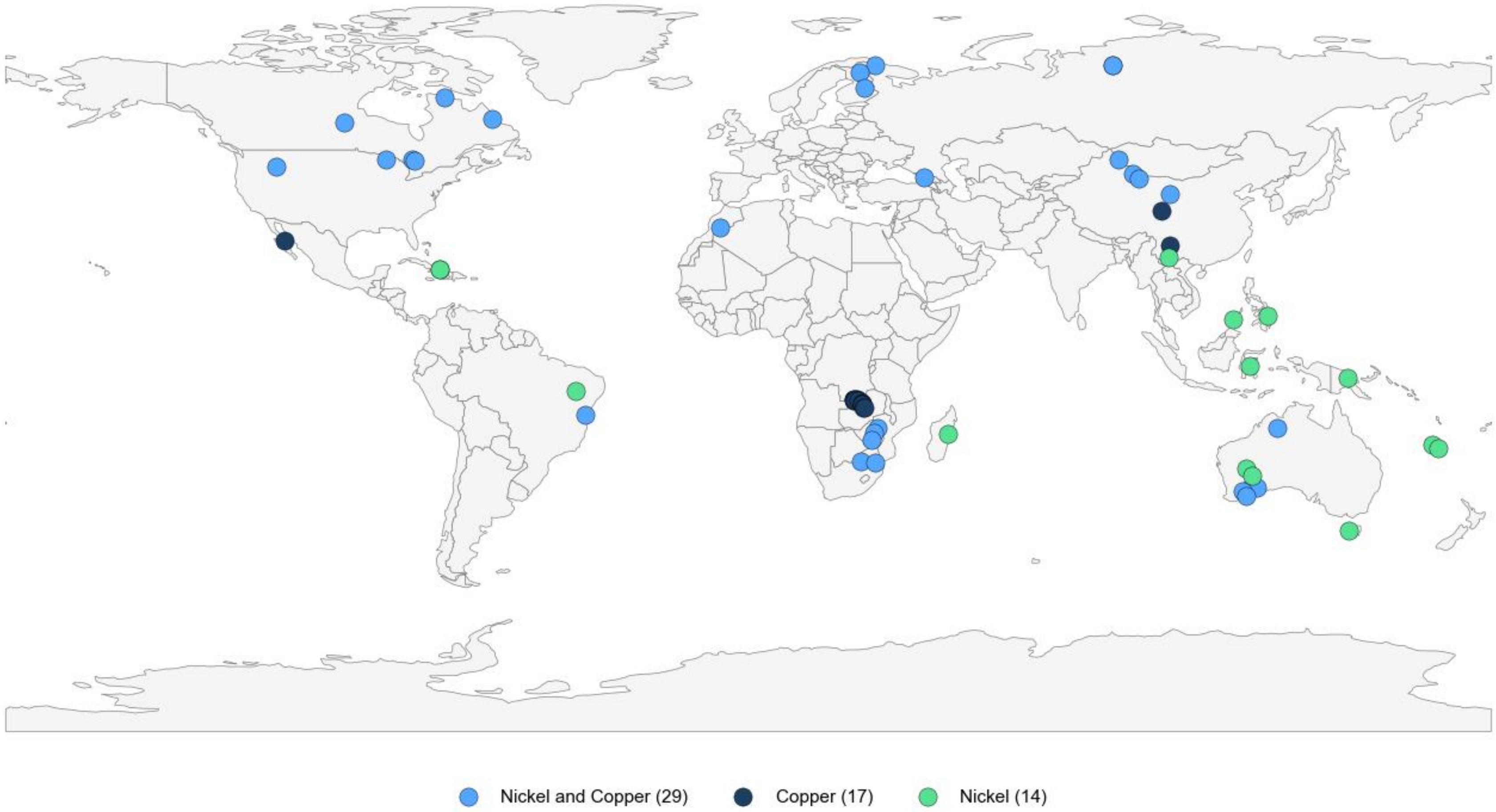

Figure 5: Cobalt mines 2022 (S&P Capital IQ 2024c).
There are 29 cobalt mines that also contain copper and nickel, 17 that contain cobalt and copper, and 14 that contain cobalt and nickel. There are also other commodities at the mines, see the section on ' by-products'.

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By-products

All of the 60 cobalt projects included in the S&P Intelligence IQ database also contain copper and/or nickel, of which 29 mines contain both copper and nickel, 17 are reported to contain cobalt and copper, and 14 to contain cobalt and nickel. In total, 73% (120 kt) of cobalt is mined at mines with copper, 13% (22 kt) at nickel mines, and 13% at mines with nickel and copper. At these mines (reported for 19 mines), a total nickel production is reported of 985 kt and a total copper production of 600 kt (reported for 22 mines). Other commodities at cobalt mines include platinum, palladium, rhodium, gold, silver, chromite, iron ore, U3O8, zinc, iridium, vanadium, titanium, graphite, diamonds, manganese, magnesium, molybdenum, osmium, ruthenium, selenium, tellurium, tellurium, osmium, arsenic, and limestone (S&P Capital IQ 2025). The cobalt deposits in the Bou Azzer district in Morocco are among the few primary cobalt mines in the world (accounting for around 1% of production in 2022) (ONHYM 2025).

Artisanal, small-scale, and illegal mining

Artisanal cobalt mining is predominantly concentrated in the DRC, causing not only severe environmental pollution in the region but also toxic harm to vulnerable communities that depend on artisanal mining (Banza Lubaba Nkulu et al. 2018; Gulley 2023). While Gulley (2023) has found that the share of cobalt from artisanal mines in the world has been generally decreasing since 2008, when it was 18-23% of the global supply, to 6-8% of the global supply in 2020. The study also found that artisanal production was either exported to China or processed in the DRC by Chinese companies. The Annual Survey Report of the Fair Cobalt Alliance, which reports on findings from 2023 and 2024, reported the share of artisanal and small-scale mining to 5-10% of the total cobalt extracted in the DRC (Fair Cobalt Alliance 2024) Glencore PLC, the world's largest cobalt producer, is collaborating with the DRC government to formalize existing artisanal mining operations (S&P 2024).

2.1.2.3 Forecast production

According to the IEA, cobalt production from existing and announced projects is estimated to reach between 256 to 300 kt in 2035 from the base and high production case, respectively (IEA 2024a, 2025).

2.1.2.4 Processing

Processing steps

Cobalt is primarily extracted as a by-product of copper and nickel mining, with two-thirds of global production originating from sediment-hosted copper-cobalt deposits. Cobalt processing involves various methods tailored to the ore type and desired end product. Cobalt processing can be described in detailed steps for three types of ore (Petavratzi et al. 2019) - copper-cobalt sulfide ore, nickel-cobalt sulfide ore, and nickel-cobalt laterite ore. The different steps and material transformations are illustrated in Figure 6.

The two principal processing routes involve hydrometallurgy and pyrometallurgy. Hydrometallurgy begins with leaching, and following leaching, copper is recovered, and impurities are removed before the recovery of cobalt and nickel, if present. In pyrometallurgy, ores are subjected to high temperatures along with a reducing agent, promoting chemical reactions that isolate metals from other compounds. During this process, certain impurities are expelled as gases, while others form a byproduct known as slag. Following smelting, cobalt is typically found in combination with nickel, and the two metals are later separated through electrolytic techniques, such as solvent extraction and electrowinning (Petavratzi et al. 2019).

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Figure 6: Cobalt processing steps for three types of ore: copper-cobalt sulfide ore, nickel-cobalt sulfide ore and nickel-cobalt laterite ore, adapted from (Petavratzi et al. 2019)

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Refining

In cobalt refineries, cobalt metal, oxides, hydroxides, and salts are produced. Cobalt metal is available in powders, granules, briquettes, cathodes, rounds, pellets, and ingots. Cobalt salts include a large range of products, such as chlorides, sulfates, nitrates, carbonates, acetates, and many more. Refining involves different processes such as electrowinning, hydrogen reduction, evaporation, and crystallization (Petavratzi et al. 2019). See Figure 7 for the production of refined cobalt by form (2020) (Cobalt Institute 2025a).

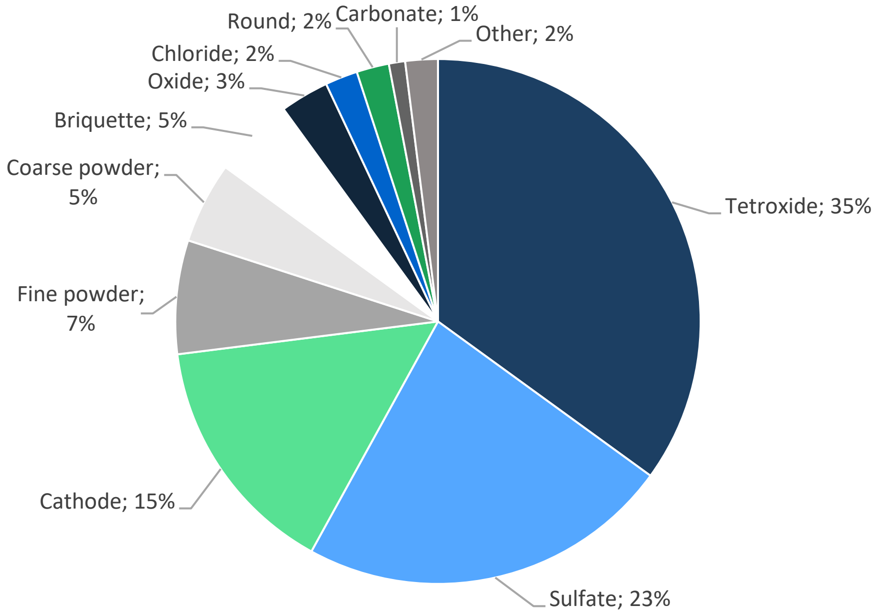

Figure 7: Production of refined cobalt by form (2020) (Cobalt Institute 2025a).

Processing plants

According to data from the British Geological Survey (2024), the total refined cobalt supply was 161 kt in 2022. Figure 8 presents the supply of refined cobalt in 2022 for the main producing countries. Most cobalt was refined in China (78%), followed by Finland (8%) and Canada (3%), other countries each refined 2% or less of total production.

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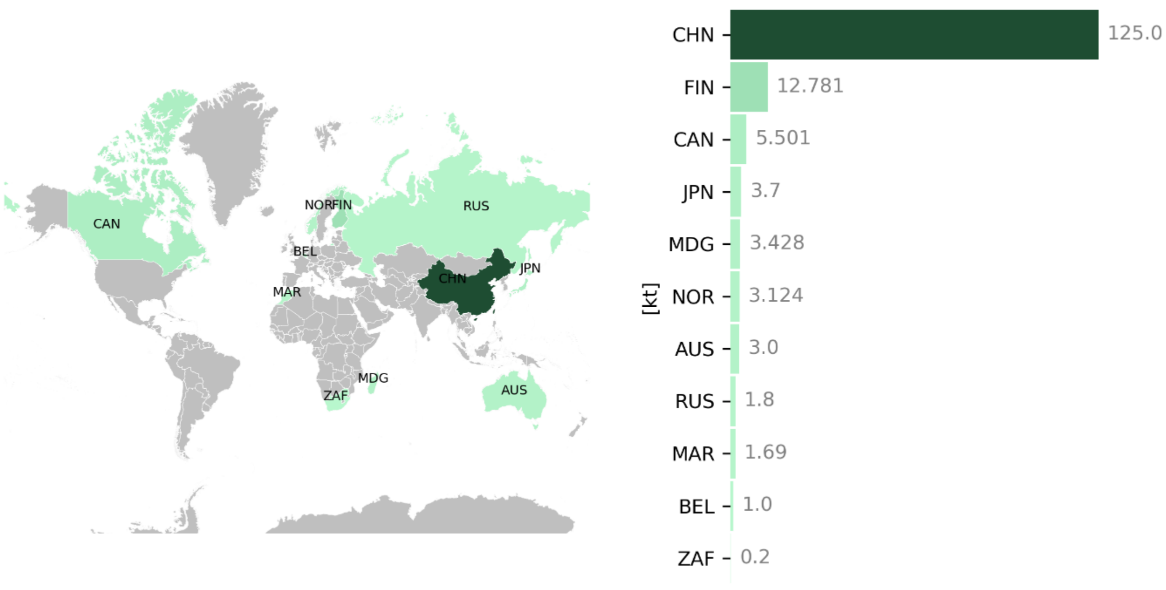

Figure 8: Refined cobalt supply 2022 by production share by country (British Geological Survey 2024).

According to S&P Capital IQ data (S&P Capital IQ 2024a), the total primary refined supply of cobalt in 2022 was 180.5 kt. That is about 19kt higher than the value reported by the British Geological Survey. Furthermore, S&P Capital IQ indicates that there are 83 processing plants globally that handle cobalt, including concentrators, refineries, and smelters, as shown in Figure 9. Among these facilities, only 13 process cobalt as the primary commodity, while others focus on different primary commodities: nickel (44), copper (12), ferronickel (7), zinc (5), platinum (1), and silver (1). In the data, no information is included on whether these plants were active cobalt producers in 2022.

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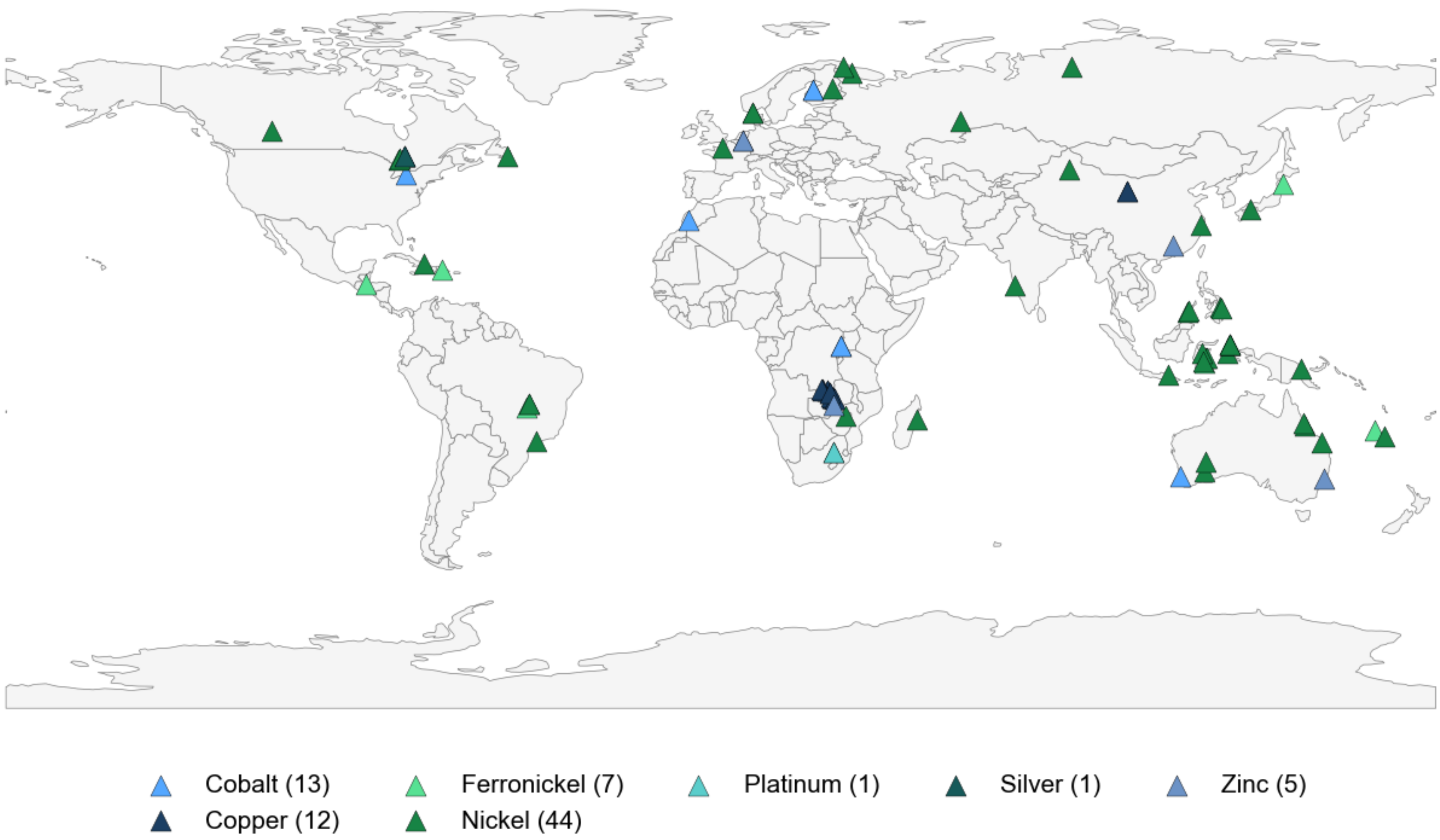

Figure 9: Global distribution of cobalt-producing refineries and smelters, categorized by primary commodity. Cobalt production data for 2022 is unavailable. (S&P Capital IQ 2025).

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2.1.2.5 Battery manufacturing countries

As described in section 1.1.1, most cobalt is used in chemical uses, of which 70% is consumed in batteries. Following cobalt processing, refined cobalt is combined with other materials, such as nickel, manganese, or aluminum, to create cathode materials. China has 70% of the world's production capacity for cathodes, South Korea accounts for 15% and Japan 14% (IEA 2022). The remaining 1% is production in the United States (there are also two small cathode facilities (Blois 2023), and in other countries. Demand for cathode material was 520 kt in 2021. In 2023, Umicore in Belgium also opened a facility to produce battery cathode materials (Elective 2023).

China is by far the largest producer of Li-ion batteries, with almost 80% of global production. Countries that manufacture lithium-ion batteries in the European Union and their share of global production in 2021 were: Hungary (4%), Poland (3%), Germany (2%), Sweden (0.6%), and the Czech Republic (0.1%) (Llamas-Orozco et al. 2023). Other European countries are scaling up battery cell manufacturing. Spain is set to increase production to 50 GWh by 2025 and double its capacity by 2026 (Europe Battery Cell Production 2025). France, Norway, and the UK are also projected to produce batteries by 2030. (IEA 2022) .

2.1.3 Changes in ownership

2.1.3.1 Cobalt operator and owner companies

In the S&P Capital IQ data (S&P Capital IQ 2025) 46 companies are listed that operate one or more cobalt mines. The largest operator producer is Glencore plc with 29% of production, followed by the Eurasian Natural Resources Corporation Limited (16%) and CMOC Group Limited (12%).

There are 59 mine owner companies with a percentage ownership of the projects and attributable production. The three largest owner companies are the same companies as the operators, but their ownership percentage over production is slightly lower (Glencore, with 25%, Eurasian Group, with 16%, and CMOC Group Limited, with 10%).

In addition, there are 59 companies that are listed as the first owner of a refinery that processes cobalt (among other metals), but the cobalt production of each company is unknown (S&P Capital IQ 2025). Some own multiple refineries.

2.1.3.2 Foreign Direct Investment

Based on the headquarters location of the mine operator companies and their attributable production, the three countries with the highest foreign direct investment in cobalt are Switzerland with 29%, China with 24% and the United Kingdom with 17%. Of the mine operator companies, six have headquarters in the European Union and four in the United Kingdom.

Based on the headquarters location of the mine owner companies and their attributable production, the three countries with the highest foreign direct investment in cobalt are Switzerland with 25%, China with 25% and Kazakhstan with 16%. Of the owner companies, eight have headquarters in the European Union and three in the United Kingdom (S&P Capital IQ 2025).

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2.1.3.3 Network Analysis

Figure 10 presents a network graph of the cobalt supply chain with cobalt mines and refineries, their operators and owners, and the countries that they are located in. For mines, all owners are included, for refineries, only the owner company with the largest share.

The size of cobalt mines, countries, and cobalt company owners are ranked by cobalt mine production. For mine operators, refineries, and refinery owners, production is not included; these nodes all have the same size.

There are two types of links illustrated:

- Geographic links: mines/refineries with the location (country).
- Ownership links: mines/plants with the operator/owner companies.

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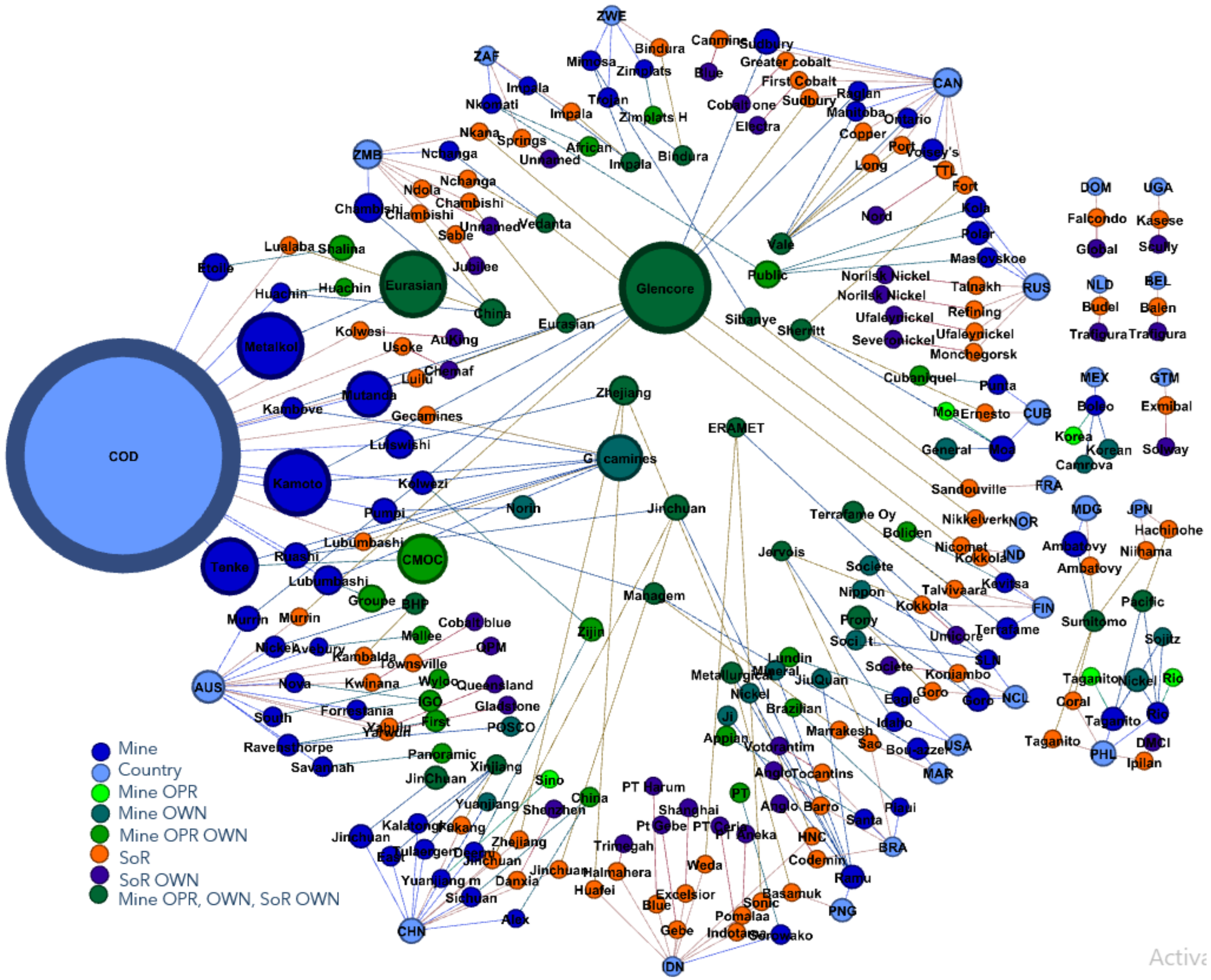

Figure 10: Cobalt company network: Abbreviations can be found in Table 14 in Appendix 8.2 (S&P Capital IQ 2025). Sizes of the nodes with mine production are gradually increasing in size with the smallest nodes with production under 1000 tonnes of cobalt to the largest node with 113000 tonnes of cobalt.

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The network analysis shows that 22 companies are vertically integrated and own both mines and smelters or refineries. Of these, 10 companies own mines in the same countries as refineries, and 12 companies own mines and refineries in different countries.

Degree centrality indicates the number of connections each node has. Companies with the highest degree of centrality in the main network include Glencore PLC (11), Gécamines SA (8), Vale S.A. (6), and Sumitomo Corporation and Metal Mining (5). These are in the centre of the graph (Fig. 8). The companies with the highest betweenness centrality are Glencore, Zhejiang Huayou Cobalt Co., Ltd, and Jinchuan Group International Resources Co. Ltd., reflecting their role in connecting different nodes in the 'network' by being part of the shortest paths that pass through them. This highlights their influence in linking other companies and in this network, geographic locations. The companies with the highest closeness centrality in the main network are Jervois Global Limited, Public Joint Stock Company Mining and Metallurgical Company Norilsk Nickel, and Umicore S.A. This metric shows how near a node is to other nodes in the network, calculated as the average shortest path length from the node to all other nodes (Golbeck 2015).

2.1.4 Changes in location - trade

Cobalt trade flows in 2022 are analysed based on data from BACI, HS 92 for cobalt products and HS 22 for cobalt waste and scrap (Gaulier and Zignago 2010).

The cobalt trade flows are divided into four categories: 'cobalt ores and concentrates', 'cobalt mattes and other intermediate products of cobalt metallurgy', 'cobalt chemicals', and 'cobalt waste and scrap'. Of note is that there can also be cobalt waste and scrap included in the category of cobalt mattes and other intermediate products, so there is some overlap between these flows.

Cobalt ores and concentrates

The global trade of cobalt ores and concentrates (HS260500) amounted to 33 kt in 2022. Almost 90% of the exports were from the Democratic Republic of Congo, followed by Austria with 4% and Italy with 3%, see Figure 11 and Figure 12.

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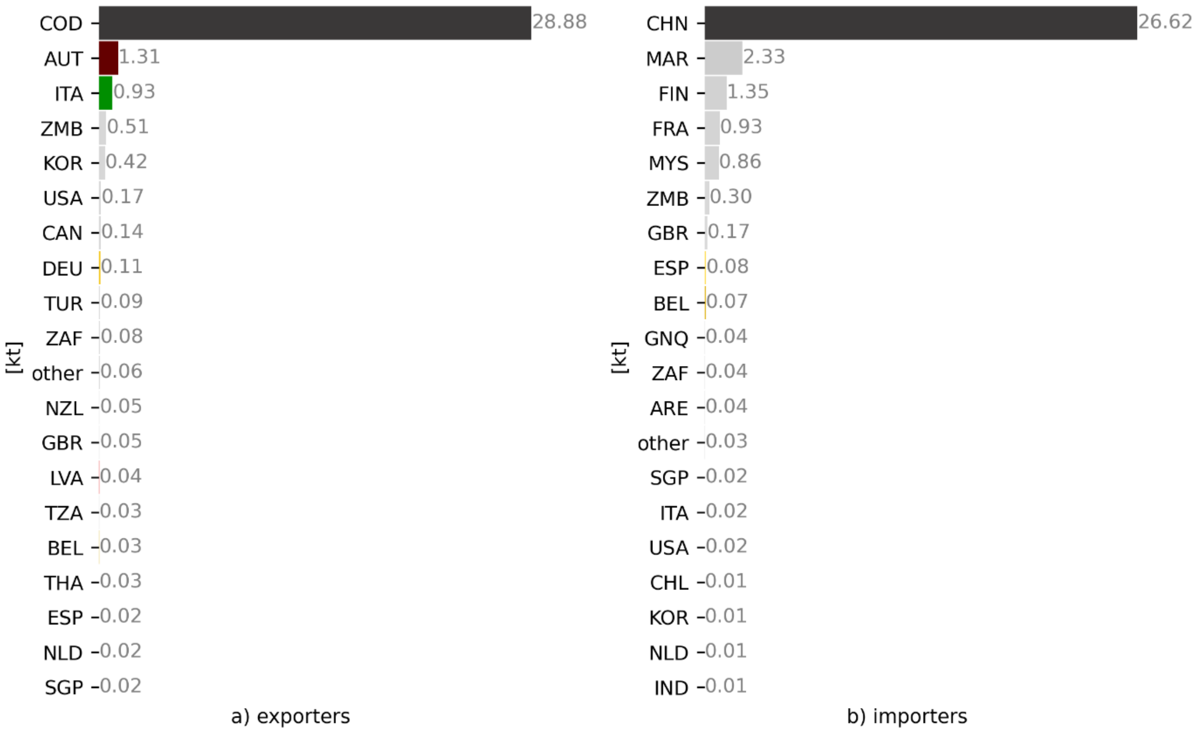

Figure 11: Cobalt trade flow 2022: cobalt ores and concentrates (HS260500) (BACI HS 92) (Gaulier and Zignago 2010).

As Austria and Italy have no cobalt mines, they are likely re-exporting the ore that they may have imported and stocked in previous years. The leading importing country was China, with 80% of the imports, followed by Morocco with 6% and Finland with 4%. China and Finland have cobalt refineries, Morocco only has cobalt mines, but aims to refine cobalt in the future (Benchmark Minerals 2023).

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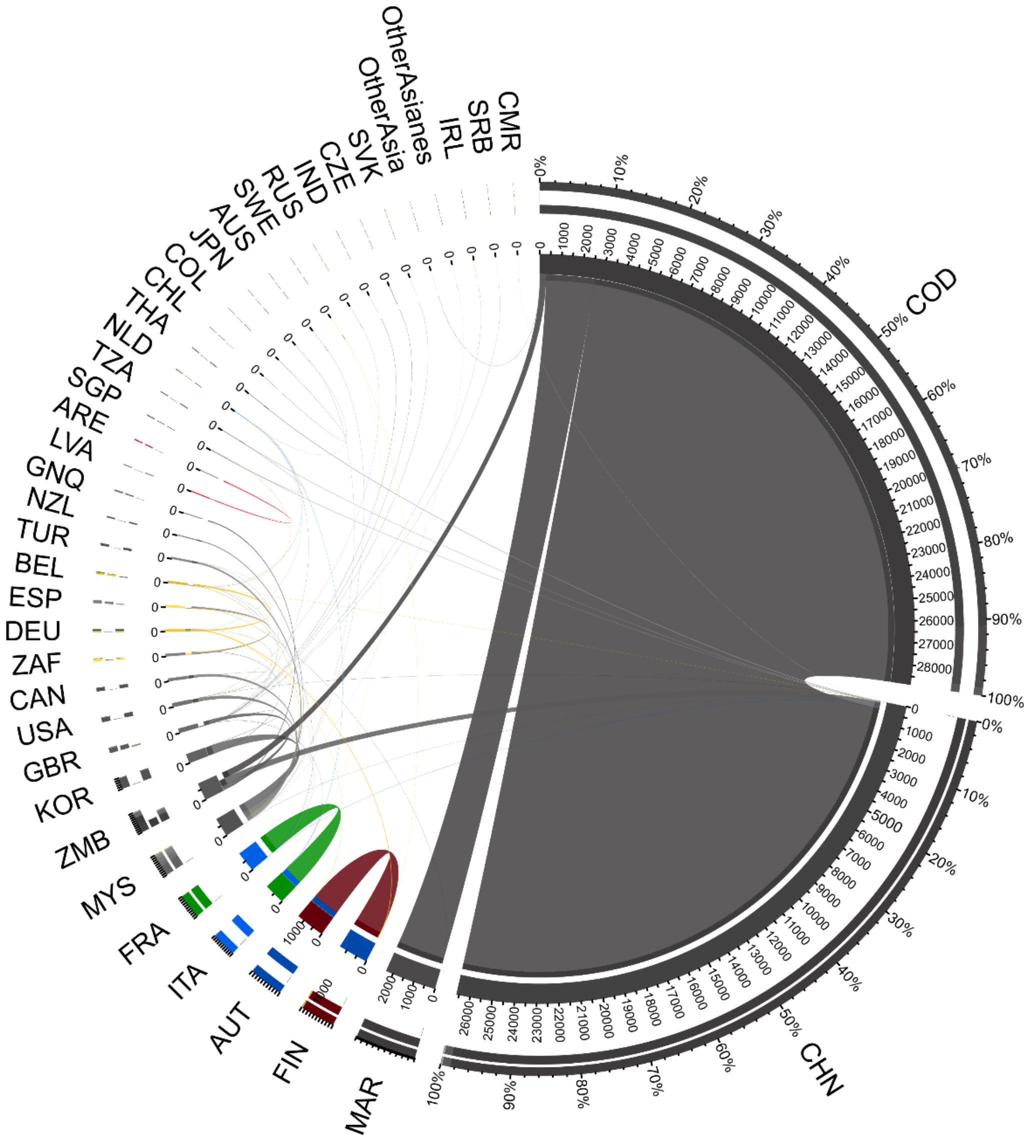

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Figure 12: Cobalt trade chord 2022: cobalt ores and concentrates (HS260500) (BACI HS 92) (Gaulier and Zignago 2010).

Cobalt mattes and intermediate products of metallurgy

The global trade of cobalt mattes and intermediate products of metallurgy (HS 810510 and HS 810590) amounted to 484 kt in 2022. Around 80% of the exports were from the Democratic Republic of Congo, followed by Canada with 2% and Mozambique with 2%, see Figure 13 and Figure 14. The main importing country was China with 75%, followed by Singapore (5%) and Malaysia (3%).

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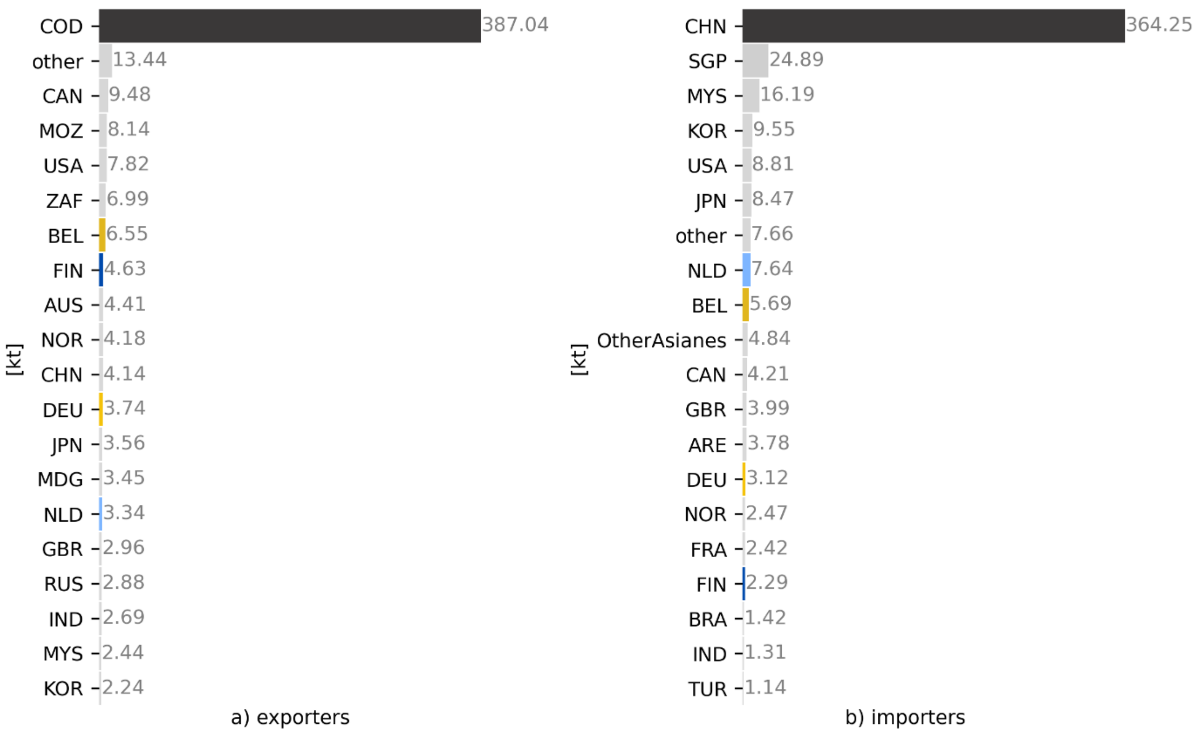

Figure 13: Cobalt trade flow 2022: Cobalt: mattes and other intermediate products of cobalt metallurgy, unwrought cobalt, waste and scrap, powders (HS 810510) and Cobalt: articles n.e.s. in heading no. 8105 (HS 810590) (BACI HS 92) (Gaulier and Zignago 2010).

The flows traded between the countries, illustrated in Figure 14, show that the largest flows of these cobalt products were those of the exports from the DRC to China. There is also a flow from Singapore to China. Singapore had only very small import flows in 2022. Malaysia also imported some of these cobalt products from Mozambique. All the other traded flows are comparatively very small. As for European-related flows, the figure shows that Belgium has the most significant European trade flows of these products, with even small exports to China. The Netherlands, Finland, Norway, the United Kingdom, and Germany, among others, are all European countries trading these cobalt products.

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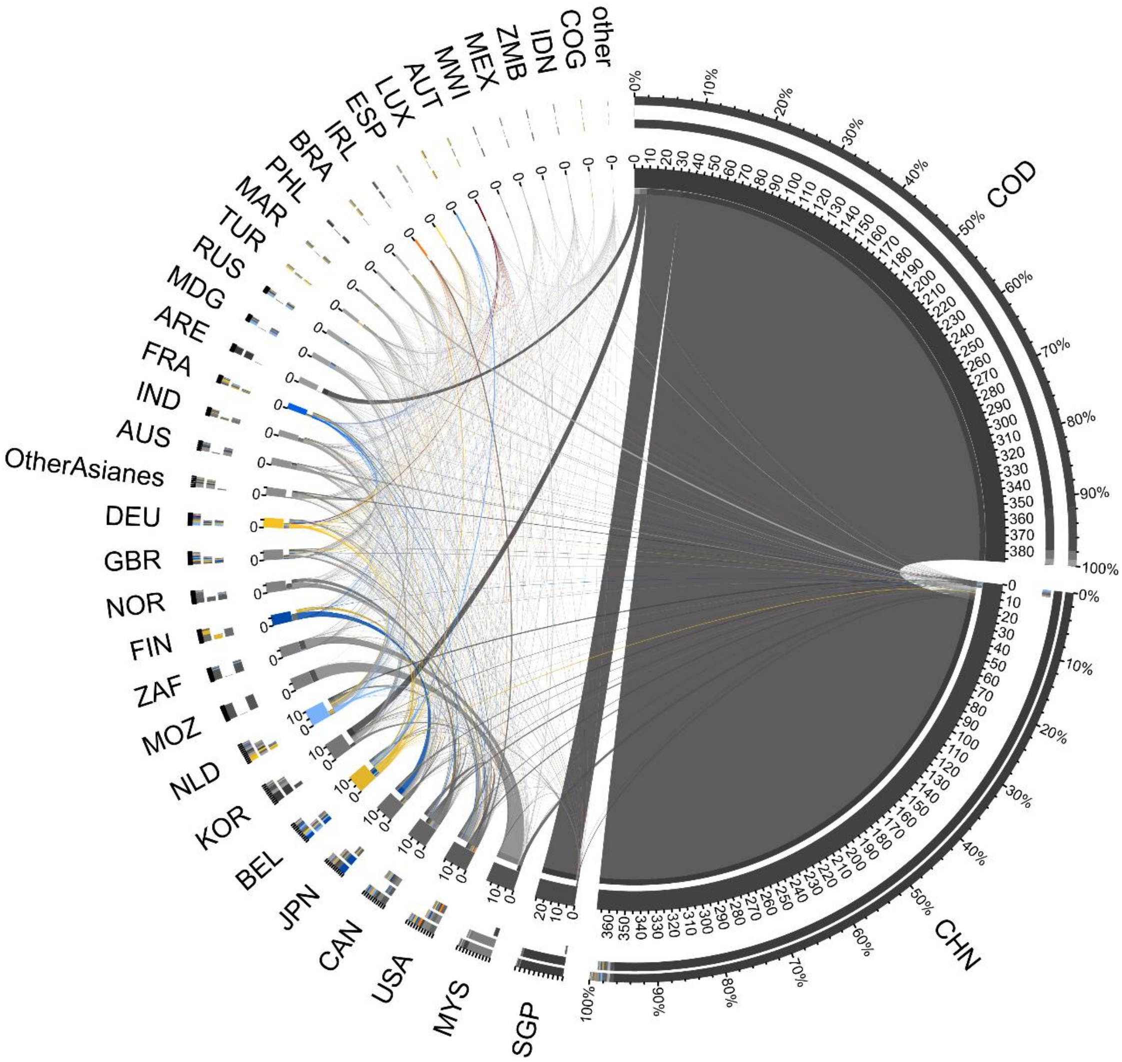

Figure 14: Cobalt trade chord 2022: Cobalt mattes and intermediate products of metallurgy. HS 810510 Cobalt: mattes and other intermediate products of cobalt metallurgy, unwrought cobalt, waste and scrap, powders and HS 810590 Cobalt: articles n.e.s. in heading no. 8105 (BACI HS 92) (Gaulier and Zignago 2010).

Cobalt chemicals

The global trade of cobalt chemicals (HS 282734, 'HS 282200, and HS 291523) amounted to 87 kt in 2022, see Figure 15 and Figure 16. Around 43% of the exports were from the DRC, followed by South Africa (19%) and China (11%). The leading importing country was Finland with 14% of the imports, followed by China (11%) and Singapore 8%).

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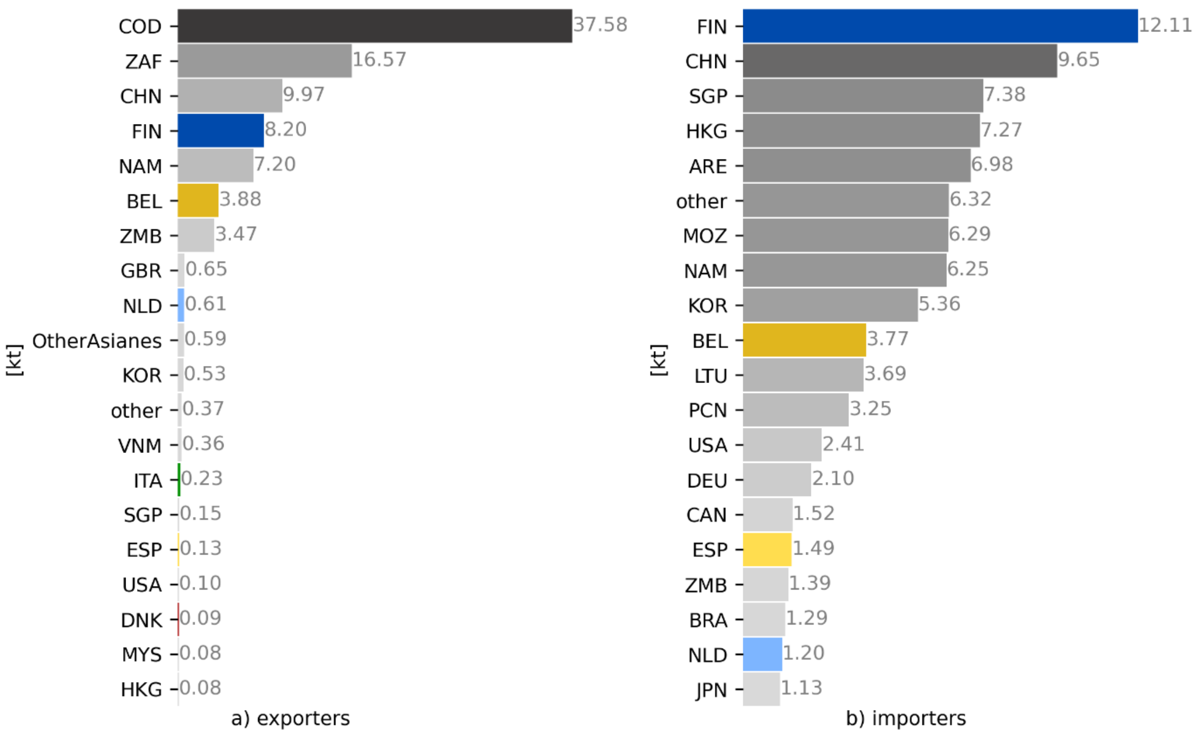

Figure 15: Cobalt trade flow 2022: cobalt chemicals: 'Chlorides: of cobalt' (HS 282734), 'Cobalt oxides and hydroxides: commercial cobalt oxides' (HS 282200) and 'Acids: saturated acyclic monocarboxylic acids: cobalt acetates' (HS 291523) (Gaulier and Zignago 2010).

The traded flows of these cobalt intermediate products, illustrated Figure 16 shows a larger number of significant traders than the previous cobalt products – a more diversified market. The DRC is still the main exporter, followed by South Africa. Both Finland and China import and export significant amounts, with most of Finland's imports coming from non-European sources (South Africa and Vietnam) and being exported to mostly European countries. Most of the flows imported by Vietnam, which are then exported to Finland and Europe, originated from the DRC.

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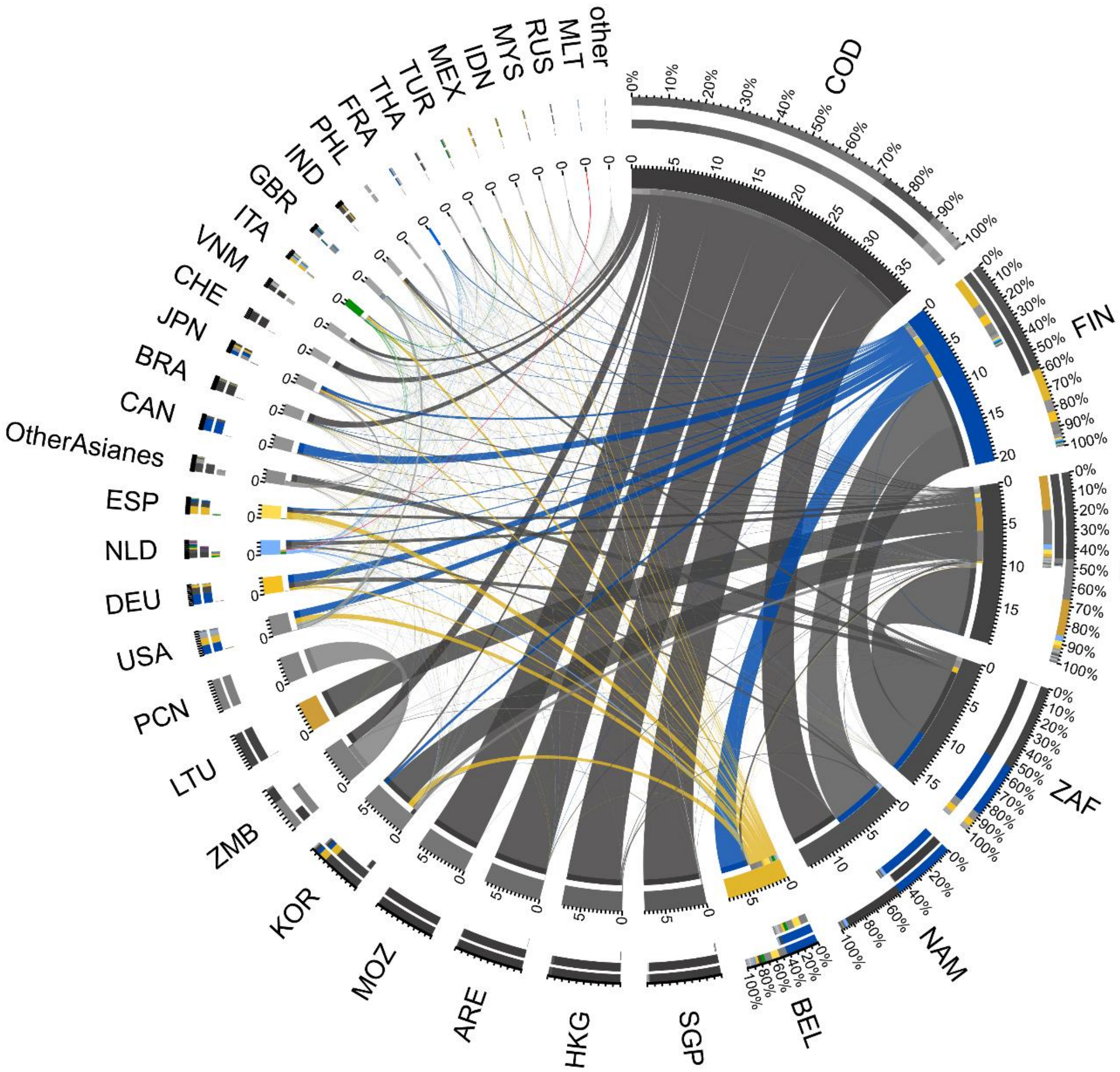

[kt]

Figure 16: Cobalt trade chord 2022: Trade flows cobalt chemicals: ‘Chlorides: of cobalt’ (HS 282734), ‘Cobalt oxides and hydroxides: commercial cobalt oxides’ (HS 282200) and ‘Acids: saturated acyclic monocarboxylic acids: cobalt acetates’ (HS 291523) (Gaulier and Zignago 2010).

2.1.5 Secondary sources and flows

2.1.5.1 Cobalt recycling

According to S&P Capital IQ data (S&P Capital IQ 2024a), the total secondary supply of cobalt was 9.3 kt in 2022. Supply from secondary sources is expected to increase to 50 kt in 2028 (next to 276 kt of primary supply). An estimated 65% of recycled cobalt originates from battery recycling, where the value of recoverable cobalt makes lithium-ion battery recycling economically appealing to recyclers. Hard metal scrap recycling follows as the second-largest secondary source, accounting for 24% (Cobalt Institute 2025b). See Table 13 in Appendix 8.1 for an overview of the largest companies that recycle lithium-ion batteries.

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2.1.5.2 Secondary flows

The global trade of cobalt waste and scrap (HS 810530) amounted to 10 kt in 2022, see Figure 17 and Figure 18. Around 28% of the exports were from the United States of America, followed by Japan (13%) and Great Britain (9%). The main importing country was Canada with 25% of the imports, followed by the United States of America (18%) and Great Britain (15%).

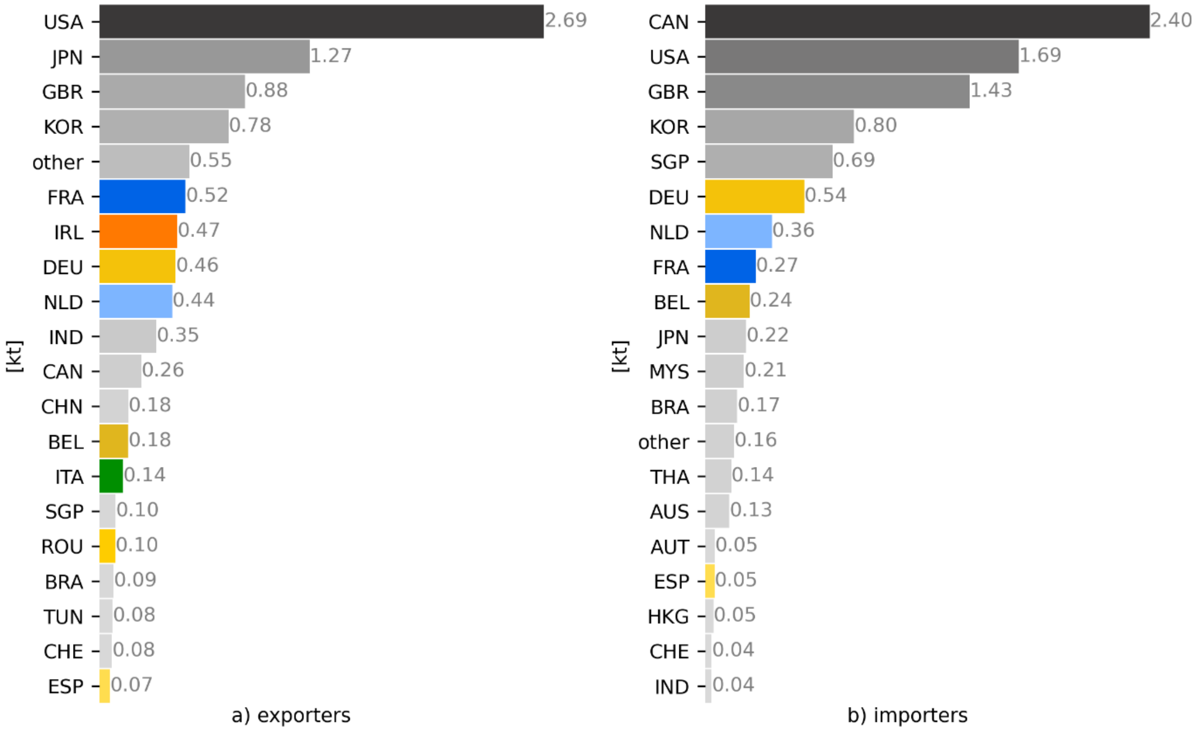

Figure 17: Cobalt trade flow 2022: cobalt waste and scrap (HS 810530) (Gaulier and Zignago 2010).

The largest trade flows were exchanged between the USA, Canada, and the United Kingdom. There are also significant flows being imported from Japan to South Korea and from South Korea to Singapore. Germany trades with multiple countries, primarily European. France has relatively significant exports to the USA, as well as to Ireland. Finally, it should be noted that the main importers/exporters of cobalt waste and scrap are not the main importers/exporters of the other cobalt intermediate products and ore (China and the DRC).

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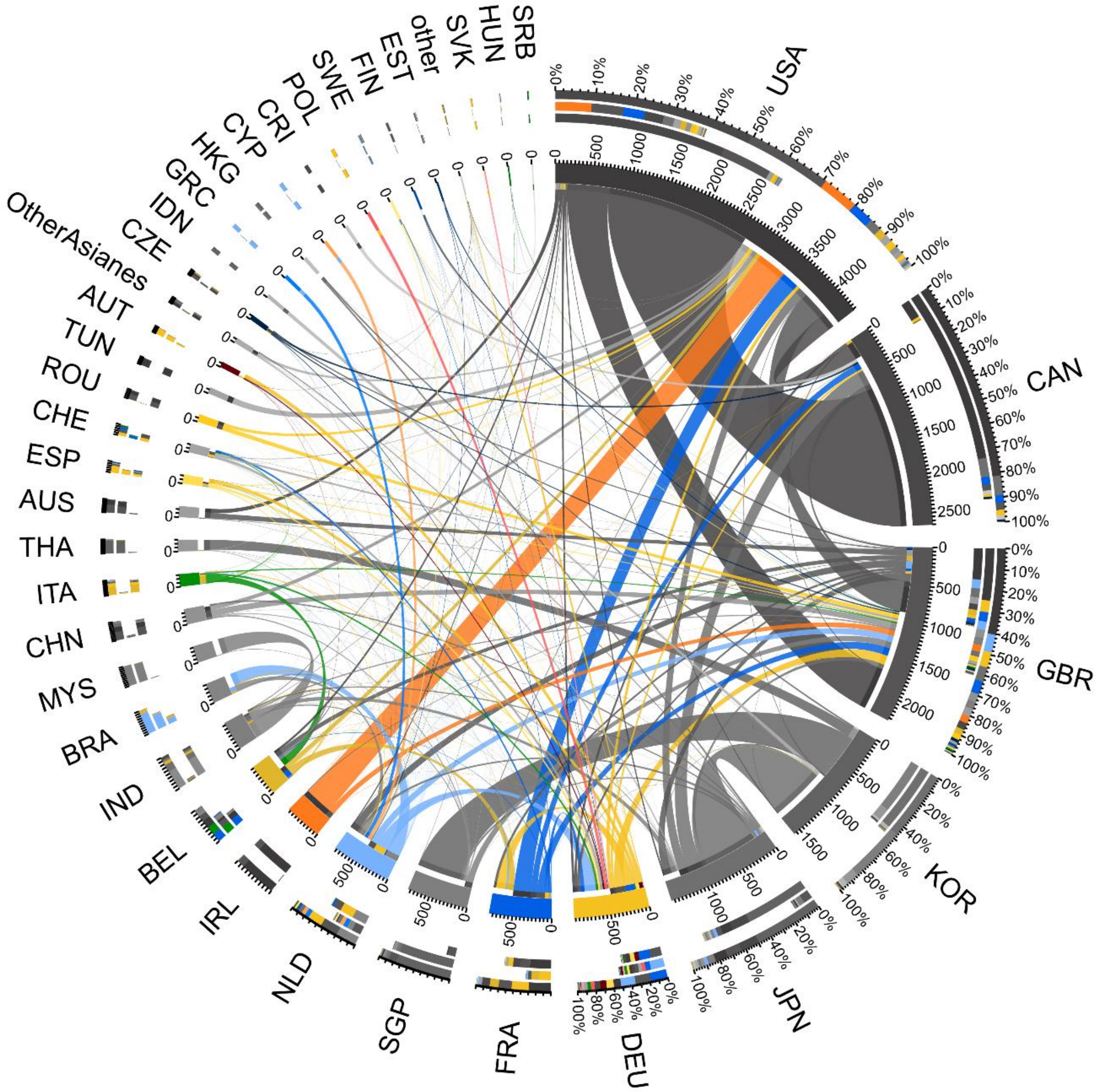

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Figure 18: Cobalt trade chord 2022: cobalt waste and scrap HS 810530 (BACI HS 22) (Gaulier and Zignago 2010).

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2.2 Lithium

2.2.1 Introduction and lithium market

This case study provides a comprehensive mapping of the global lithium supply chain, with a specific focus on identifying leverage points for the application of traceability technologies.

Given the diverse forms of lithium products, which contain varying amounts of lithium, this deliverable standardizes quantities using the industry benchmark "lithium carbonate equivalent" (LCE) as the unit of measurement (see Appendix 8.4, Table 16 for conversion factors).

The primary use of lithium is in battery production, which includes electric vehicle batteries, electronics, energy storage systems, electric bikes, and other battery types. These applications collectively accounted for 82% of lithium consumption in 2022 (S&P 2024); see Figure 19). Additionally, lithium is used in various industrial applications such as ceramics, glass, lubricants, grease, and catalysts, which together represented approximately 18% of lithium consumption in 2022. In Appendix 8.4, Figure 77 the different lithium production routes are illustrated in (Sun et al. 2017).

To complement this, recent analysis highlights Europe's strategic vulnerability in the lithium market: while China remains a dominant global refiner, Europe lacks comparable refining capacity and is heavily reliant on supply chains centered in China (BRGM (for Ecomine / MineralInfo) 2025).

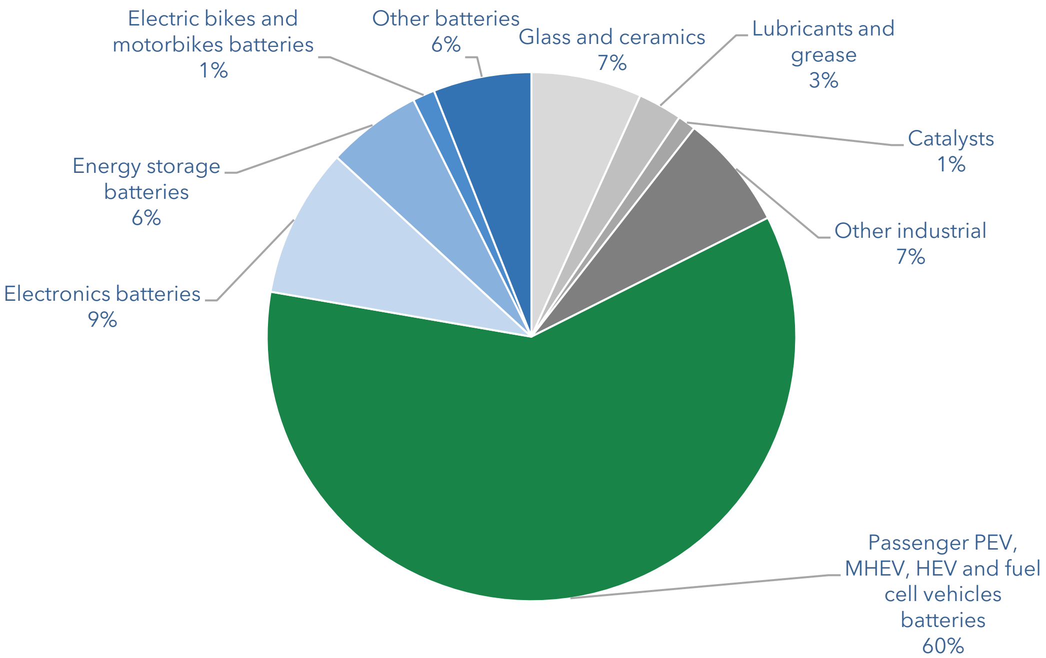

Figure 19: Lithium consumption 2022 by product . Adapted from S&P Global Market Intelligence (S&P 2024).

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The demand for lithium is projected to grow rapidly, driven primarily by the expansion of battery applications. Current projections indicate that demand will nearly double from approximately 700 kt LCE in 2022 to around 1370 kt LCE by 2025 (S&P 2024). Despite this sharp increase, S&P Global Market Intelligence forecasts that lithium supply will continue to outpace demand over the next five years. In 2022, total chemical supply was estimated at approximately 730 kt LCE and is expected to rise to 1440 kt LCE by 2025.

Looking ahead to 2030, the IEA projects that under current stated policies, global lithium demand will reach approximately 2,500 kt LCE by 2030. In the more ambitious Net Zero Emissions (NZE) scenario, demand could increase to around 3,700 kt LCE by the same year (International Energy Agency, 2024). However, supply is expected to fall short of meeting this projected demand. According to the IEA (IEA 2024a), the supply of lithium in chemical form is estimated to reach 1,985 kt LCE by 2030, resulting in a potential shortfall of around 700 kt under the NZE scenario. S&P Capital IQ (2024) offers a slightly more optimistic outlook, estimating a 15% higher supply at 2,285 kt LCE of "saleable lithium" in 2030 (see also Section 1.3.2). In the alternative NZE scenario, if sodium-ion batteries gain wider acceptance in the electric vehicle market, total lithium demand in 2030 could be reduced by 10%. Additionally, the early adoption of vanadium redox flow technologies could decrease lithium demand in stationary applications by 6% (IEA 2024a).

Lithium prices have experienced considerable volatility in recent years. Between 2020 and 2022, the global average price of lithium carbonate surged from $6,700 per tonne to $68,000 per tonne. However, since 2022, prices have sharply declined to $10,600 per tonne. This price drop is largely attributed to a slowdown in the uptake of passenger electric vehicles (PEVs), leading to an oversupply. The reduced demand has caused the cancellation of several battery projects in both the US and Europe (S&P Capital IQ 2024a).

2.2.2 Transformations in material state and chemical modifications

2.2.2.1 Deposits and reserves

Lithium resources can be sourced from several primary categories of deposits: hard-rock deposits (pegmatites and granites), surface and near-surface brines (continental), unconventional resources (seawater or deep geothermal brines), or clay (less explored) (Choubey et al. 2017; Sanjuan et al. 2022; Zhao, Wang, and Cheng 2023) . Historically, pegmatites have been the predominant source of lithium. The three largest lithium-bearing pegmatite deposits are located in North Carolina (USA), Manono (Democratic Republic of Congo), and Greenbushes (Australia). Active extraction is currently occurring only at Greenbushes in Australia, but is planned at the other deposits (see 1.3.2). Although over 100 minerals are known to contain lithium, only a few are economically viable to extract, including spodumene, lepidolite, petalite, eucryptite, amblygonite, hectorite, and jadarite (British Geological Survey 2016). Among these, spodumene is the most abundant and widely mined lithium-bearing mineral. However, due to increasing market demand and prices, other minerals such as hectorite and zinnwaldite are becoming more attractive and potentially feasible for extraction (Khakmardan et al. 2023).

Lithium can also be sourced from brines, which are fluids containing high levels of dissolved salts. Although lithium is present in many brines or waters, it typically occurs at low concentrations. High-temperature geothermal water can increase lithium concentrations, and economic deposits usually form in regions with high solar evaporation, which further concentrates lithium (British Geological Survey 2016). One of the most important regions for lithium-bearing continental brine deposits is the salt lakes and salt pans of the central

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Andres in South America, known as the salars. One of the most notable deposits in this region is the Salar de Atacama in Chile. This playa lake is one of the largest in the world (British Geological Survey 2016). In addition to continental brine, other sources include geothermal and oilfield brines, as well as volcano-sedimentary deposits (Shaw 2021). However, conventional evaporitic technology is not applicable for extracting lithium from these more dilute brines, and economically viable technologies are still being explored (Vera et al. 2023). Figure 78 in Appendix 8.4 illustrates the types and locations of global lithium deposits (Shaw 2021).

Currently, 20 countries worldwide have lithium reserves, totaling approximately 28,000 kilotonnes (kt) (USGS 2024). Figure 20 shows the lithium reserves per country. The top five countries with the largest reserves are Chile (33%), Australia (22%), Argentina (13%), China (11%), and the United States (4%). Figure 2 depicts the current lithium reserves per country, with countries identified by their ISO 3166 Alpha-3 codes. Table 17 in Appendix 8.4 presents the resources and reserves by country, based on USGS data.

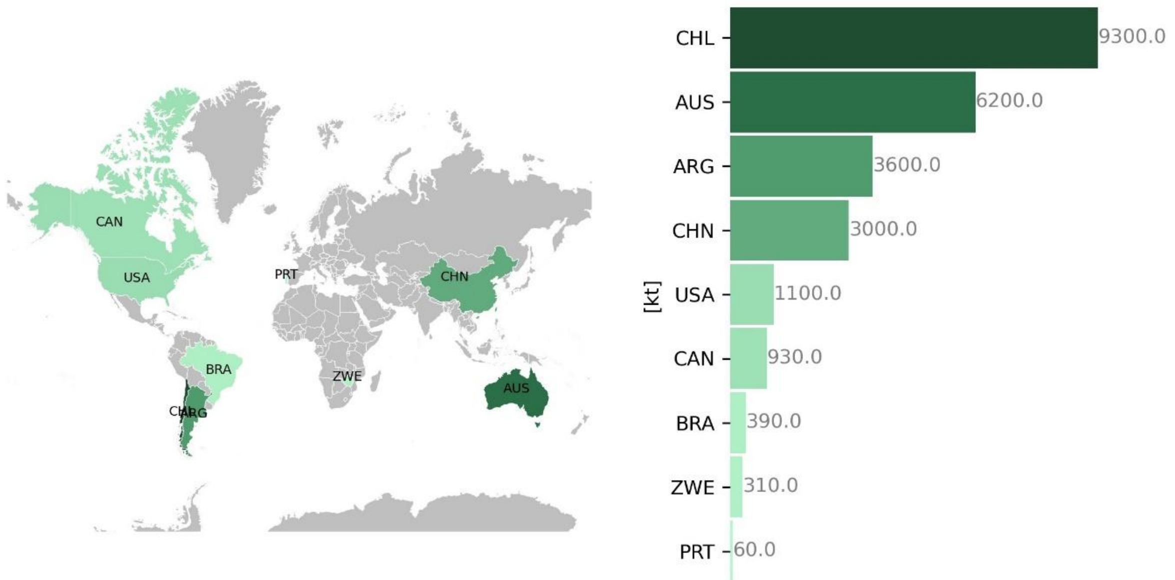

Figure 20: Lithium reserves per country (lithium content) (USGS 2024).

2.2.2.2 Extraction

Lithium mines

In 2022, there were 30 operational lithium mines (S&P Capital IQ 2024a and see Appendix 8.4, Table 18). The total production from these lithium projects was 783 kt LCE, out of an estimated 789 kt LCE (S&P Capital IQ 2024a). The primary suppliers of mined lithium were Australia (49%), Chile (26%), and China (13%), see Figure 21. Of the total production, 343 kt LCE originated from continental brine deposits, while 440 kt LCE came from pegmatite and granite ore deposits, see their geographic locations in Figure 22.

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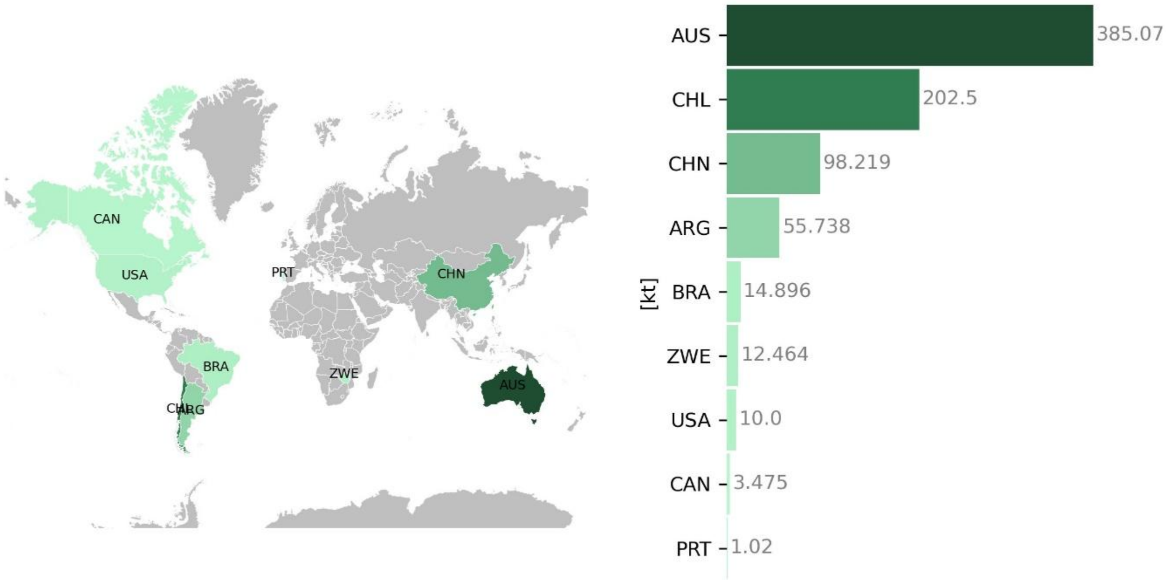

Figure 21: Lithium mined per country in 2022, in kilotonnes (kt) of LCE. Based on S&P Global mining projects data (2024).

By-products

At the 30 lithium projects included in the S&P Intelligence IQ database (2022), there are also some other commodities reported to be present at the mines, including: potash (13 mines), spodumene (11 mines), tantalum (10 mines), niobium (5 mines) and at three mines or less: tin, iron ore, caesium, magnesium, gold, potassium sulfate, silica, zinc, lead and manganese.

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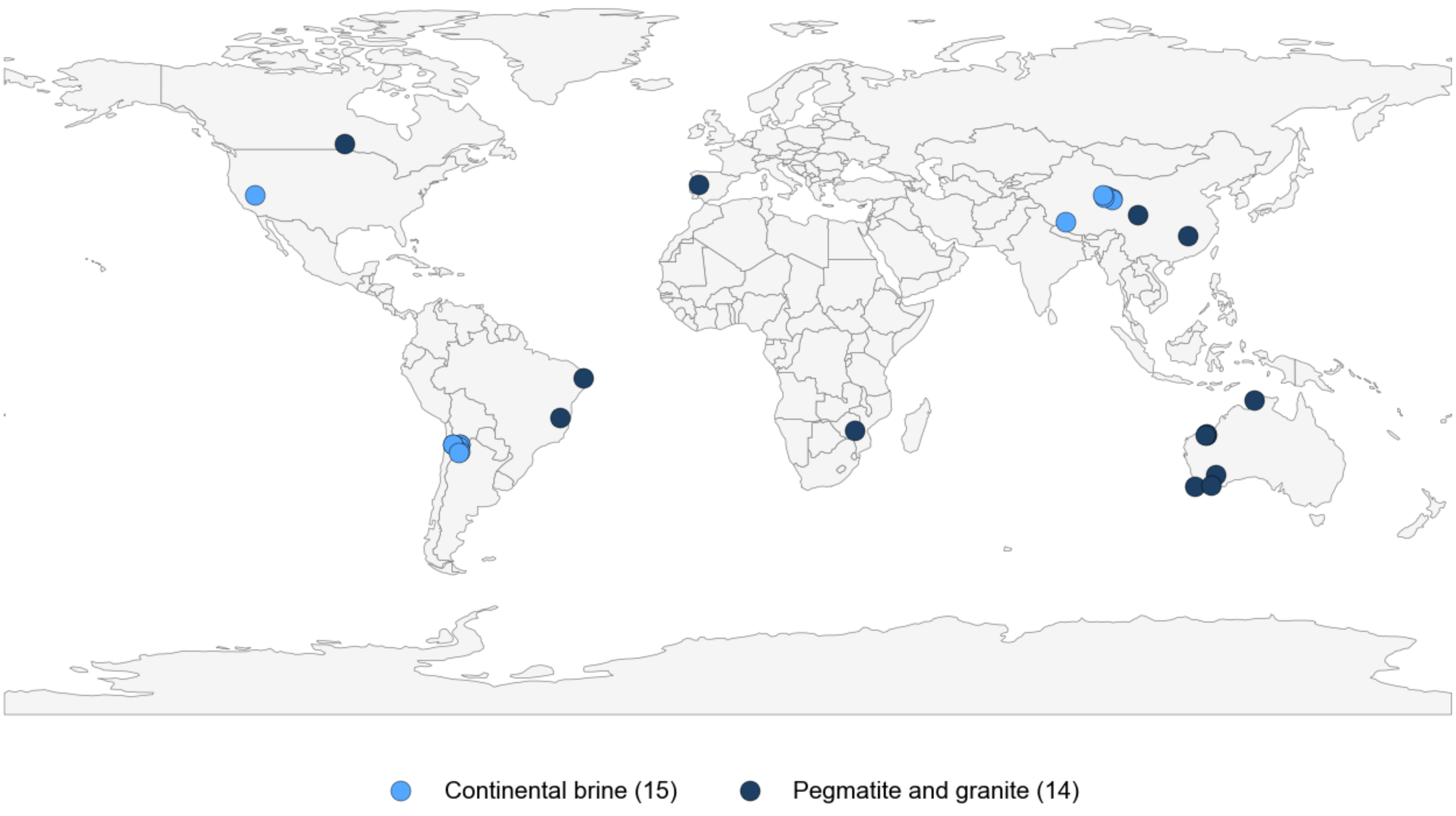

Figure 22: Lithium mines in 2022 (S&P Capital IQ 2024a), there are 15 mines at continental brine deposits and 14 mines at pegmatite and granite deposits. The locations are based on open-source data (see Appendix 8.4, Table 18).

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Artisanal and illegal lithium mining
While usually lithium mining is carried out by large-scale operations, there are some reports of artisanal and small-scale mining and illegal lithium mining. For example, in Nigeria (AP News 2024) and Zimbabwe (Business & Human Rights Resource Centre 2023). Though there are some reports, quantities are probably small compared to artisanal mining of other minerals like gold, tin, and cobalt. In China, the mining of lithium has been linked to forced labour practices with the Uyghur population in the Xinjiang Uyghur Autonomous Region (U.S. Department of Homeland Security 2024).

Forecast production
The global production of lithium will increase by around 450 kt in 2035 (IEA 2025) Among these, the largest new lithium mines will be the Kathleen Valley mine in Australia and the Manono mine in the DRC, each expected to produce over 100 kt LCE in 2030. In Europe, saleable production is expected at the Keliber mine in Finland (13 kt) and is expected to continue at the Alvarroes mine in Portugal (0.7 kt) (Detailed references for each project are in Appendix 8.4).
As of 2024, the S&P Capital IQ screener lists 649 lithium projects in total. Of these, the majority (387 projects) are in the early stages of development, such as 'exploration' or 'grassroots'. Additionally, 97 projects are in the later stages of development, including feasibility completion or the commencement of construction. As of 2024, 27 projects are operational, and 8 are expansions of existing projects. One notable project is the Kings Mountain mine in North Carolina, USA, which is in the scoping phase. This mine is situated at one of the world's three largest lithium-bearing pegmatite deposits (CNBC 2024).
There are 43 projects in Europe, of which three are almost finalised or finalised (Keliber in Finland, Alvarroes in Portugal, and Vulcan in Germany). Also, projects in Spain (Alberta II), Czechia (Cinovec), France (EMILI), Serbia (Jadar), Italy (Lazio), Bosnia and Herzegovina (Lopare), Portugal (Mina do Barroso), Spain (San Jose), Austria (Wolsberg) and Germany (Zinnwald) are in an active late development stage (feasibility started, completed, or in reserves development) (Jamasmie 2024; MDO Data Online Inc. 2025; Rustici 2022). Some of these projects were also selected as the EU's strategy projects in March 2025 (European Commission. 2025). These include the EMILI project in France, an integrated extraction and processing project operated by IMERYS Ceramics France, the Barroso Lithium Project in Portugal, an extraction project operated by Savannah Lithium Unipessoal, Lda; the Cinovec Lithium Project in Czechia, developed by Geomet s.r.o. as an integrated extraction and processing facility; and the Keliber Lithium Project in Finland, led by Keliber Technology Oy.

2.2.2.3 Processing

Processing steps

The Production and Conversion to Lithium Concentrates

The initial step in lithium production involves generating a lithium concentrate or run-of-mine ore, which varies based on the type of lithium ore. Hard rock ores, such as spodumene, are processed into lithium concentrate through a series of steps, including digging, drilling, and screening. Conversely, sedimentary ores like jaderite undergo a different process to produce run-of-mine ore, and lithium-rich brines are processed to produce a lithium brine concentrate. Detailed lithium processing methods at locations like the Mount Cattlin mine in Australia and the Zhangjiagang plant in China are described by (Khakmardan et al. 2023). Figure 23 presents an overview of the various lithium processing steps (based on (International Lithium Association 2024) and (British Geological Survey 2016)).

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Conversion to Technical Grade Lithium Carbonate

There are several methods to produce technical-grade lithium carbonate. For lithium ore concentrate, the process involves acid roasting and carbonation, as detailed by (Khakmardan et al. 2023) for the Zhangjiagang plant in China. For run-of-mine ore, methods include calcination, water leaching, and either causticisation or electrolysis. Alternatively, the ore can undergo acid leaching or roasting followed by purification and carbonation to produce lithium carbonate. Processing lithium brine concentrate involves drilling, pumping, solar evaporation, solvent extraction, precipitation, filtration, drying, screening, and milling. Additional purification processes, such as carbonation, centrifuge separation, magnetic separation, and solvent extraction, can also be applied to create technical-grade lithium carbonate (International Lithium Association 2024). Lithium-rich brine can further be concentrated to lithium chloride, from which lithium metal and other chemicals are produced (Sun et al. 2017).

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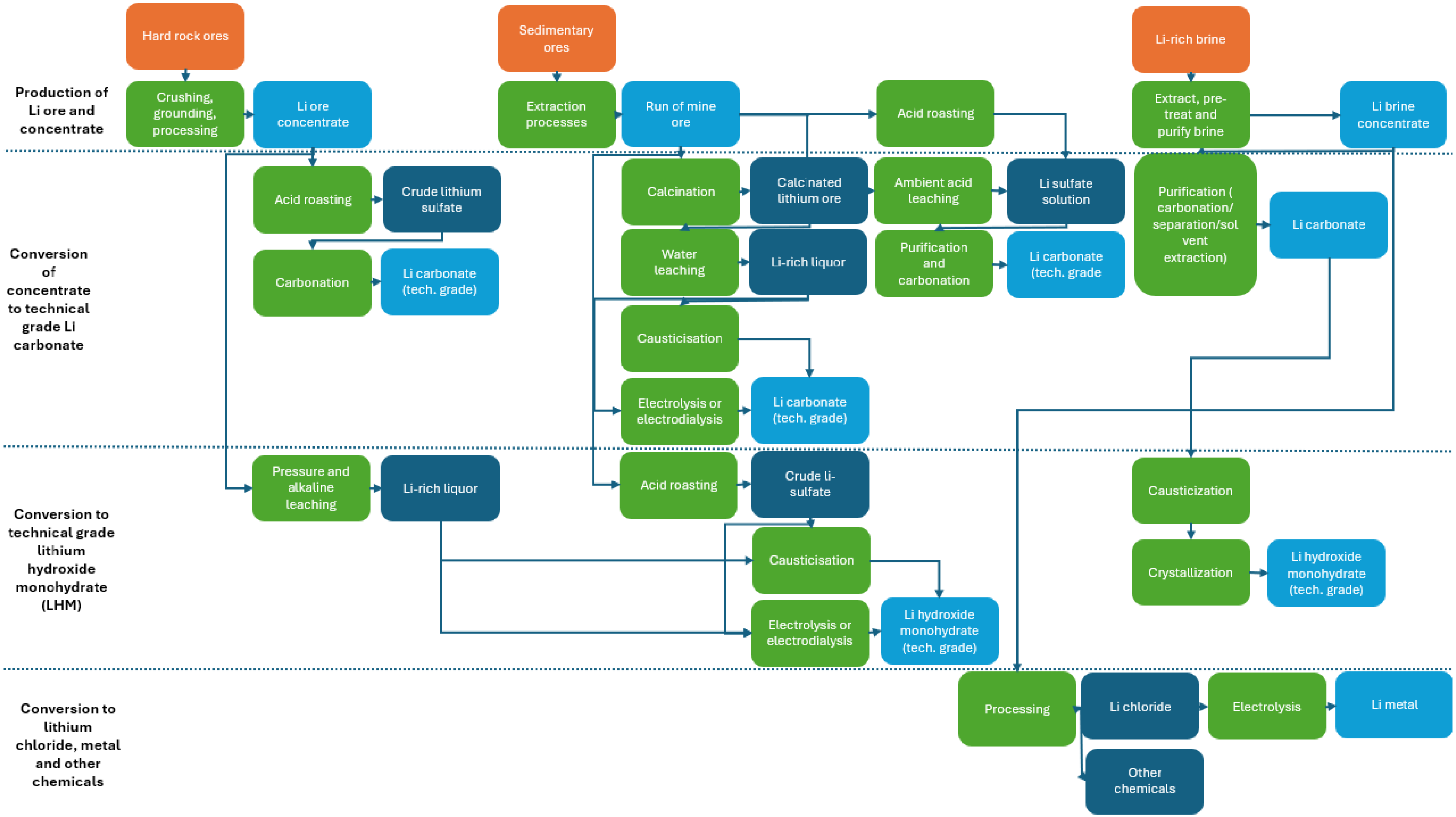

Figure 23: Lithium processing steps based on (Grant, Deak, and Pell n.d.; International Lithium Association 2024) and (British Geological Survey 2016)

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Conversion to Technical Grade Lithium Hydroxide Monohydrate

Technical grade lithium hydroxide monohydrate can be produced through various routes. Using lithium ore concentrate as input, pressure leaching and alkaline leaching generate a lithium-rich liquor, which is then subjected to causticisation or electrolysis. For run-of-mine ore, acid roasting or leaching creates crude lithium sulfate, which is similarly processed by causticisation or electrolysis. Purification processes can further refine lithium hydroxide monohydrate into battery-grade material (International Lithium Association 2024).

Conversion to Lithium Metal, Chloride, and Other Chemicals

Lithium carbonate, which accounts for 90 percent of lithium consumption, is the most widely used form of lithium. Other forms, such as lithium hydroxide, butyl-lithium, lithium metal, and lithium chloride, are derived through further processing of lithium carbonate, except for lithium metal, which is produced by electrolysis of a mixture of molten lithium chloride and potassium chlorid (British Geological Survey 2016).

Processing plants

The total chemical supply of lithium is estimated at 729 kt (S&P Capital IQ 2024a), a little lower than the total estimated mine production of 789 kt LCE (S&P Capital IQ 2024a). Figure 24 presents the processing capacity of different countries of lithium chemicals.

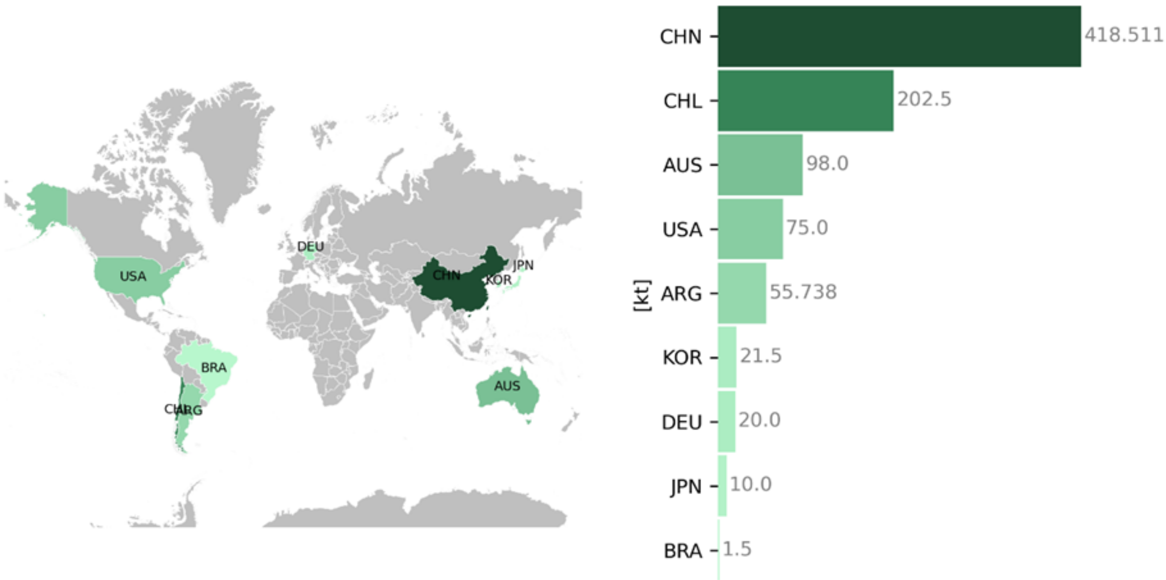

Figure 24: Lithium processing capacity, in kilotonnes (kt) of different lithium chemicals (carbonate prod. based on mine production, capacity of other chemicals: see references in Appendix 8.5,Table 16).

Based on open-source data, 44 lithium processing plants have been identified in Figure 25 (see Table 24Table 24 in Appendix 8.11). Most plants produce lithium carbonate (31 plants) and/or lithium hydroxide (17 plants). Other products include lithium metal (5 plants), lithium chloride (6 plants), butyllithium (4 plants), lithium fluoride (2 plants), and lithium bromide (1 plant). It was assumed that lithium produced at continental brine mines is processed at the same site, with production quantities matching those of the mines. For other processing plants (hard rock), only their capacity is known, not their actual production; thus, only capacity data is included. Some of the producers at continental brine mines produce lithium carbonate, others also convert the lithium carbonate to lithium hydroxide monohydrate

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(Grant, Deak, and Pell 2020). As illustrated in Figure 23As illustrated in Figure 23, lithium carbonate, produced from brine, can also be further processed into lithium hydroxide monohydrate (LHM). In one example, the carbonate produced at the Salar in Chile is processed to LHM at the same processing plant, while in another example, in Argentina, the Carbonate is transported to the United States and is converted to LHM there (Grant et al. 2020)The total processing capacity and production of these lithium plants is estimated to be 903 kilotonnes of lithium carbonate equivalent (LCE). Nearly half of the lithium processing occurs in China (46%), followed by Chile (22%) and Australia (11%).

Historically, all chemical processing of spodumene mined in Australia was likely conducted in China (British Geological Survey 2016). However, Australia has recently developed its processing capacity, exemplified by the Kemerton refinery of Albemarle (Albemarle 2024c) and the Kwinana refinery of Covalent Lithium (Covalent Lithium 2024).

There are some known production links between mines and processing plants (see Table 25Table 25, in Appendix 8.11), although the specific quantities processed from certain mines remain unknown. Lithium from a single mine can be processed at two different plants, initially to produce lithium carbonate and subsequently to produce battery-grade lithium hydroxide.

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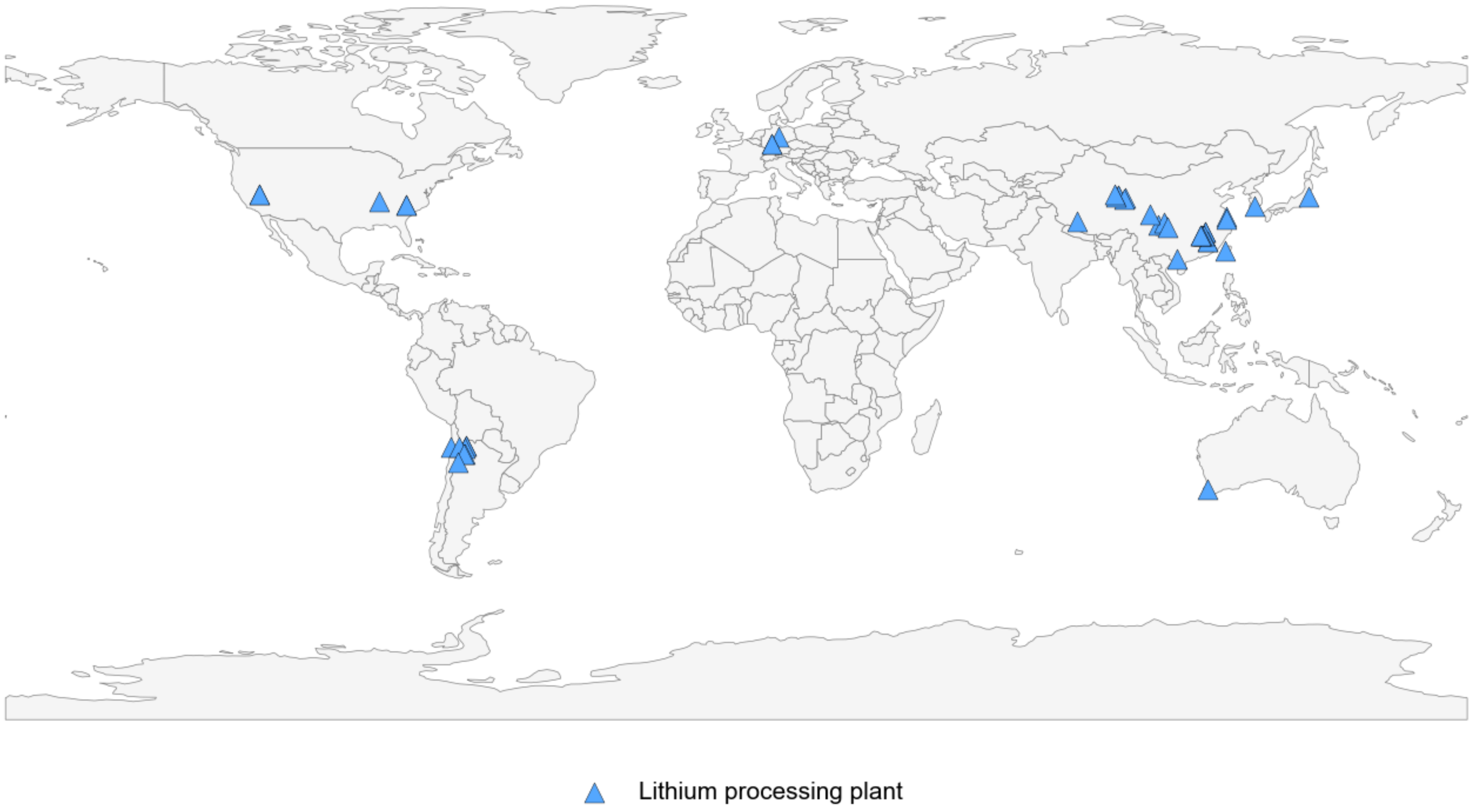

Figure 25: Lithium processing plants based on open-source data, see references in Appendix 8.11,Table 24.

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While not identified in the sources of Figure 25, Russia also has production capacity, as shown in Figure 26. This could be attributed to possible changes based on the reference years or inconsistencies in different databases. However, CMP Lithium, for example, is the leading Russian manufacturer and supplier of lithium products (hydroxides and metal) and has been operating since 1956 (JSC Chemical-Metallurgical Plant (CMP) 2025). Discrepancies such as these underscore the need for greater transparency in the lithium supply chain.

Future production

Global lithium production expected to reach Next to these plants, in France, the Viridian Lithium plant is expected to begin production in 2028, with a planned capacity of 28.5 kt (Viridian Lithium 2025). Another French project, EMILI, led by Imerys, includes both a lithium mine and a conversion plant for lithium hydroxide, with production also set to begin in 2028 (EMILI.Imerys 2025). Sibanye-Stillwater's Keliber project encompasses a lithium mine, a concentrator, and a lithium hydroxide refinery in Kokkola, Finland. Production is scheduled to start in 2025, with an expected annual output of 15 kt (Sibanye-Stillwater 2025). Finally, Vulcan Energy Resources Limited starts lithium hydroxide production in 2024 at its Central Lithium Electrolysis Optimisation Plant (CLEOP) in Industriepark Höchst, Frankfurt-Höchst, Germany. First-year production is estimated at 24 kt (Think Geo Energy 2024).

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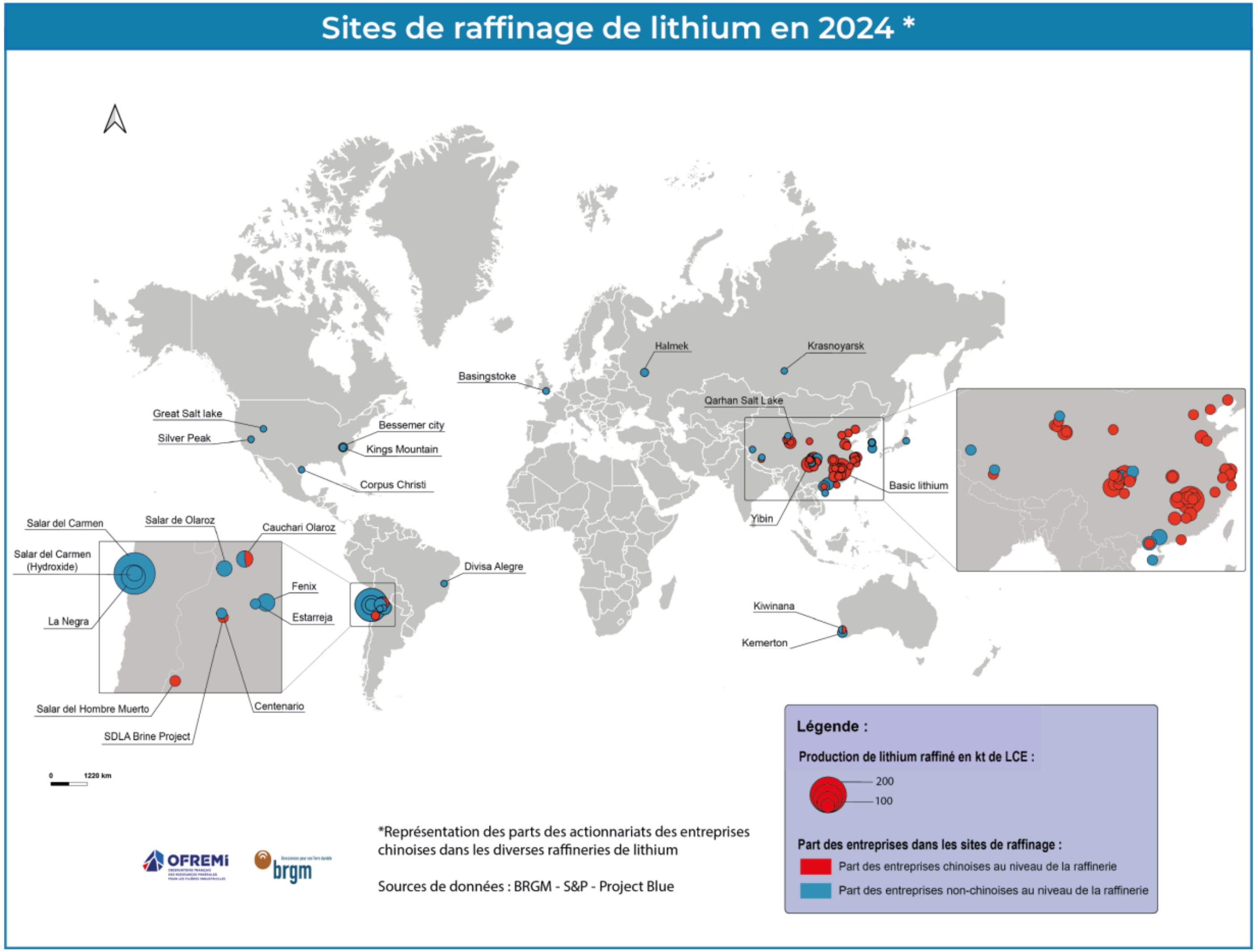

Figure 26: Lithium refining sites in 2024 (BRGM (for Ecomine / MineralInfo) 2025).

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2.2.2.4 Lithium battery manufacturing

Production countries of battery cell components: cathode materials

Lithium hydroxide and lithium carbonate are used to produce lithium-ion battery cathode materials, of which lithium-ion batteries are made. China has 70% of the world's production capacity for cathodes, South Korea accounts for 15% and Japan 14% (IEA 2022) The remaining 1% is production in the United States (there are also two small cathode facilities (Blois 2023) and in other countries. Demand for cathode material was 520 kt in 2021. In 2023, Umicore in Belgium also opened a facility to produce battery cathode materials (Elective, 2023).

Production countries of Lithium-ion batteries

China is by far the largest producer of Li-ion batteries, accounting for almost 80% of global production. Countries that manufacture lithium-ion batteries in the European Union and their share of global production in 2021 were: Hungary (4%), Poland (3%), Germany (2%), Sweden (0.6%), and the Czech Republic (0.1%) (Llamas-Orozco et al. 2023). Other European countries that are projected to produce batteries in 2030 are Norway, Italy, France, and Slovakia (IEA 2022).

2.2.3 Changes in ownership

2.2.3.1 Lithium producer and owner companies

In total, 43 companies were found in open-source data that were either operators and/or owners of lithium mining companies or processing plants (see Figure 20 in Appendix 8.4). The leading lithium mining companies in 2024 are listed in Figure 27, Talison Lithium and Autres together contribute half of the global lithium. Followed by SQM, which contributed 15% of the mining capacity (BRGM (for Ecomine / MineralInfo) 2025). It was assumed that

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the companies that operate and own the continental brine mines are the same companies as those that are operating and owning the processing plants at the site.

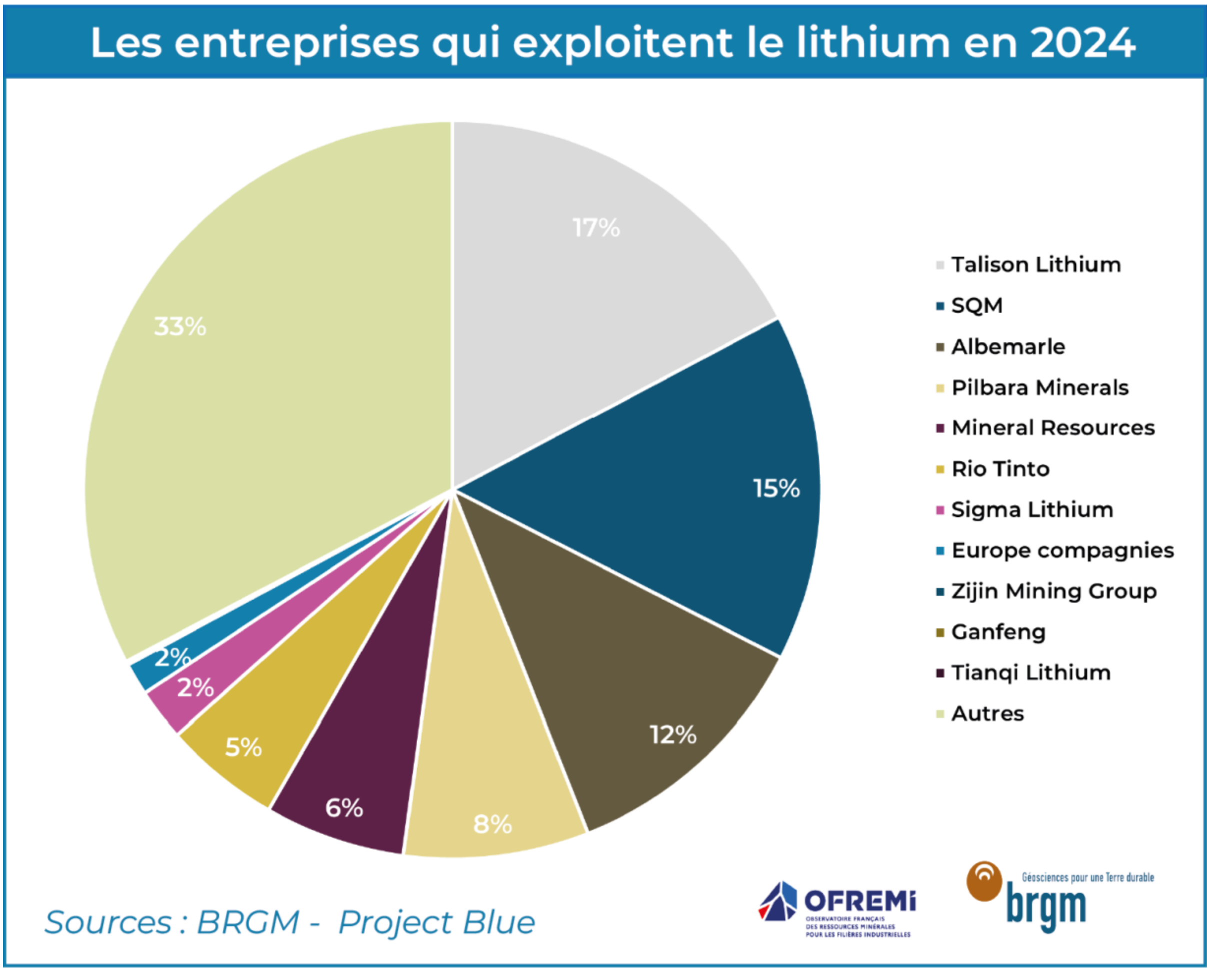

Figure 27: Leading lithium mining companies worldwide in 2024. (BRGM (for Ecomine / MineralInfo) 2025).

Foreign Direct Investment

The headquarters of the countries that own mines (or shares in mines) are located in Australia, Brazil, Canada, Chile, China, Ireland, Portugal, the Netherlands, the United States, and Zimbabwe.

2.2.3.2 Network analysis

Figure 28 presents a network graph of the lithium supply chain, featuring various actors: lithium mining countries, mines, processing plants, operator companies, and owner companies.

The network graph illustrates the total production sizes of each node. The countries' nodes reflect both lithium mining and processing, the company nodes reflect the production based on the amount of their shares in operations, and the mines and processing plants reflect their lithium production.

There are three types of links illustrated:

- Geographic links: mines/plants and the location (country);

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- Ownership links: mines/plants and their operator/owner companies;
- Production links: between mines and processing plants.
    - Continental brine: It is assumed that lithium produced from continental brine is processed by plants on site; therefore, the lithium mines and plants are linked.
    - Ownership links between mines and processing plants that are connected through the same owner company.
    - Production links (supplier-buyer) most buyer-supplier relations are confidential, but some companies provide information on this (see Appendix 8.11, Table 25):
        - Altura mine in Australia, owned by Pilbara minerals (100%), to Guangxi Tinyuan in China, owned by Albemarle (ASX, 2019)
        - Finniss mine in Australia, owned by Core Lithium (100%) to Sichuan Yahua and Ganfeng Lithium (CORE Lithium, 2024).
        - Mount Cattlin mine in Australia, owned by Arcadium Lithium (100%), to Zhangjiagang Jiangsu, China, owned by Tianqi Lithium (Khakmardan et al. 2023)
        - Pilgangoora, Australia, owned by Pilbara Minerals (100%), first to Pilgan plant and Ngungaju Plant, then to Ganfeng (owner of the following plants: basic lithium plant, Fengxin Ganfeng, Hebei Ganfeng, Ningdu, Xinyu Ganfeng, and Yichun Ganfeng) (Mining, 2024).

Network metrics can help analyze the position and influence of nodes; in this analysis, degree centrality, betweenness centrality, and closeness centrality are included. This analysis does not include actual buyer-supplier relationships, so the actual market position of these companies remains unknown.

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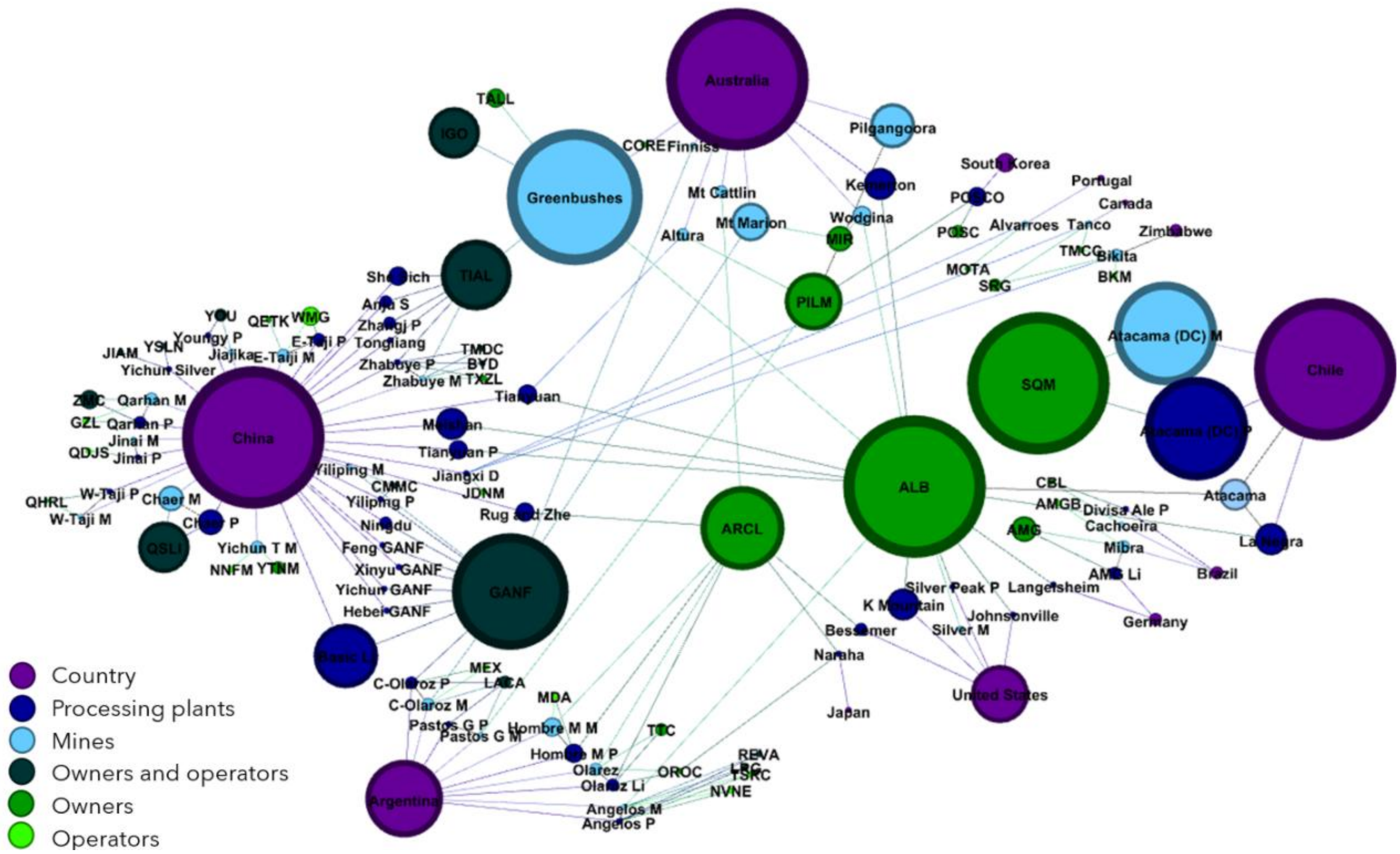

Figure 28: Lithium company network: abbreviations can be found in Table 18, Table 19, and Table 24 of the Appendix. Sizes of the nodes are gradually increasing in size with the smallest node with production under 10000 tonnes to the largest node with production over 200 000 tonnes.

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Degree centrality indicates the number of connections each node has. Among countries, China has the most mines and plants, thus the most links, followed by Argentina and Australia. Companies with the highest degree of centrality include Albemarle (14), Ganfeng Lithium (12), and Arcadium Lithium (8), indicating their ownership in the highest number of mines and plants. These companies also exhibit the highest betweenness centrality, reflecting their role in connecting different nodes in the 'network' by being part of the shortest paths that pass through them. This highlights their significant influence in linking mines, plants, other companies, and in this network, geographic locations.

Albemarle and Arcadium Lithium are connected to operations in five different countries, while Ganfeng Lithium operates in three countries. These companies, along with Tianqi Lithium Corp, also have the highest closeness centrality. This metric shows how near a node is to other nodes in the network, calculated as the average shortest path length from the node to all other nodes (Golbeck 2015).

The network analysis also shows that a large number of multinational companies are vertically integrated, with 22 companies owning both lithium mines and processing plants.

2.2.4 Changes in location - trade

Lithium trade flows are analysed based on data from BACI (Gaulier and Zignago 2010). In section 1.8.1, flows of lithium carbonates (HS code 283691) and of lithium oxides and hydroxides (HS code 282520) are analysed, and in 1.8.2, waste flows of lithium batteries (HS code 854810).

There are some limitations in this trade flow analysis. Lithium ores and concentrates are not included in the analysis because in the trade data, they are merged with other ores, and the percentage of lithium ores is unknown. They are included in HS code 253090 (Arsenic sulfides, alunite, pozzuolana, earth colours and other mineral substances, n.e.s..). The waste flows that are described in 1.8.2 with HS code 854810 are waste and scrap of primary cells, primary batteries, and electric accumulators; spent primary cells, spent primary batteries, and spent electric accumulators. This includes spent lithium-ion or nickel metal-hydride electric accumulators. The quantity of lithium waste batteries within the flows is unknown.

Lithium carbonates, oxides, and hydroxides

The global trade of lithium products amounted to 404 kt in 2022 (263 kt of lithium and 141 kt of lithium oxides and hydroxides, see Figure 29, Figure 30, and Figure 79 in appendix 8.6. The top five exporters of lithium carbonate, oxides, and hydroxides in 2022 include Chile, China, Argentina, the Netherlands, and the United States. Except for the Netherlands, these countries all possess processing plants. As there are no processing facilities identified in the Netherlands, they are possibly only trading it, supporting the role of the Netherlands as a trading hub, making it a relevant leverage point for traceability technology in Europe. The primary importers of these chemicals are China, South Korea, Japan, the United States and, Belgium, except for Belgium, these are all producers of battery cathode materials (Elective 2023).

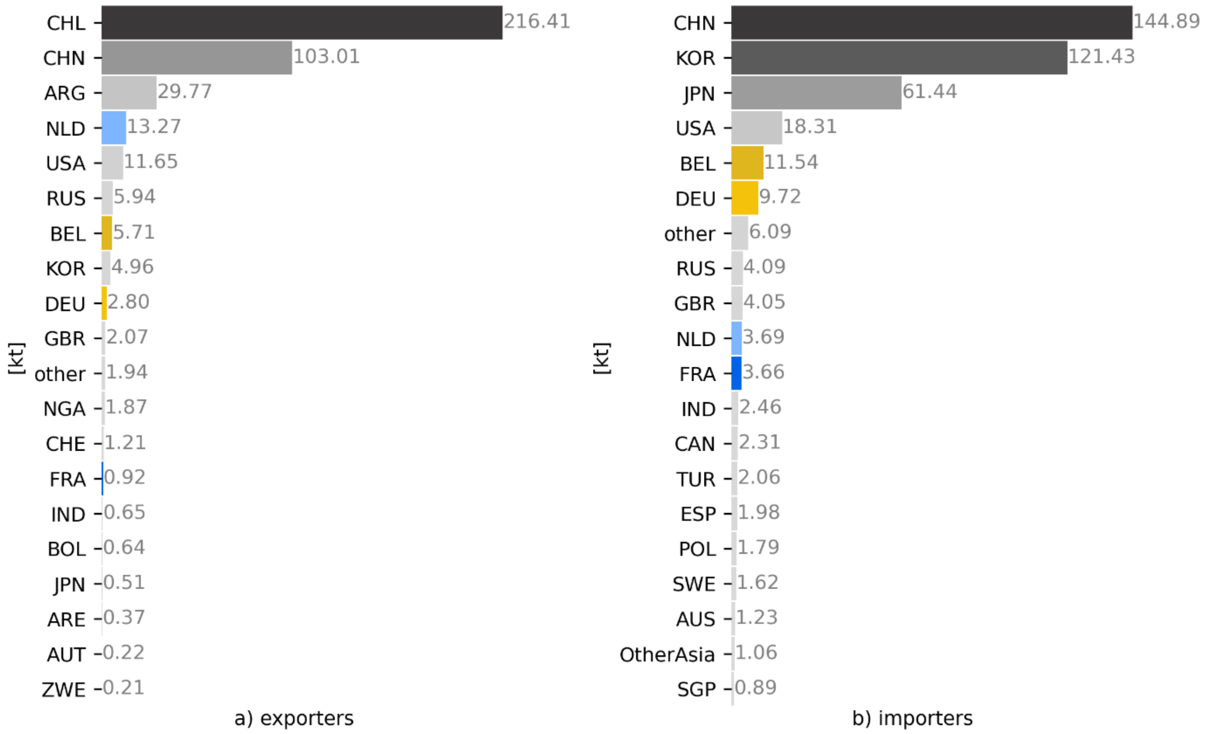

Figure 29: Lithium trade flows 2022: HS 282520: lithium oxides and hydroxides and HS 283691: lithium carbonates (Gaulier and Zignago 2010).

Most of the exports from Chile, are imported by China, that also imports from Argentina. As mentioned, China is also a top exporter and exports mostly to South Korea and Japan. Both South Korea and Japan also import from Chile. After Argentina, the USA also trades significant flows, importing mostly from Chile and Argentina, and exporting to Japan and other countries. As for European countries, Belgium imports mostly from Chile and exports to Russia, France and the Netherlands. The Netherlands and Germany are also significant European traders.

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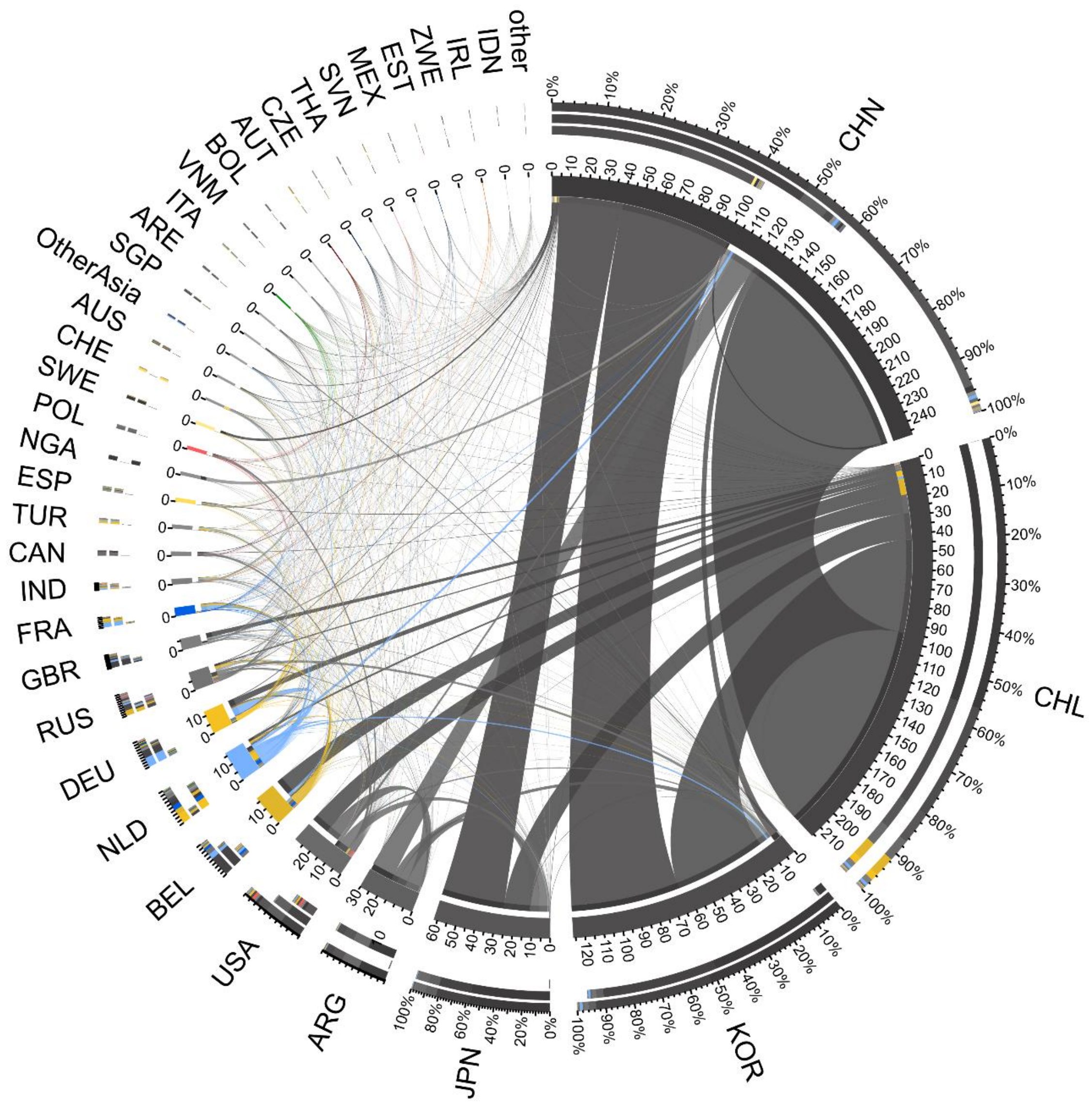

Figure 30: Lithium trade flows 2022. HS 282520 (lithium oxides and hydroxides) and HS 283691 (lithium carbonates) (Gaulier and Zignago 2010).

2.2.5 Secondary sources and flows

2.2.5.1 Lithium recycling

Various technical approaches for lithium extraction from various waste sources have been studied, mostly focused on the recycling process for Li-ion batteries. There are two main methods for recycling Li-ion batteries: the hydrometallurgical and pyrometallurgical processes. Umicore, a Belgian recycling process, has operated the first industrial Li-ion battery recycling process with the pyrometallurgical method. However, the recycling of Li-ion batteries poses explosion hazards and requires appropriate handling as they contain heavy metals and toxic inorganics. Besides, in March 2025, five projects related to lithium

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recycling (battery grade) were selected as strategy projects, which shows the effort from the policy side of the EU to engage the circular economy of the union. Examples include ORANO Batteries' Hydrometallurgy project and the OLVOLT project. For these reasons, less than 10% of Li-ion batteries were recycled globally in 2018, and it is estimated that the cost of recycling lithium is five times that of lithium extracted using the brining process (Kim et al. 2021).

According to the (IEA 2024a), recycling practices are not well established yet for lithium. Secondary supply and reuse of lithium is estimated at 5 kt in 2023, and forecasted production is 28 kt in 2030 and 154 kt in 2040 (IEA 2024a).

The European Union parliament recently approved new rules for the management of all types of batteries. The minimum levels of lithium materials that should be recovered will be 50% by 2027. The minimum levels of recycled content from manufacturing and consumer waste for use in new batteries, eight years after the entry into force of the regulation, will be 6% for lithium (European Commission 2023b).

Table 13 in Appendix 8.1 provides an overview of 39 lithium-ion battery recyclers. Their current capacity is almost 375 kt of input of lithium-ion batteries and scrap. Some of these facilities are planned to expand, and the forecasted capacity is estimated at 740 kt.

2.2.5.2 Secondary flows

There is limited data available on lithium waste flows, as there are no HS codes specifically for lithium waste products. The HS code that is included in this report is HS 854810: waste and scrap of primary cells, primary batteries, and electric accumulators; spent primary cells, spent primary batteries, and spent electric accumulators. This code contains spent lithium-ion or nickel metal hydride electric accumulators (8548102910), but also other waste, therefore the exact quantity of lithium-ion electric accumulator waste is unknown.

The global trade of lithium products amounted to 1549 kt in 2022 (see Figure 31 and [kt]

Figure 32). The main exporting countries of waste and scrap of primary cells are the United States, France, the Netherlands, Canada and Germany (and other Asia, not elsewhere specified). The top five main importers are Mexico, South Korea, India, Germany and Spain. South Korea and Germany have lithium battery recycling facilities (see 1.6), the other countries could have other battery recycling facilities included in this HS category

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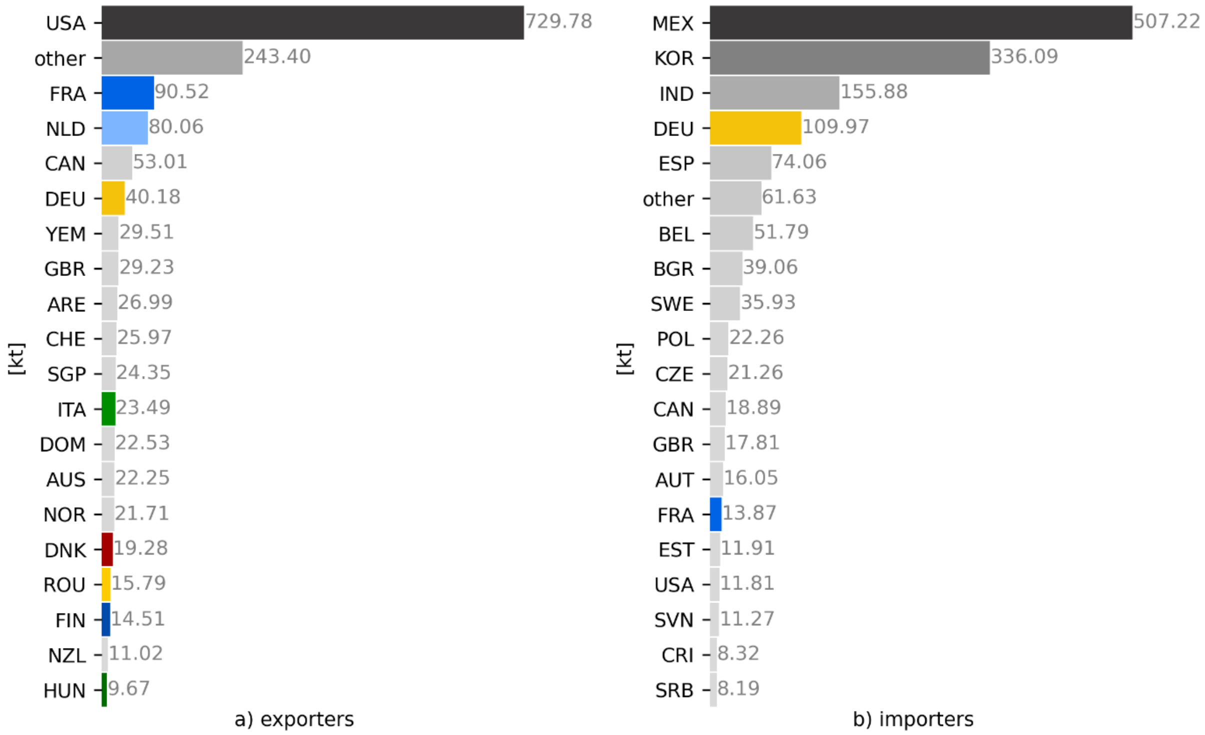

Figure 31: Lithium trade flows 2022: HS 854810: waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells, spent primary batteries and spent electric accumulators. “Other” refers to “Other Asia not elsewhere specified” in the trade data (Gaulier and Zignago 2010).

Most of the exports from the USA, were to Mexico followed by South Korea, two countries that mostly import this waste and scrap whose flows between countries are illustrated in [kt]

Figure 32. Germany imports and export this waste and scrap, and in 2022 it mostly imported from France and The Netherlands. As in the case of cobalt waste and scrap, here tha main traders of these waste flows are also not the same countries that mine, refine or trade intermediate lithium product.

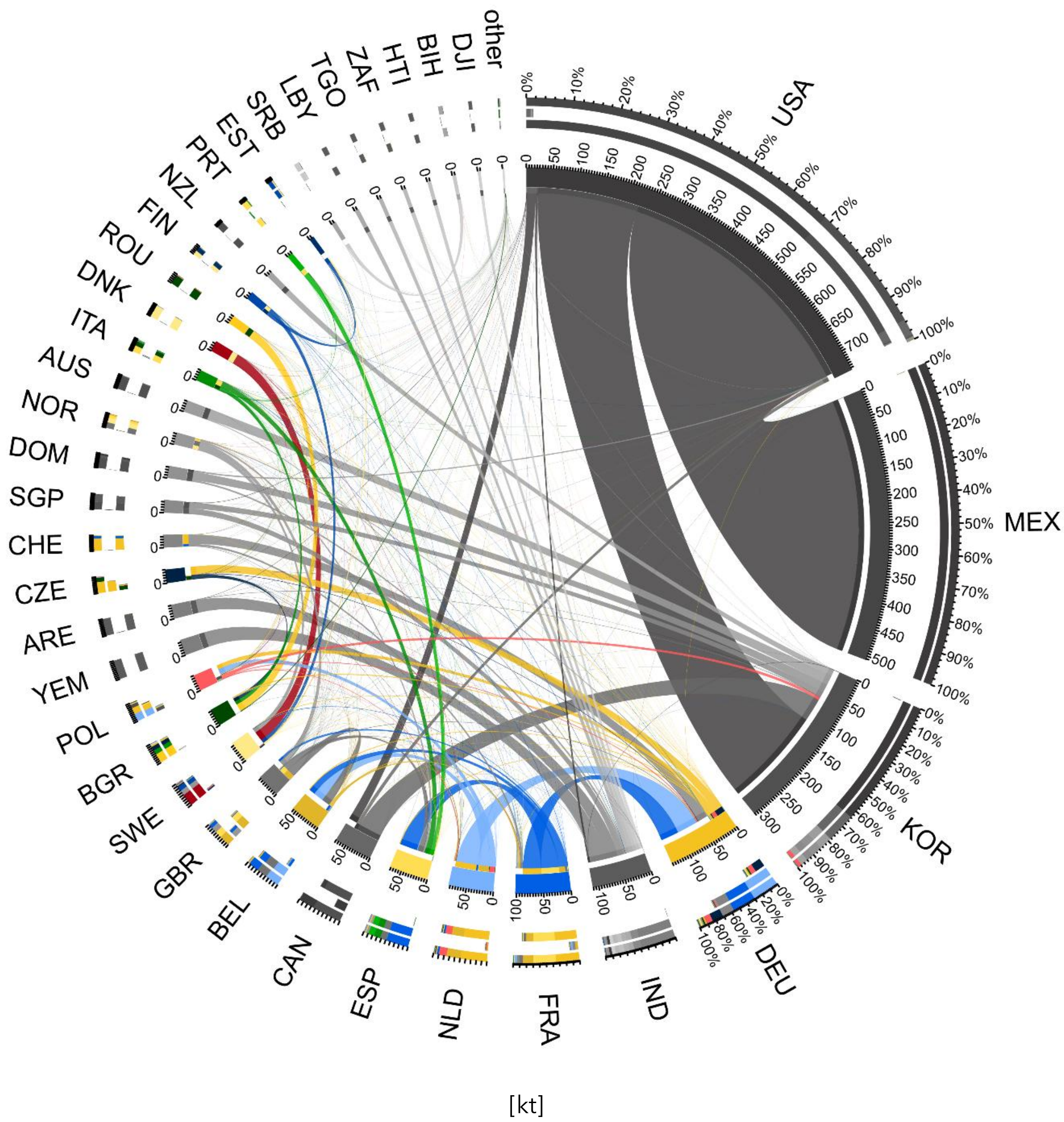

Figure 32: Flows of waste batteries including spent lithium-ion electric accumulators in 2022, HS code 854810: waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells, spent primary batteries and spent electric accumulators) (Gaulier and Zignago 2010).

2.3 Natural Graphite

2.3.1 Introduction and graphite market

This case study provides a comprehensive mapping of the global natural graphite supply chain, with a specific focus on identifying leverage points for the application of traceability technologies.

Graphite, due to its excellent conductivity, has a wide range of industrial applications (Natural Resources Canada 2024). Some of the key applications include:

- Batteries: Graphite is widely used as an electrode material in lithium-ion and lead-acid batteries. Its excellent conductivity and stability help improve battery efficiency and extend lifespan.
- Metallurgical Industry: Graphite is essential in high-temperature furnaces used for smelting, enhancing production efficiency, and protecting equipment.
- Industrial electrodes: Graphite serves as a crucial electrode material, particularly in processes like aluminum electrolysis and other electrolytic applications, due to its durability and conductivity.
- Other Applications: Graphite is also extensively used in the chemical industry, electronics, and as a solid lubricant. In the chemical industry, it supports various processes beyond electrolysis. In electronics, graphite is applied in conductive materials, electrical contacts, and semiconductor devices. As a lubricant, it is valuable for reducing friction and extending the lifespan of mechanical parts operating under high temperature or high pressure.

In 2022, global graphite consumption totaled approximately 3,132 kt. Around half of this amount was used for industrial electrodes, followed by metallurgy, which accounted for roughly 21%. Notably, battery applications—including electric vehicle batteries, portable electronics, and energy storage systems—constituted about 10% of total graphite consumption, equivalent to approximately 317 kt (S&P 2024), as shown in Figure 33.

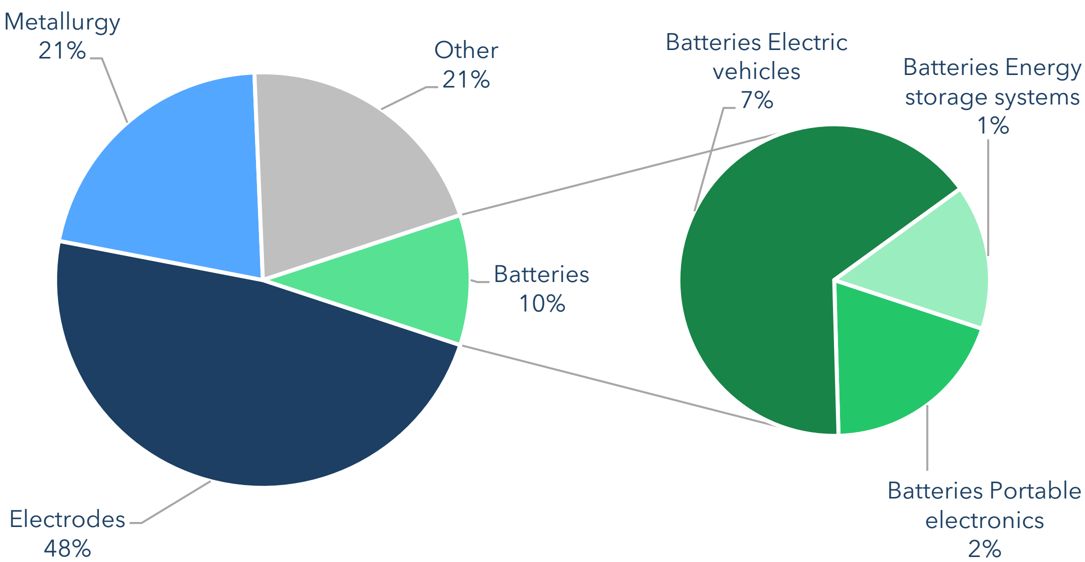

Figure 33: Graphite uses for different applications in 2022. Data based on: (S&P 2024)

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Graphite is a key mineral for energy transition, together with lithium and cobalt, it plays a pivotal role in battery production. It is a key component in lithium-ion, sodium-ion, and other energy storage devices, serving as a fundamental material for virtually every type of battery. Graphite consumption is expected to continue to increase, owing mainly to growth from the EV market. According to the IEA (2021), a single electric vehicle (EV) typically contains 66.3 kg of graphite (IEA 2021). By 2030, global annual graphite demand is projected to exceed 10 Mt, with approximately 60% of this demand driven by energy-related technologies, including applications in electric vehicle batteries and energy storage systems (IEA 2024a).

Unlike other critical materials, graphite can be sourced either from natural deposits in the lithosphere (natural graphite) or manufactured through industrial processes (synthetic graphite). For use in battery anodes, three types of graphite are available, as detailed in Table 1.

While synthetic graphite offers performance advantages in some applications, like cycle life and stability, as shown in Table 1, it is generally more expensive and has a much higher energy footprint than natural graphite (Zhao et al. 2022). Synthetic graphite production requires high-temperature processing, which is energy-intensive and contributes significantly to greenhouse gas emissions. In addition, this process relies heavily on fossil fuel by-products such as metallurgical coke and petrochemicals as primary feedstocks. This reliance on fossil-derived materials hinders efforts to transition away from fossil fuels and poses a significant barrier to achieving carbon neutrality in industries that use synthetic graphite (Engels et al. 2022).

Feature	Natural Graphite	Synthetic Graphite	Mixed (Composite) Graphite
Source	Extracted from graphite-bearing ore deposits	Produced from calcined petroleum coke or coal tar pitch	Blend of natural and artificial graphite
Charge Storage Capacity	Higher	Lower	Optimized based on formulation
Production Cost	Lower	Higher (also higher energy consumption)	Moderate
Cycle Life	Shorter	Longer	Balanced between natural and synthetic graphite
Purity and Consistency	Lower	Higher	Improved compared to natural graphite
Stability	Lower	Greater stability	Enhanced compared to natural graphite
Operational Reliability	Less reliable	More reliable	Improved by leveraging the strengths of both types

Table 1: Performance Characteristics of Different Graphite Types for Battery Anodes (ECGA 2025).

To address these challenges, research is progressing towards more sustainable production methods, such as those based on biomass-derived feedstocks. Biomass-based processes aim to reduce the energy intensity and environmental impact of synthetic graphite

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production by replacing fossil-based inputs with renewable alternatives (Istrate et al. 2024). Although promising, these processes remain at an experimental stage and have not yet reached large-scale commercial application. Overcoming the technical and economic barriers to scale-up will be critical for these sustainable methods to become viable market alternatives.

2.3.2 Transformations in material state and chemical modifications

2.3.2.1 Deposits and reserves

As shown in Table 2, natural graphite exists in three primary forms: crystalline (flake) graphite, microcrystalline (amorphous) graphite, and vein (lump) graphite. These types differ in particle size, carbon content, and impurity levels, making them suitable for distinct applications. Amorphous graphite is not currently used for battery anodes because it lacks the crystallinity and structural order required for efficient lithium-ion intercalation, which is essential for high-capacity and stable cycling performance (Simandl, Paradis, and Akam 2015). Both flake and vein graphite are suitable for battery anode materials (ECGA 2025).

	Amorphous	Flake	Lump and Vein
Form	earthy to compact microcrystalline aggregates; grain size <4 μm	well-developed crystal platelets; grain size 40 μm–4 cm	interlocking aggregates of coarse crystals; powders to 10cm pieces
Product Grade (% graphite)	60–90	75–97	90–99.9
Prices ($/metric ton)	$600–800	$1150–2000	$1700–2070
Main Uses	Steel recarburiser, foundry mould facing, lubricants, pencils	Refractories, batteries, brake linings, flame retardants	Carbon brushes, brake linings, lubricants, batteries
Major producer	China, Mozambique, Madagascar	China, Mexico, North Korea, Turkey	Sri Lanka

Table 2: Types of natural graphite deposits. Data source: (Simandl et al. 2015) (Zhang, Liang, and Dunn 2023) (USGS 2024) (Arshad et al. 2020)

China dominates global production of natural graphite, particularly in the amorphous and flake categories. In contrast, vein graphite, which has the highest purity level of up to 99.9% carbon content, is exclusively produced in Sri Lanka. However, the limited availability of vein graphite results in lower production volumes and significantly higher prices compared to other types. Consequently, flake graphite is the preferred material for battery anode production. Approximately 70% of China's natural graphite production is amorphous in 2023, with the remaining 30% being flake graphite (Fastmarkets 2024).

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Recycling efforts for graphite are summarized in Table 2, encompassing the recycling of spent refractories, insulation materials, and lithium-ion batteries. Specific details on the recycling of graphite from spent lithium-ion batteries are provided in Section 2.3.5.

As shown in Figure 34, the total global reserve of natural graphite was estimated at 330 million tonnes in 2022. Turkey held the largest share, with approximately 90 million tonne, followed by Brazil and China, with reserves of 74 million tonnes and 52 million tonnes, respectively. Europe is also rich in natural graphite reserves. In addition to Turkey, countries such as Russia, Ukraine, and Norway possess substantial deposits.

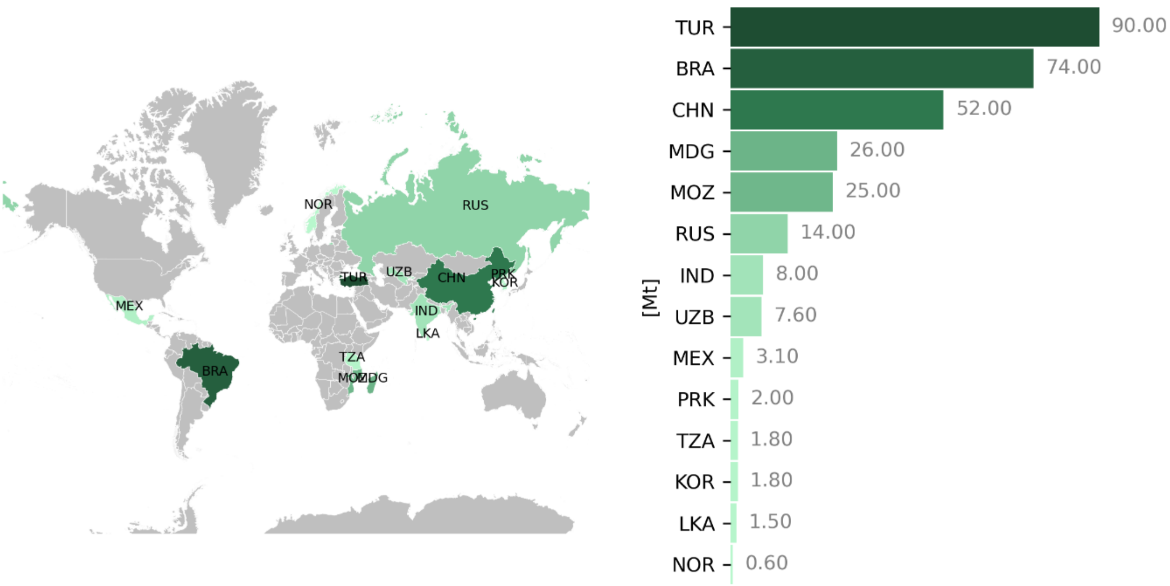

Figure 34: Reserves of natural graphite per country in 2022 (USGS 2024).

According to the USGS, global natural graphite reserves declined from 330 million tonnes in 2022 to 280 million tonnes in 2023 (USGS 2024). This decline primarily stems from a significant revision of Turkey's reserves, which dropped from 90 million tonnes in 2022 to just 6.9 million tonnes in 2023, and an increase in China's reserves from 52 million tonnes to 78 million tonnes. Canada has also newly added scaled reserves (5.7 million tonnes), ranking ninth globally, reflecting recent discoveries and updated assessments (Natural Resources Canada, 2024). These changes are based on updated data from government and company reports. For detailed reserve data of natural graphite in 2023, please see Figure 80 in Appendix 8.7.

2.3.2.2 Natural graphite extraction

Global natural graphite extraction amounted to 1680 kt (see Figure 35) in 2022. The leading producer of natural graphite was China, with 72% of the total global extraction, followed by Mozambique (10%), Madagascar (8%), Brazil (4%), and South Korea (1.4%). Other suppliers of natural graphite were Russia, Canada, India, Norway, and North Korea, which represented 3.5% of global natural graphite extraction.

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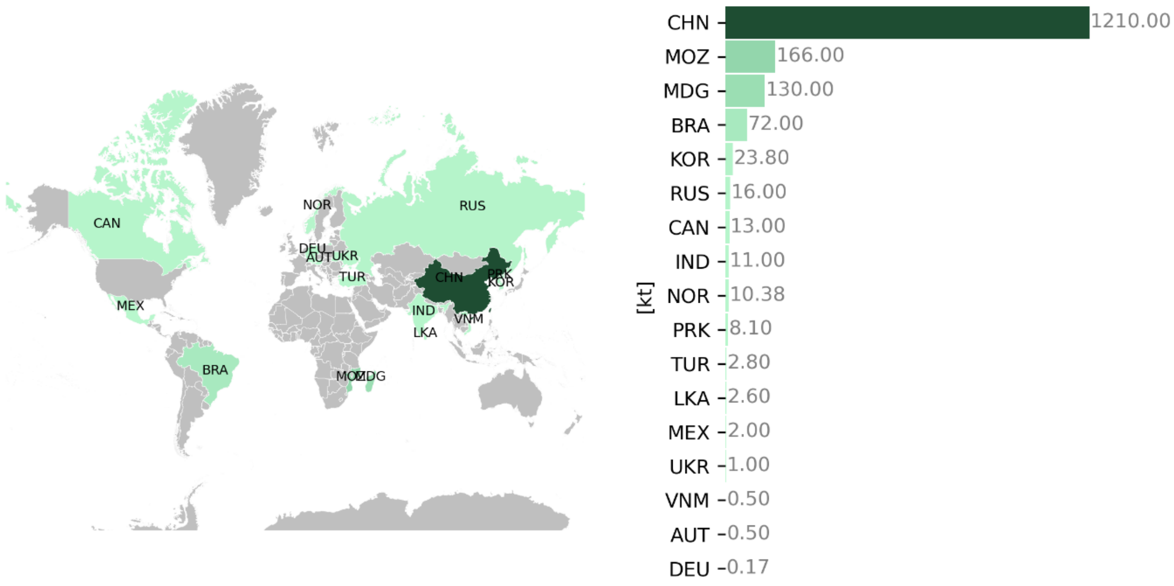

Figure 35: Natural graphite mined per country for 2022, in kilotonnes (kt). Based on: (USGS 2024).

Several natural graphite mines are in the EU, with the majority concentrated in the Scandinavian region, like Sweden and Greenland. Besides, Norway also has the Traelen natural graphite running in 2022, see Figure 36.

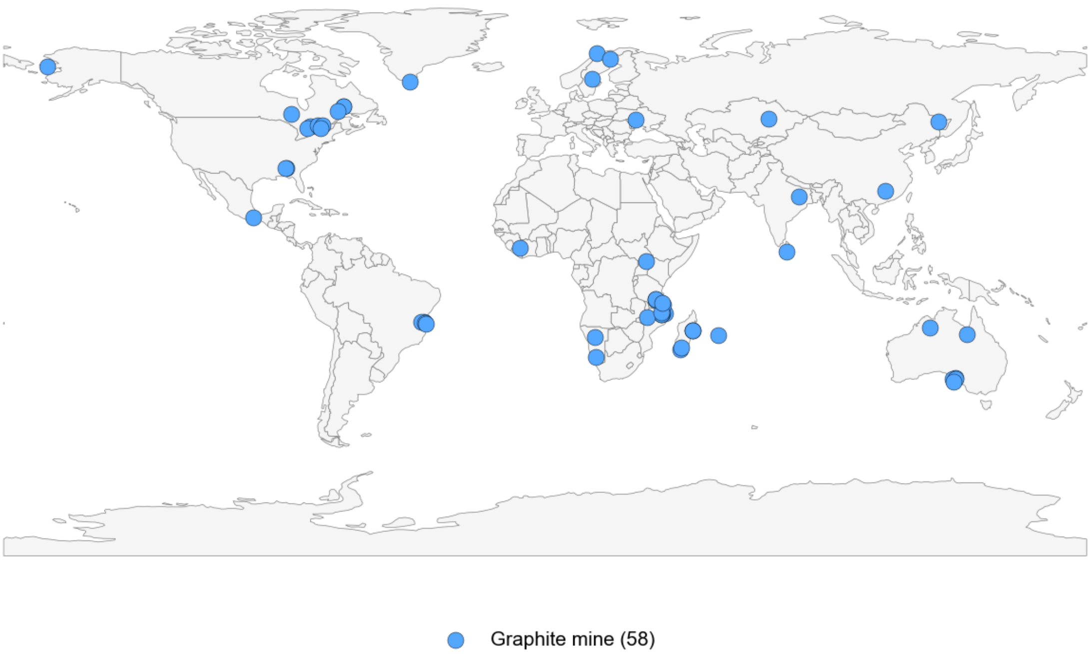

Figure 36: Global graphite mining projects based on the open-source data, this figure presents global graphite mining projects with reported capacities as of 2022. The data is sourced from publicly available information and includes only mining projects with specified production capacities. Notably, only one project in China (Beishan) is listed, as no other publicly available data on production volumes for Chinese natural graphite projects could be found (S&P, 2024)

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Artisanal, small-scale, and illegal mining

In contrast to lithium and cobalt, graphite exhibits limited potential for small-scale mining projects, as its relatively low value per unit weight of extracted ore typically necessitates involvement by large-scale operators (IISD 2024).

Future demand and production

Looking ahead, the annual supply of natural graphite from mines is expected to increase by 20% from 2022 to more than 2,000 kilotonnes (kt) by 2028 and 9.1 million tonnes by 2035(IEA 2025). China is expected to remain the dominant supplier, accounting for 60% of the global market. Mozambique and Brazil are expected to follow with 10% and 5% of the supply, respectively. However, the supply landscape is expected to become more diversified, with countries such as Tanzania (5%), Guinea (2%), and Canada (3%) expected to increase their production. Among the European countries, Sweden is projected to contribute around 1% of the global natural graphite supply, followed by Norway (S&P 2024) .

2.3.2.3 Processing

Initial processing (mineral processing) typically involves mechanical separation and flotation, usually carried out close to the mine site. These early stages are shared across most graphite applications, including refractories, lubricants, and expandable graphite. Further processing is required to produce higher value products such as anode materials, expanded graphite, and graphite for various applications. Depending on the end use, this additional processing may include milling and classification (shared with other applications), as well as more specialized steps like spheroidization and high-purity chemical or thermal purification (mainly required for battery-grade anode materials). In the production of natural graphite anode materials, the spheroidization process - the deformation of graphite flakes - results in material losses in excess of 50%. This is because a significant portion of the flake is either too small or misaligned to be shaped into spheres and is removed as fine graphite dust or off-spec material. In practical terms, at least twice as much flake graphite is required to produce a given weight of spheroidized graphite. In practical terms, this means that at least twice as much flake graphite input is required to produce a given weight of spheroidized graphite for anodes. (IEA 2024a). Figure 37 presents a simplified schematic of battery - grade graphite production processes.

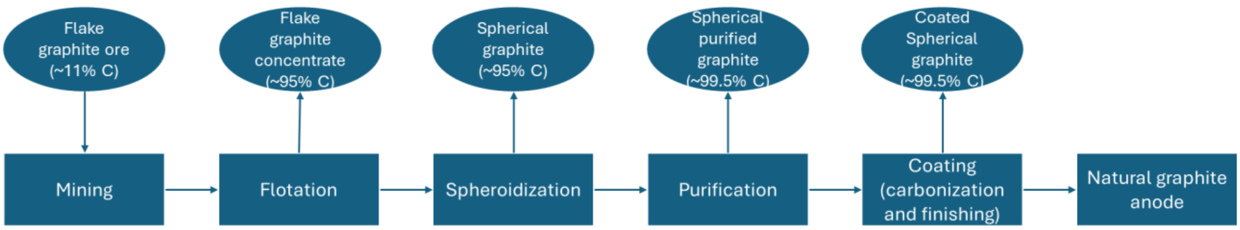

Figure 37: Simplified flowchart of battery-grade graphite production, changes based on (Engels et al. 2022) (Lower et al. 2023)

Processing plants

Based on data from S&P and other open sources, the main natural graphite processing plants are shown in Figure 38. In 2023, global consumption of natural flake graphite reached

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1,500 kt, with approximately 87% consumed in Asian countries and around 6% in Europe (Natural Resources Canada 2024). However, due to data limitations, processing plants in China are not included in Figure 38. As for European processing projects, they currently do not produce spherical graphite, but there are plans underway to develop this capability in the future (i.e. Woxna in Sweden). Notably, several graphite processing projects in Europe have been recognised for their strategic relevance in supporting the battery value chain (European Commission. 2025). In France, the *BAM4EVER* project (Phase I & II), promoted by Tokai COBEX Savoie, focuses on processing battery-grade graphite. Another French-based initiative, the *GALLICAM* project, led by Sibanye-Stillwater Sandouville Refinery, processes a range of battery materials, including graphite, nickel, cobalt, lithium, manganese, and copper. The *European Initiative for Strategic and Sustainable Graphite Production*, promoted by NGC Battery Materials GmbH, is a multi-country effort with operations in France (as the main location), Namibia, and Germany, targeting sustainable graphite supply for batteries. In Estonia, the *CO2 Graphite* project, developed by UP Catalyst, is advancing the processing of battery-grade graphite using carbon dioxide conversion technologies. Additionally, Hycamite TCD Technologies Ltd. in Finland is operating a graphite processing project that contributes to regional capacity for battery-grade graphite production.

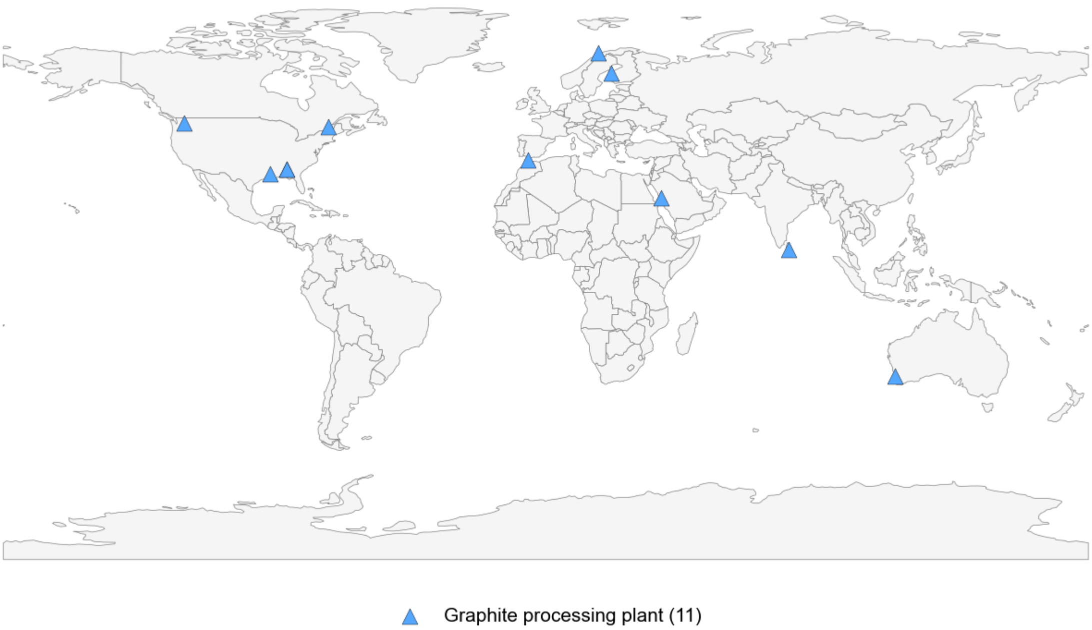

Figure 38: Natural graphite processing plant in 2022 from open sources outside China.

2.3.3 Changes in ownership

Key companies/actors or focus on Europe and natural graphite

In this section, the main battery-grade graphite manufacturer was provided. Currently, around 90% of global battery anode material originates from China (IEA 2024b). Table 3 lists the key manufacturers of battery-grade graphite with facilities located in Europe. The region accounts for approximately 2% of global anode material production (Fleischmann and McKinsey & Company 2024). The main European anode producer like SGL and Imerys Graphite and Carbon SA, mainly produced synthetic graphite for now. Talga's Luleå Anode Refinery, located in Sweden, is Europe's first natural graphite anode production facility. The refinery processes graphite extracted from Talga's Vittangi project, specifically the

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Nunasvaara South mine, with an initial production capacity of 19,500 tonnes of anode material per year (Talga Group. 2025).

Firm Name/ (if foreign headquarters)	Facility Location(s)	Country	Graphite Type(s)
Imerys Graphite & Carbon SA (Switzerland)	Willebroek	Belgium	Natural, Synthetic
Targray Group (Canada)	Straznicka	Czechia	Natural, Synthetic
GreenRoc	Amitsoq Graphite	Greenland[2]	Natural
Sangraf (USA)	Narni	Italy	Natural
Leading Edge Materials (Canada)	WOXNA	Sweden	Natural
Talga Resources (Australia)	Talga's Luleå Anode Refinery*	Sweden	Natural
Grafintec Oy	Graphite Anode Materials Plant (GAMP)	Finland	Natural
Mineral Commodities Ltd (Australia)	Skaland Processing Facility	Norway	Natural
Heraeus Group	Kleinostheim	Germany	Synthetic
SGL Carbon S.A. (Germany)	Passy	France	Synthetic
SGL Carbon SE Group (Germany)	Saint Martin d'Heres	France	Synthetic
SGL Carbon SE Group (Germany)	Verdello	Italy	Synthetic
SGL Carbon SE Group	Bonn	Germany	Synthetic
SGL Carbon SE Group	Meitingen	Germany	Synthetic
SGL Graphite Solutions Polska (Germany)	Nowy Sącz	Poland	Synthetic
SGL Graphite Solutions Polska (Germany)	Racibórz	Poland	Synthetic
Imerys Graphite and Carbon SA	Bodio	Switzerland	Synthetic
Superior Graphite (USA)	Sundsvall Plant	Sweden	Synthetic
Tokai Cobex (Germany)	Savoie	France	Synthetic
Vianode	Herøya	Norway	Synthetic

Table 3. Battery-grade graphite: companies and facilities located within Europe. Data source: (ECGA 2025; Talga Group. 2025; Tsuji 2022).

[2] Greenland is a territory within the Kingdom of Denmark.

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2.3.4 Changes in location - trade

The global trade of natural graphite totaled 876 kt in 2021 (see Figure 39 and Figure 40). In this report, natural graphite is categorized as either powder or flakes (HS code 250410) or other forms, excluding powder or flakes (HS code 250490) (see Table 21 in Appendix 8.8). Of the total trade volume, approximately 813 kt consisted of powder or flakes, with the remainder comprising other forms. China is the largest bilateral trading partner for graphite, with a net export of 70 kt in 2022. The most significant trade flow was the import of 312 kt of powdered or flaked natural graphite from Mozambique to China. Apart from China, Mozambique and Madagascar are the second and third largest exporters of natural graphite in the world, while Japan and the USA are the second and third largest importers of natural graphite. In 2022, the EU imported 122 kt of natural graphite in total (excluding inter-EU trade), and exported 26 kt of natural graphite. Within the EU, Germany, the Netherlands and Austria have significant shares in the graphite trade, with net imports of around 24 kt, 10 kt and 12 kt respectively.

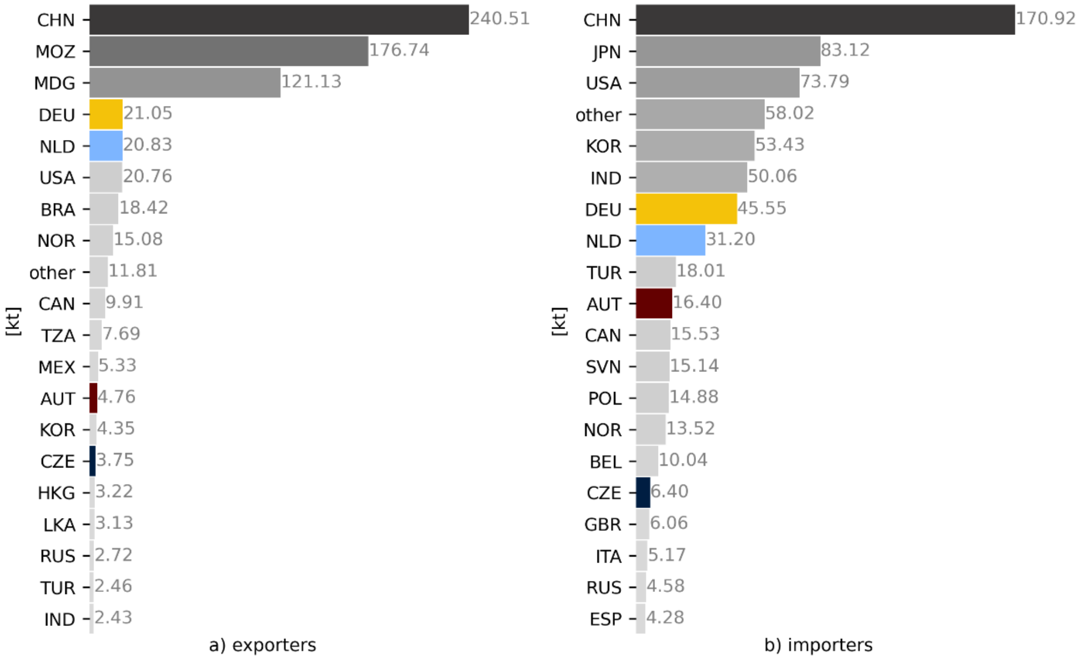

Figure 39: Top-20 (a) exporters and (b) importers of natural graphite in kilotonnes (kt) in 2022. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

Figure 40 illustrates the partners of the traded flows. The figure shows that China, Mozambique, and Madagascar are the main exporters of natural graphite. China is the main importer from Mozambique and Madagascar, and exports mostly to Japan, South Korea, and the USA. Germany and the Netherlands are key European trading nations. Germany imports from China, Mozambique, and Madagascar, and exports mainly to other European countries. As for the Netherlands, it has an import/export relation with Norway, but also imports from China and Mozambique.

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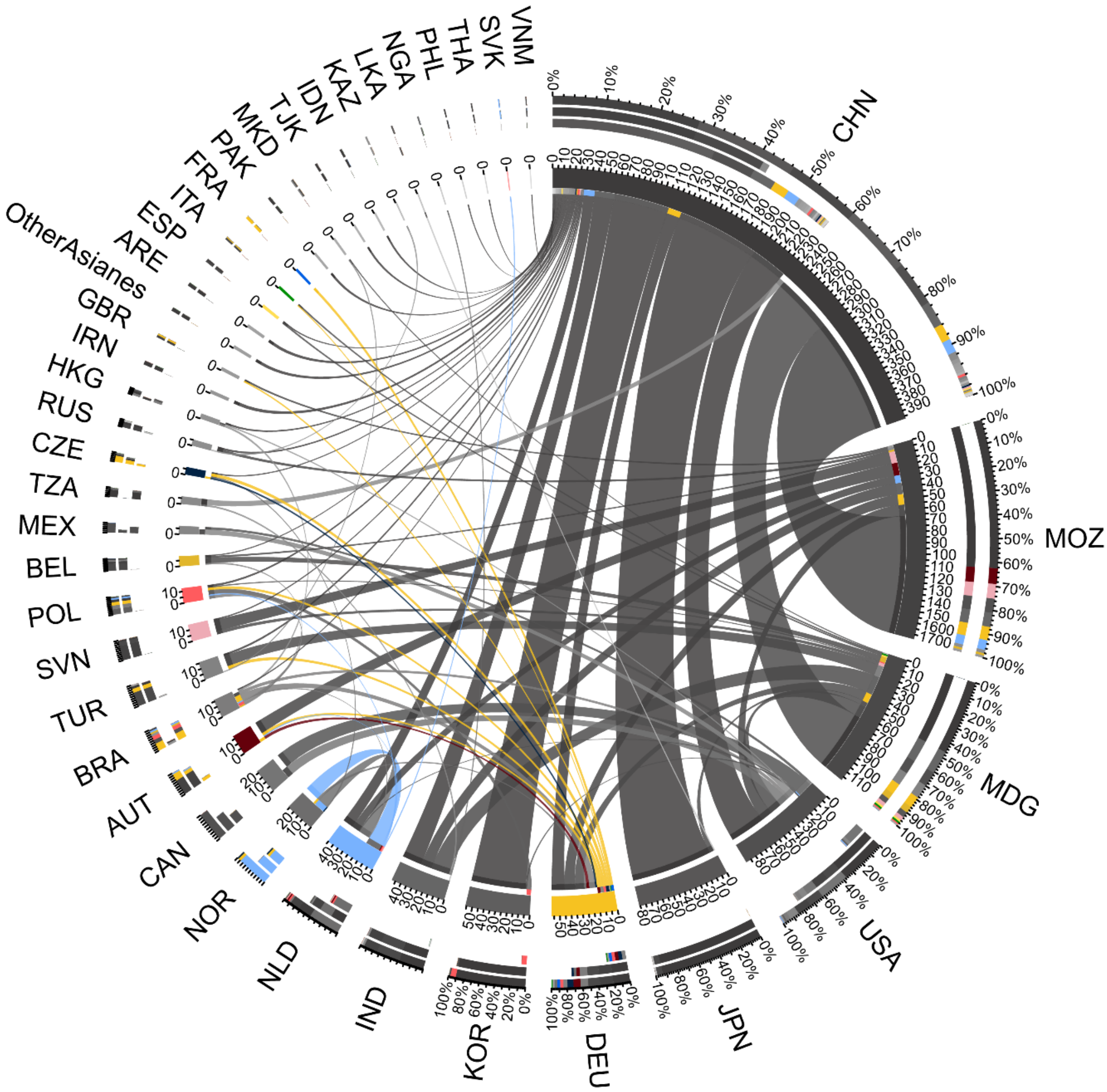

[kt]

Figure 40: Chord diagram representing natural graphite trade flows between countries for 2022. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

2.3.5 Secondary sources and flows

Graphite recycling is established for certain applications, such as refractory bricks used in steelmaking (Horckmans et al. 2019), but it is not yet widely applied to energy technologies like lithium-ion batteries. The energy transition is accelerating the adoption of EVs, leading to an increasing number of EV batteries entering the end-of-life phase in the near future. This shift will drive demand for graphite while simultaneously presenting spent lithium-ion batteries as a significant potential source of recyclable graphite—both natural and synthetic—given that each EV battery contains an average of 50–100 kg of graphite (IEA 2021). Several lithium-ion battery recyclers are listed in Table 13 of Annex 8.1, highlighting the growing role of recycling in end-of-life batteries, although it's not clear whether they are involved in graphite recycling. Currently, pyrometallurgy, a mature recycling method used to recover

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minerals from spent electronics and batteries, poses challenges for graphite recycling. In this process, high-value materials like nickel and copper are extracted, but all carbon is burned off, rendering graphite recovery impossible. Alternatively, hydrometallurgy involves chemical leaching and purification to separate individual metal products. While advanced hydrometallurgical techniques are being developed to recover graphite, these processes remain in their early stages compared to the more established recovery methods for lithium, nickel, and cobalt (IEA 2024c).

The economic feasibility of graphite recycling remains limited due to its relatively low market value, which makes it difficult to compete with primary graphite for battery production. Despite this, graphite recycling represents an environmental responsibility compared to the current dominant practice of landfilling or using it as road material (Zhang et al. 2023). Life cycle assessment studies have examined the environmental impacts of various graphite recycling methods for end-of-life lithium-ion batteries, reporting carbon emissions ranging from 0.5 to 9.8 kg per kilogram of recycled graphite (Rey et al. 2021). These emissions are comparable to those associated with the production of virgin natural graphite anode(Engels et al. 2022). Despite these challenges caused by the factors mentioned above, recycled graphite shows potential for applications in sectors with less purity requirements.

2.4 Neodymium (rare earth elements)

2.4.1 Introduction and neodymium market

This case study provides a comprehensive mapping of the global neodymium (rare earth elements) supply chain, with a specific focus on identifying leverage points for the application of traceability technologies.

Similar to battery materials, rare earths (REs), a group of seventeen elements (also known as fifteen lanthanides on the periodic table plus scandium, and yttrium) have attracted considerable attention due to their central role in energy, materials science, socioeconomics, and geopolitics (Fishman and Graedel 2019). Of particular importance are permanent magnets composed primarily of light rare earth elements such as neodymium (Nd) and praseodymium (Pr), and heavy rare earth elements such as dysprosium (Dy) and terbium (Tb). Neodymium-iron-boron (NdFeB) magnets, including bonded magnets and sintered ones, are indispensable in a wide array of applications, including electronic devices, household appliances, and low-carbon energy technologies. Sintered magnets, which are primarily utilised in wind turbines and electric motors, are manufactured with a composition of approximately 30% RE elements, 69% iron, and 1% boron based on their mass (Smith et al. 2022).

Figure 41 depicts the global consumption trends of REs over the past two decades, showing that, on average, more than 50% of rare earth elements have been utilized annually in magnet production for various applications. The distribution of RE demand across end-use sectors varies significantly by country. For instance, in the United States, around 74% of REs are used in catalysts (USGS 2024), whereas in China, approximately 63% of RE consumption is attributed to magnet production (W.-Q. Chen et al. 2024). Currently, magnets used in wind turbines and EV motors account for only 14%–17% of the total RE consumption. However, this share is projected to increase significantly, reaching approximately 42% by 2030 as demand for these technologies accelerates under the International Energy Agency’s Net-Zero Emission by 2050 scenario (IEA-NZE) (IEA 2024a). Under the IEA-NZE scenario, the demand for REs used in wind turbines and electric vehicle motors is projected

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to be approximately four times that of 2023, reaching 62 kilotonnes by 2030. Currently, the globally existing and announced rare earth production capacity for 2030 is estimated at 110 kilotonnes. However, the demand for rare earth elements required for magnet production is expected to reach approximately 150 kilotonnes, highlighting a significant gap (~40kt) between supply and demand.

In 2021, approximately 80% of the total RE elements used in the production of magnets is neodymium, followed by praseodymium, dysprosium, gadolinium, and samarium (Roskill, 2022). The supply of neodymium is closely linked to the supply of other RE elements, which are typically mined together and then separated into either single elements or mixtures, making the supply chain interdependent and complex.

The geographic concentration of supply creates a vulnerable rare earth supply chain, increasing the risk of disruption. At the same time, their critical role in emerging technologies makes a global supply chain for REs inevitable, underscoring the importance of diversification and stability in their supply chains.

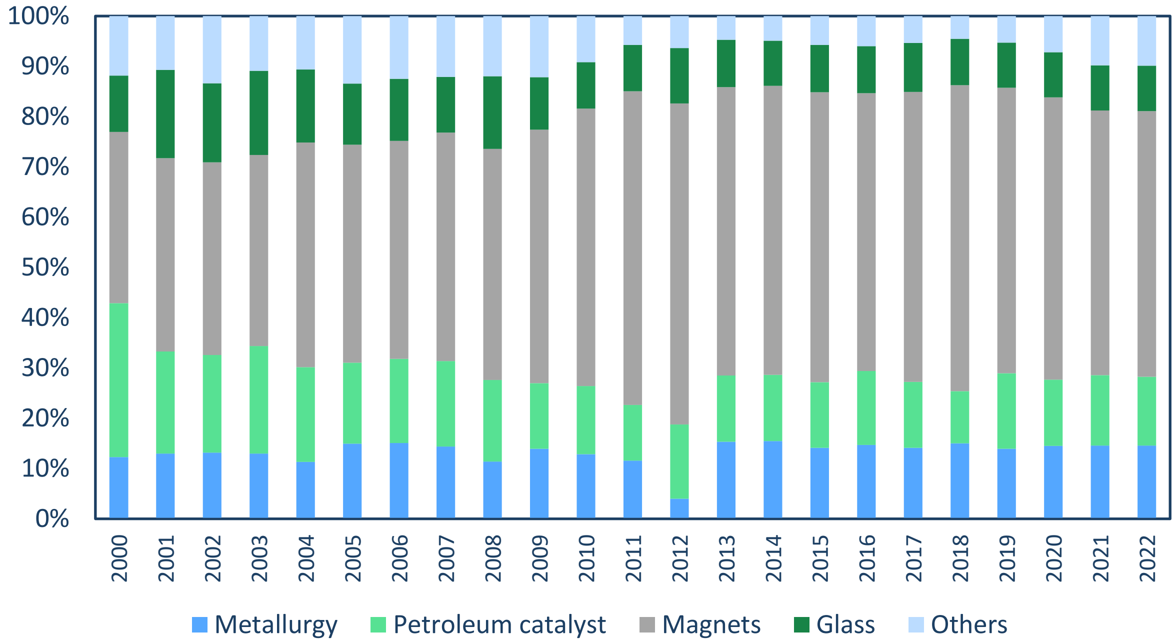

Figure 41: Global consumption of RE elements by end-use application. Data based on: (W.-Q. Chen et al. 2024). Global consumption of RE elements by end-use application. Data based on: (W.-Q. Chen et al. 2024)

Figure 42provides an overview of the supply chain for rare earth magnets. The supply chain can be divided into four main stages: the extraction and production of raw materials; the processing and refinement of these materials into high-purity components suitable for further use; the manufacturing stage, where these refined materials are formed into various components; and finally, the production and assembly of the finished magnets, ready for use in wind turbines and electric vehicles.

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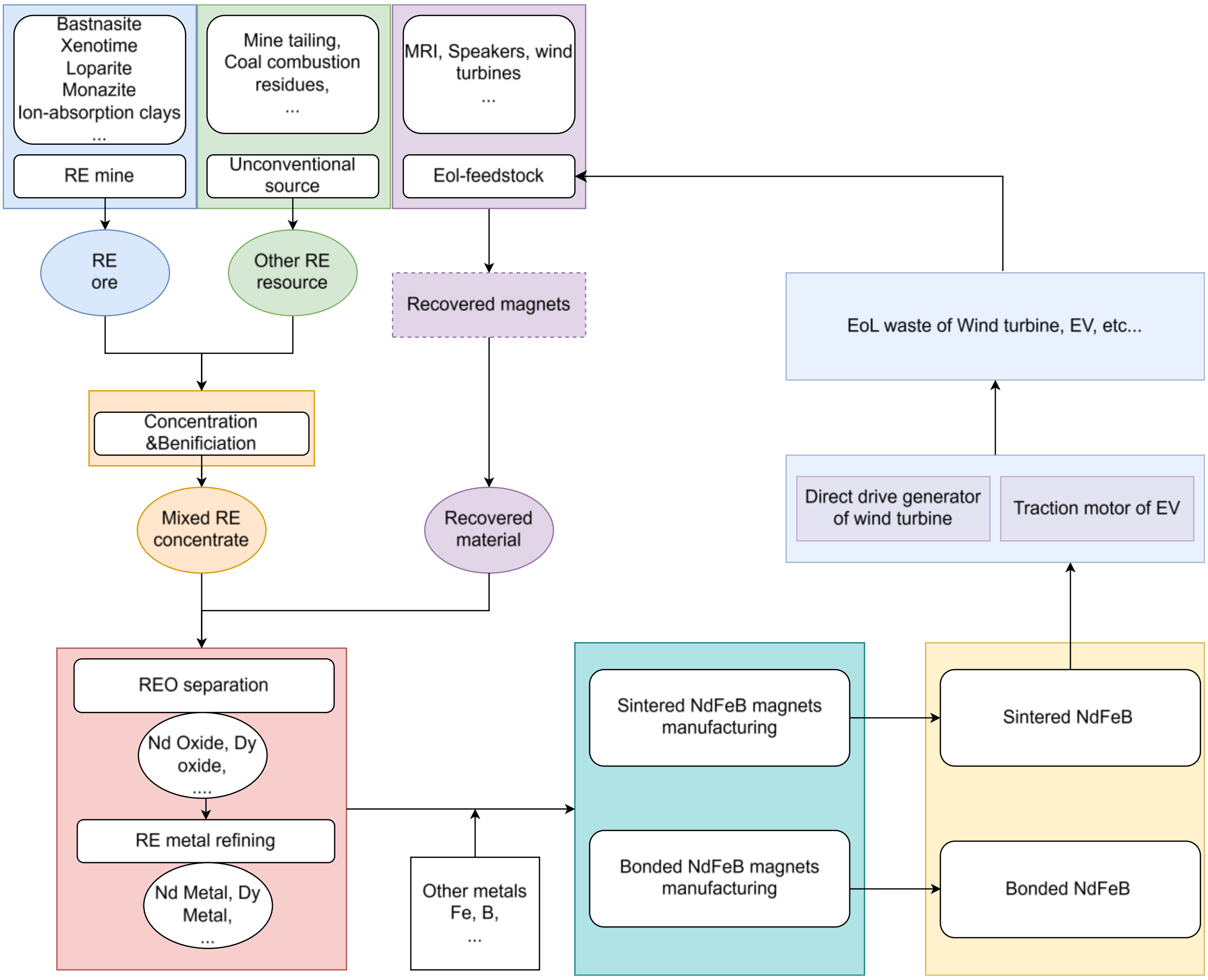

Figure 42: Stages of the rare earth magnets supply chain. Revised based on (Smith et al. 2022). Stages of the rare earth magnets supply chain. (Europe Battery Cell Production 2025)

2.4.2 Transformations in material state and chemical modifications

2.4.2.1 Deposits and reserves

Global markets currently obtain rare earth from four primary types of mineral deposits: carbonatite, alkaline igneous, heavy mineral sand, and regolith-hosted ion-adsorption clay deposits (Foley and Ayuso 2024). Table 4 lists the major types of RE deposits.

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Deposit Type	Description	Key Locations
Carbonatite	Igneous rocks rich in carbonate minerals, often containing RE elements. (Bastnaesite)	Mountain Pass (USA), Bayan Obo (China)
Alkaline Igneous	Igneous rocks with high concentrations of alkali metals and RE elements.	Khibiny (Russia), Ilímaussaq (Greenland)
Heavy Mineral Sand	Sedimentary deposits containing heavy minerals like monazite and xenotime.	Richards Bay (South Africa), Eneabba (Australia)
Regolith-hosted Ion-adsorption Clay	Weathered crusts rich in RE elements, especially heavy RE elements.	South China, Myanmar, Madagascar

Table 4: Rare earth deposit types and their global landscape (Foley and Ayuso 2024; Haque et al. 2014; USGS 2024; Weng et al. 2013).

Figure 43 offers a comprehensive view of the global rare earth mining landscape, highlighting the geographic distribution and deposit types of over 130 RE mines and deposits worldwide. The majority of existing rare earth mine types are carbonatite-related, including well-known sites such as Bayan Obo and Maoniuping in China, Mount Weld in Australia, the Araxá Project in Brazil, and Mountain Pass in the United States. In addition, ion-adsorption clay deposits are mainly concentrated in South China and Myanmar, underscoring the regional specialization of different deposit types.

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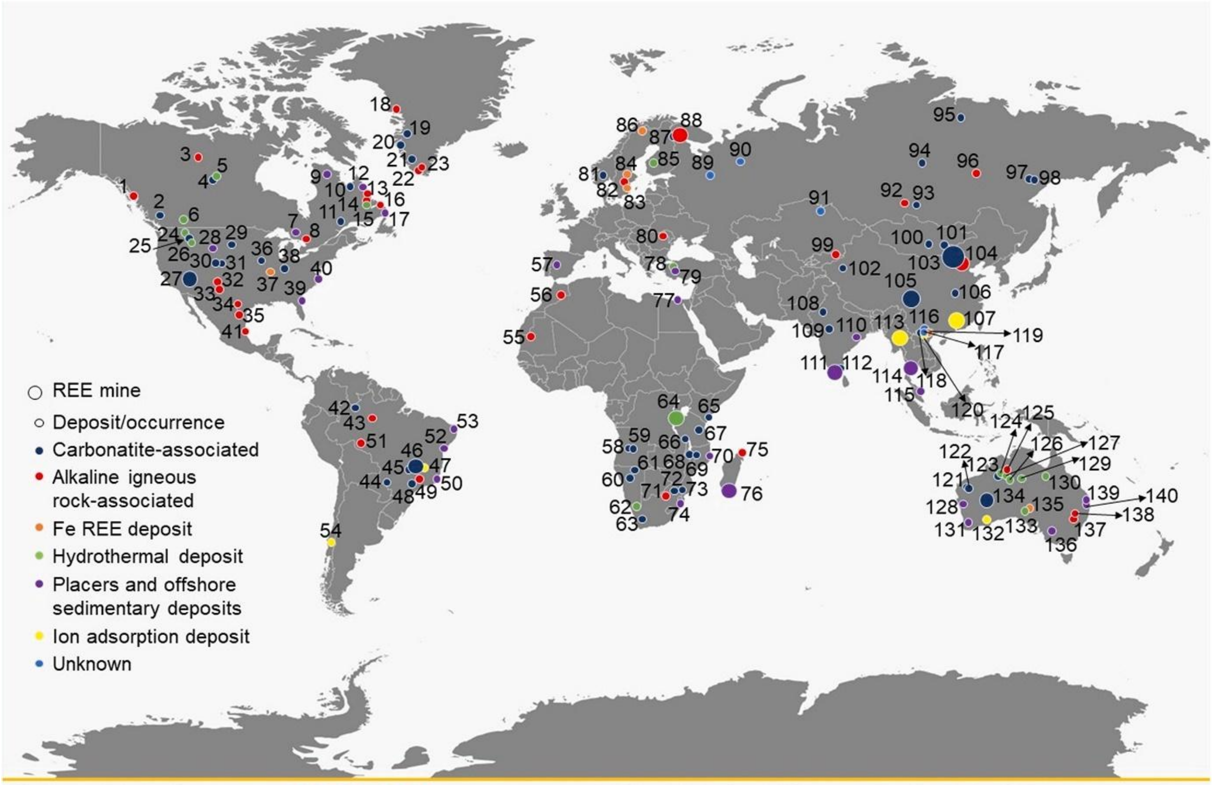
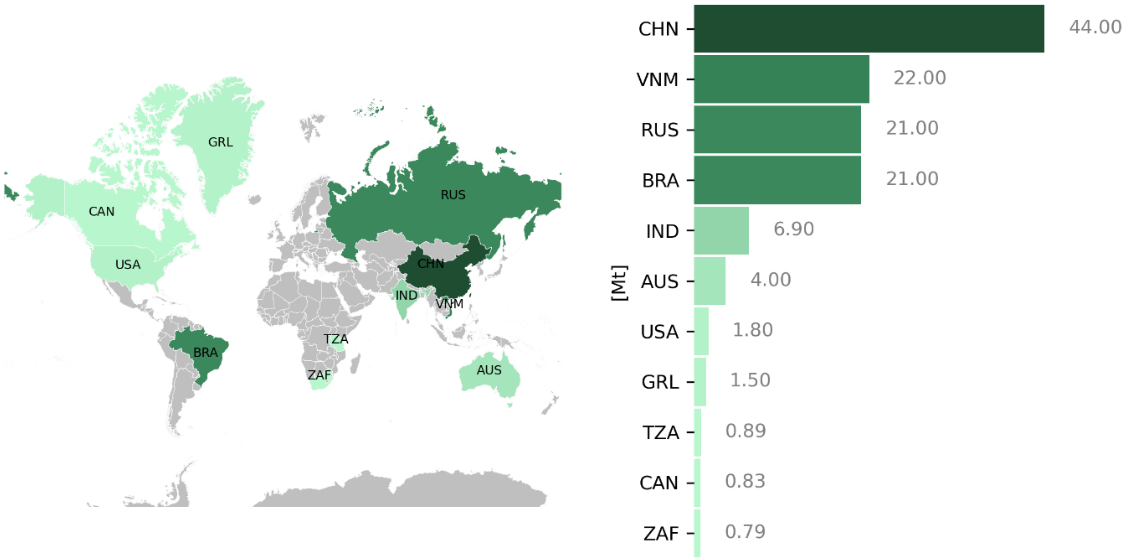


1 Bokan Mountain, USA
2 Alay, Canada
3 Thor Lake, Canada
4 Nisikkatch, Canada
5 Hoidas Lake, Canada
6 Rock Canyon Creek, Canada
7 Elliot Lake, Canada
8 Kipawa/Zeus, Canada
9 Rex-Duquet/Rex South, Canada
10 Ashram/Eldor, Canada
11 Saint-Honoré, Canada
12 Fosse du Labrador, Canada
13 Strange Lake, Canada
14 Red Wine/Two Tom, Canada
15 Kwyjibo, Canada
16 Foxtrot/Deep Fox, Canada
17 Henley Harbour, Canada
18 Karrat, Greenland
19 Sarfartoq, Greenland
20 Qeqertaasaq, Greenland
21 Tikiusaaq, Greenland
22 Kvanefjeld, Greenland
23 Motzfeldt, Greenland
24 Snowbird, USA
25 North Fork, USA
26 Lemhi Pass, USA
27 Mountain Pass, USA
28 Bald Mountain, USA
29 Bear Lodge, USA
30 Iron Hill, USA
31 Wet Mountain, USA
32 Gallinas Mountain, USA
33 Pajarito Mountain, USA
34 La Paz, USA
35 Jemi, Mexico
36 Elk Creek, USA
37 Pea Ridge, USA
38 Hicks Dome, USA
39 Green Cove Springs, USA
40 Carolina Placers, USA
41 Sierra de Tamaulipas, Mexico
42 Morro dos Seis Lagos, Brazil
43 Pitinga, Brazil
44 Chiriguelo, Brazil
45 Catalão I/II, Brazil
46 Araxá, Brazil
47 Serra Verde, Brazil
48 Barra do Itapirapuã, Brazil
49 Poços de Caldas, Brazil
50 Riode Janeiro/Buena Mine, Brazil
51 Bom Futuro, Brazil
52 Bahia, Brazil
53 Guaju Mine, Brazil
54 Penco Module/ Biolantanidos, Chile
55 Bou Naga, Mauritania
56 Tamazeght complex, Morocco
57 Matamulas, Spain
58 Coola, Angola
59 Longonjo, Angola
60 Lofdal, Namibia
61 Etanero, Namibia
62 Steenkampskraal, South Africa
63 Zandkopsdrift, South Africa
64 Karonge (Gakara), Burundi
65 Mrima, Kenya
66 Nkombwa Hill, Zambia
67 Wigu Hill, Tanzania
68 Kangankunde, Malawi
69 Songwe, Malawi
70 Congolone, Mozambique
71 Pilanesberg, South Africa
72 Naboomspruit, South Africa
73 Phalaborwa complex, South Africa
74 Richards Bay, South Africa
75 Ambohimirahavavy, Madagascar
76 Mandena, Madagascar
77 Nile Delta and Rosetta, Egypt
78 Kizilcaören, Turkey
79 Aksu Diamas, Turkey
80 Ditrău, Romania
81 Fen, Norway
82 Norra Kärr, Sweden
83 Olserum, Sweden
84 Bastnäs, Sweden
85 Korsnas, Finland
86 Kiruna, Sweden
87 Khibiny complex, Russia
88 Lovozero complex, Russia
89 Inventory of monazite when USSR
90 Yaregskoe, Russia
91 Uranium Deposit, Mongolia
92 Zashikhinskoye, Russia
93 Belozíminskoe, Russia
94 Chuktokun, Russia
95 Tomtor, Russia
96 Seligdar, Russia
97 Gornoe Ozero, Russia
98 Khamna, Russia
99 Kutessay II, Kyrgyzstan
100 Mushgai Khudag, Mongolia
101 Lugin Gol, Mongolia
102 Wajiertage, China
103 Bayan Obo, China
104 Weishan, China
105 Maoniuping/Dalucao, China
106 Miaoya, China
107 IADs, South China
108 Sarnu, India
109 Amba Dongar, India
110 Orissa, India
111 Chavara, India
112 Manavalakurichi, India
113 IADs, Northern Myanmar
114 Thai Peninsula, Thailand
115 Perak, Malaysia
116 Then Chau deposit, Vietnam
117 Muong Hum deposit, Vietnam
118 Nam Xe deposit, Vietnam
119 Sin Quyen deposit, Vietnam
120 Dong Pao deposit, Vietnam
121 Gifford Creek/Yangibana, Australia
122 *, Australia
123 Cummins Range, Australia
124 John Galt, Australia
125 Brockman, Australia
126 Boulder Ridge, Australia
127 Browns Range, Australia
128 Eneabba, Australia
129 Nolans, Australia
130 Brightlands Milo, Australia
131 Jangardup, Australia
132 **, Australia
133 ***, Australia
134 Mount Weld, Australia
135 Olympic Dam, Australia
136 WIM 150, Australia
137 Narraburra, Australia
138 Dubbo Zirconia, Australia
139 Fraser Island, Australia
140 North Stradbroke Island, Australia

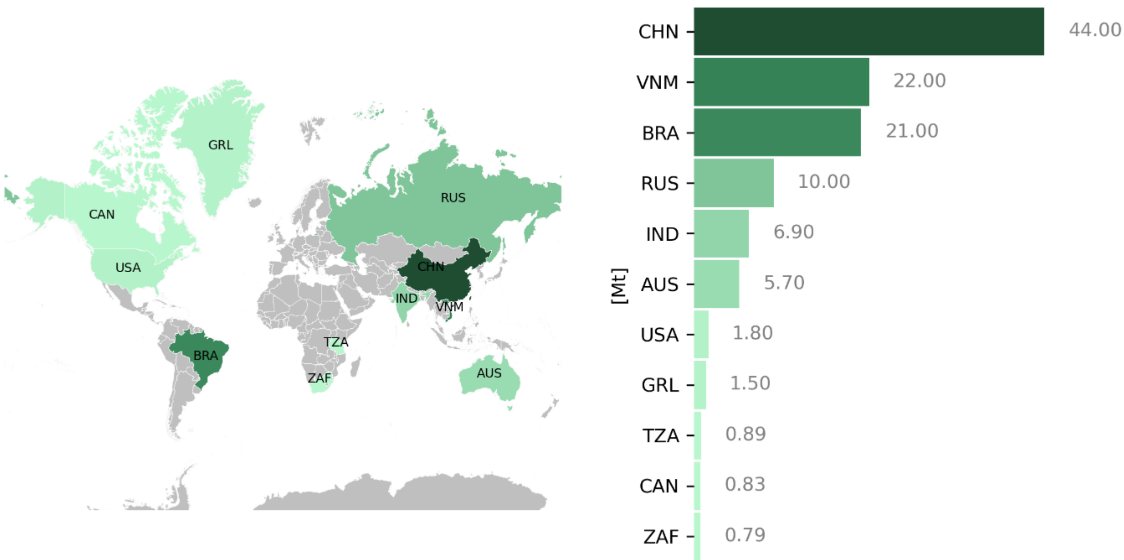
* 122 Gascoyne, Kingfisher, Mick Well, Arthur River, Mangaroon, Mt Clere
** 132 Circle valley, Cascade, Mt Ridley, Lort River
*** 133 Lake Labyrinth Shear Zone, Comet

Figure 43: Global rare earth mines and deposit. (P. Chen et al. 2024; Deady 2021; Foley and Ayuso 2024; Liu et al. 2023) The black text represents data from BGS (Deady 2021), while the red text indicates projects added between 2021 and 2024.

From a geological standpoint, rare earth elements are not rare; in fact, they are abundant in the Earth's crust. As of 2022, global rare earth reserves exceed 120,000 kilotonnes (see Figure 44). China has the largest reserves, followed by Vietnam, Russia, Brazil, and India. Notably, Russia's rare earth reserves have shrunk by half, from 21,000 kilotonnes in 2022 to 10,000 kilotonnes in 2023 (USGS 2024). Hence, values should be carefully considered. Reserves are defined as the economically accessible portion of resources and are subject to change in response to economic, technological, environmental, and social circumstances. The current turmoil may be causing Russia's RE reserves to decline.



a) 2022 Reserves



b) 2023 Reserves

Figure 44: Global RE oxides reserves in a) 2022 and b) 2023. Data: (USGS 2024)

As previously stated, Neodymium naturally occurs exclusively in chemical compounds alongside other lanthanides, typically found in minerals. Examples include Monazite (Ce, La, Th, Nd, Y) PO4 and Bastnaesite ((Ce, La, Th, Nd, Y) (CO3) F) (Roskill 2024). Several studies have made assumptions and estimated the reserves of Neodymium, as illustrated in Figure 45 (Liu et al. 2022). Global reserves of neodymium exceed 16 megatonnes. China dominated the global neodymium reserves with 43% of the world's total, followed by Brazil

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with 21%. Russia and Vietnam also held significant shares, with 10% and 12% respectively. The U.S. and Australia had smaller portions, with 1% and 4%. This distribution serves to highlight the strategic importance of these regions in the global supply chain for neodymium. It is important to note that such estimates are often derived by extrapolating from total rare earth reserves, using assumed elemental distributions or market shares.

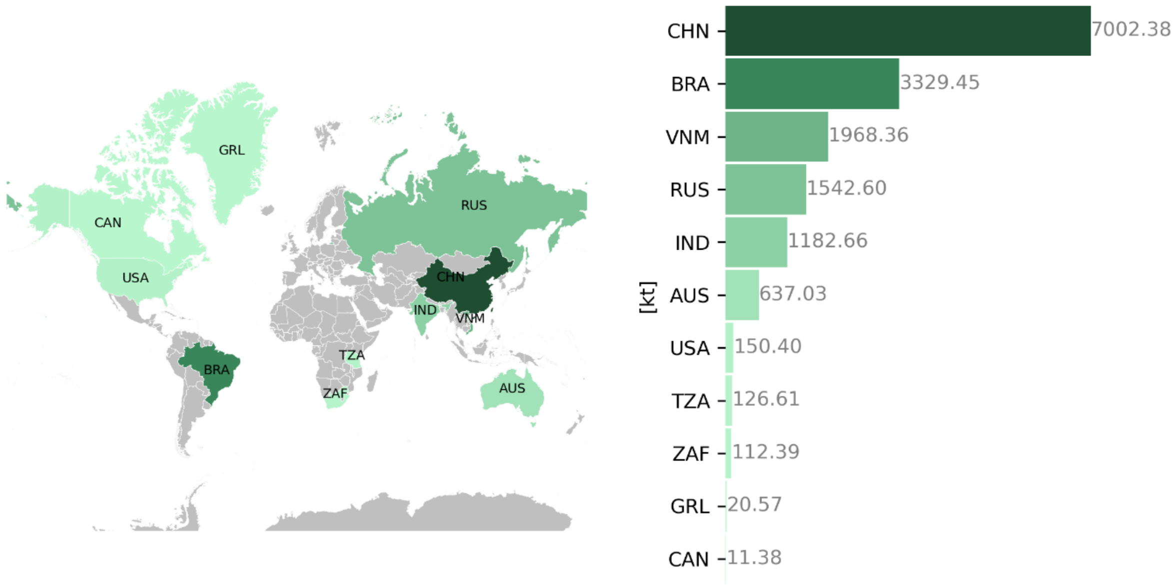

Figure 45: Neodymium reserves per country in 2020. (Liu et al. 2022)

2.4.2.2 Overview of the RE mining and refining process

The extraction, separation, and refinement of rare earth ores into usable metals entail specialized and rigorous processes that are contingent on both the geological attributes of the REO deposit and the specific properties of the target metal. Take the typical Chinese RE mines as examples, the process of RE production is shown in Figure 46. Most REs are by-products of major metals such as iron. Basically, the primary production process of REs can be divided into mining, beneficiation by gravity and magnetic separation, using sulfuric/hydrochloric acid for decomposition, separation to make the REO, and finally refining to RE metals or products.

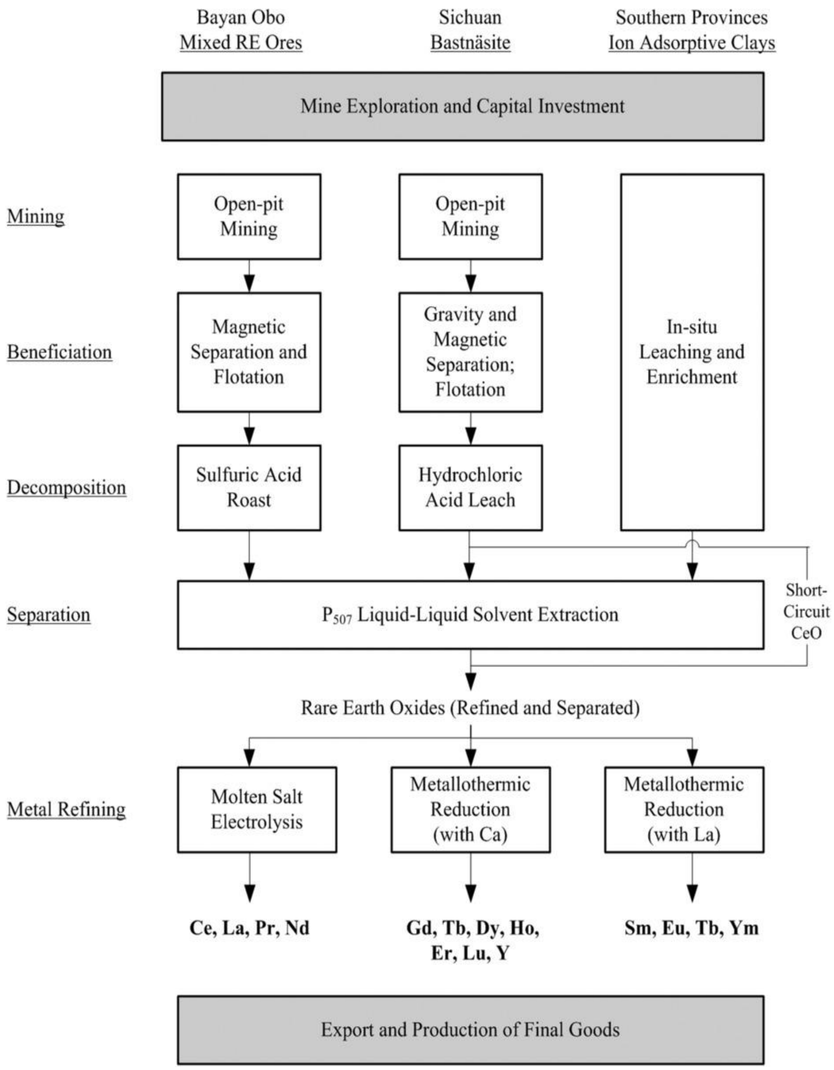

Figure 46: Rare earth mine to metal process in China (Lee and Wen 2017)

2.4.2.3 RE production and processing status

Figure 47 depicts the global rare earth oxide (REO) production by country in 2022. China is the leading producer of REO globally, with an output of 210 kilotonnes, followed by the USA (42 kilotonnes) and Australia (18 kilotonnes).

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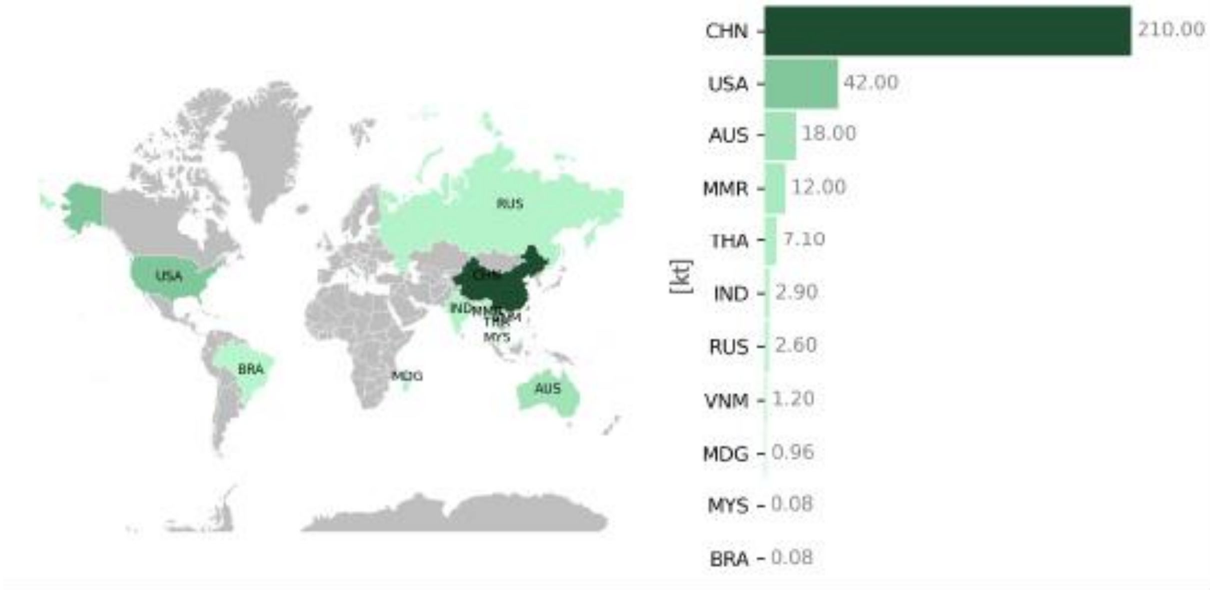

Figure 47: Rare earth oxide (REO) production per country in 2022 (unit: kt) (USGS 2024).

Currently, only China and Malaysia possess large-scale rare earth refining capabilities (Smith et al. 2022). However, efforts to build such capacity are also emerging in Europe. In the United Kingdom, Less Common Metals specializes in the production of rare earth alloys and metals, such as NdFeB, by using advanced processes like molten salt electrolysis, though it does not operate as a large-scale refiner of RE ores (Less Common Metals Ltd. 2024). In France, companies such as Solvay and Carester have initiated projects focused on rare earth recycling and processing, aiming to strengthen Europe's position in the RE value chain and reduce dependence on external suppliers (Carester 2025; Solvay 2024). The locations of the RE processing plants are presented in Figure 48.

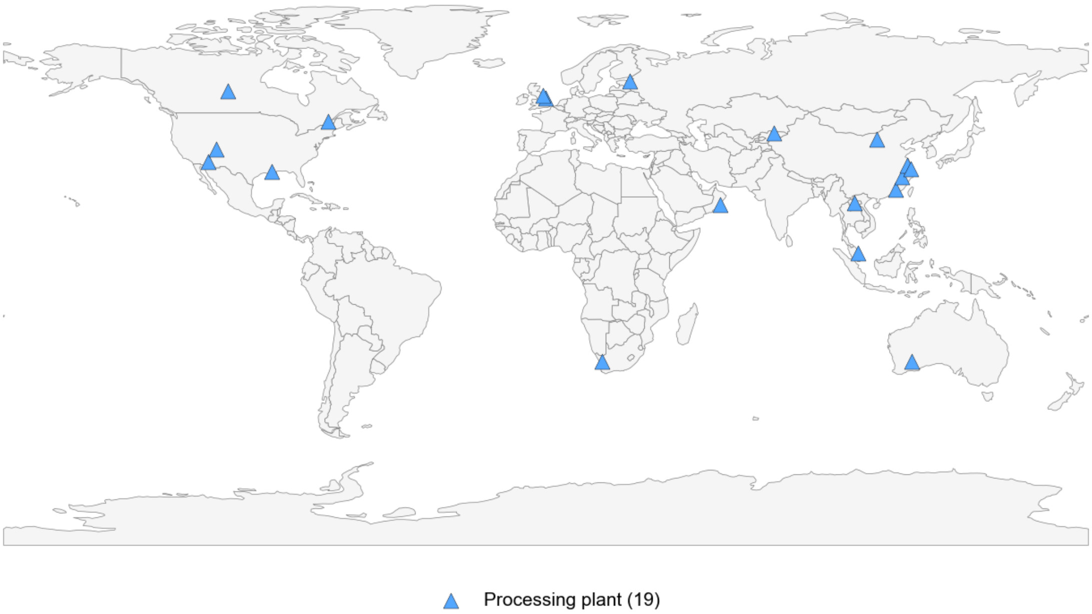

Figure 48: RE processing plants based on open-source data and S&P.

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Artisanal and small-scale, and illegal mining

Artisanal and small-scale mining (ASM) of RE is relatively infrequent but has been documented in specific regions such as southern China and Myanmar. In China, unregulated operators historically exploited ion-adsorption clay deposits using rudimentary in-situ leaching methods, leading to widespread environmental damage and contamination (Packey and Kingsnorth 2016). In Myanmar's Kachin State, informal RE mining surged in the 2010s, employing acid-based extraction, resulting in ecological destruction and human rights concerns (Global Witness 2022; Meehan, Sadan, and Lawn 2025; Yang 2021). These artisanal and illegal mining operations primarily target ion-adsorption clay deposits rich in heavy rare earth elements such as dysprosium and terbium and thus contribute little to the global supply of light REs like neodymium.

2.4.2.4 Projected RE production and refining trend

According to the International Energy Agency (IEA) (IEA 2024a), global mining capacity for magnet rare earth elements (Nd, Dy, Pr, Tb) is projected to exceed 100,000 tonnes by 2030 Figure 49, with further increases anticipated by 2035. Over half of this mining capacity will still be concentrated in China, with Australia, Myanmar, and the United States also contributing significantly. Collectively, these four countries are expected to supply over 90% of the world's rare earth elements.

Meanwhile, China is forecasted to maintain its dominance in rare earth refining capacity, accounting for more than 85% through to 2040, followed by Malaysia. Together, these two countries are projected to contribute over 90% of global refining capacity from 2030 onward.

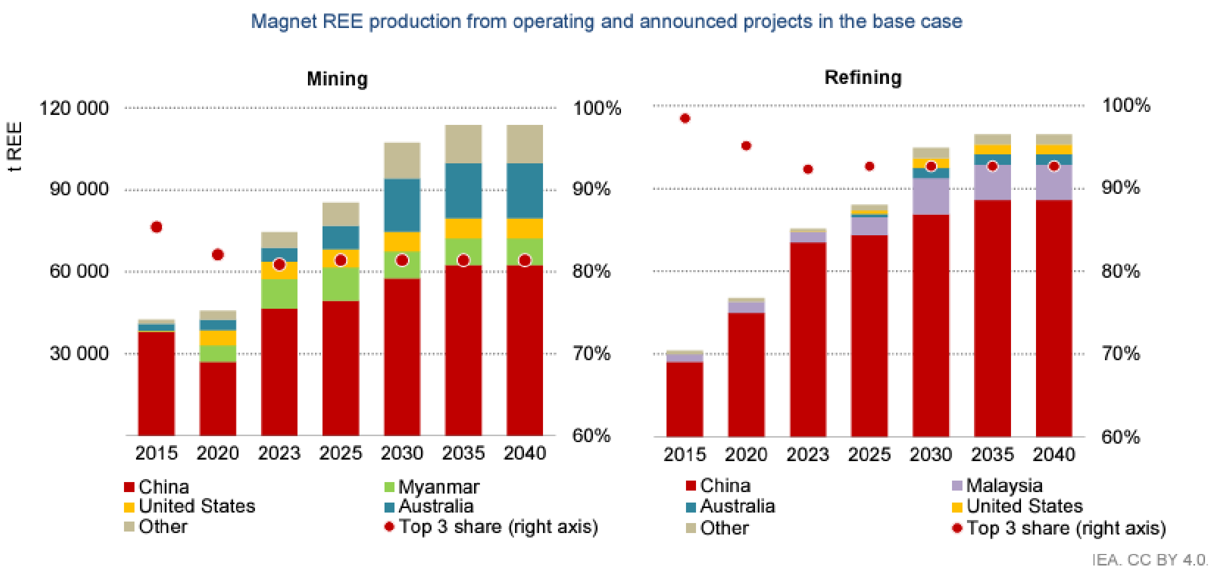

Figure 49: Global RE mining and refining capacity (IEA 2024a).

2.4.3 Changes in ownership

Key companies/actors or focus on Europe and RE elements (Neodymium)

To address the RE supply challenge and enhance the strategic autonomy of the RE value chain, the European Raw Materials Alliance (ERMA) was launched by the European Union in 2020.

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This section provides European companies that can participate (or potentially participate) in the global mine-to-magnet supply chain Figure 50. In 2022, the European Union recorded a net import of 11000 metric tonnes of RE, with total imports amounting to 18,000 tonnes and exports totalling 7000 tonnes. China emerged as the EU's largest import partner, accounting for 40% of the EU's RE imports by weight. Malaysia and Russia followed as the next most significant sources, contributing 31% and 22% of the imports, respectively (EUROSTAT 2023).

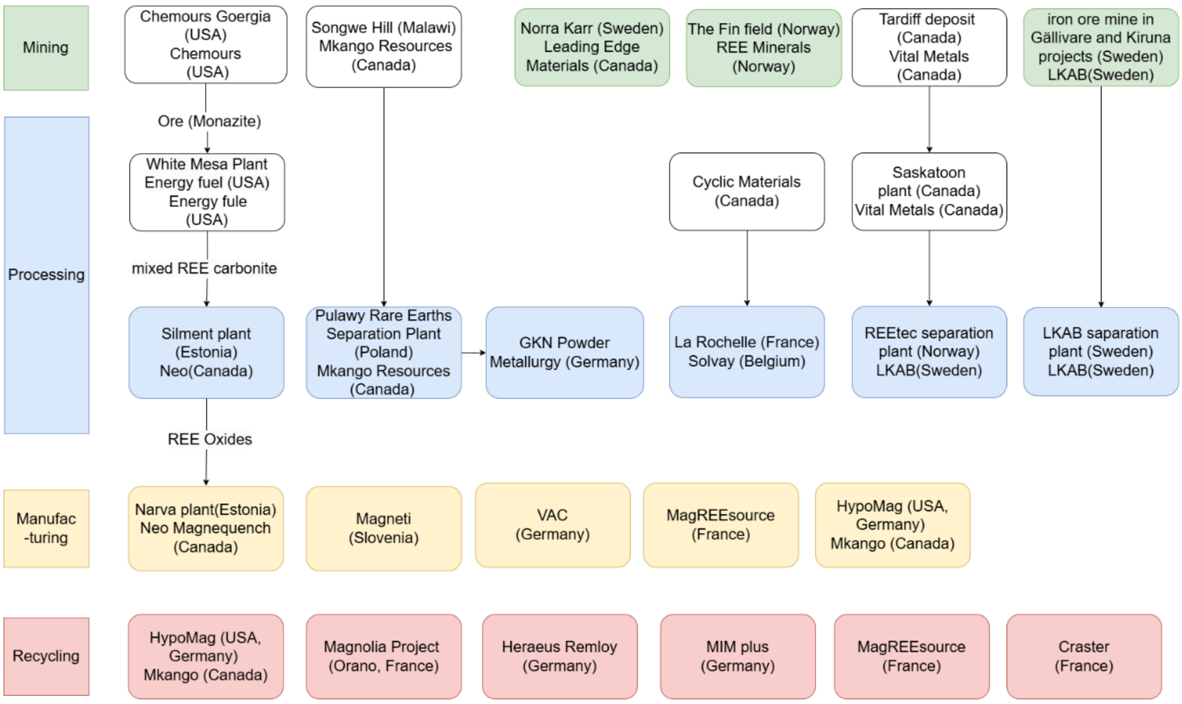

Figure 50: Key European companies (projects) in RE supply chain.

Mining

In fact, Europe holds significant rare earth reserves. The Per Geijer deposit in Sweden is the largest RE deposit in the EU, with reserves exceeding 1.3 million tonnes of rare earth oxides (REO) (LKAB 2023). Additionally, Norway's Fen field is estimated to contain 1.2 million tonnes of REO (REE Minerals 2023). Sweden's Norra Kärr deposit also has the potential to produce approximately 5,210 tonnes of rare earth oxides annually and is currently undergoing the mining lease application process (Leading Edge Materials 2025). However, despite these reserves, Europe currently lacks active rare earth mines, which remains one of the major challenges facing the region's rare earth supply chain.

Refining

The EU currently has only one commercially active rare earth processing plant, located in Estonia. Besides this, more effort has been made to strengthen domestic processing capacity, with several new facilities under development across member states. The main EU processing facility is listed below:

- **NPM Silmet plant**
  This mine-to-magnets rare earth supply chain under analysis begins at Chemours in the U.S., where initial processing of raw rare earth elements takes place. These RE concentrates are then shipped to the White Mesa, Utah, facility operated by Energy Fuels, the only company in the US currently producing commercial quantities of partially separated mixed RE carbonate. This intermediate stage is essential to purify the REs and improve their quality for downstream applications. The processed materials are then shipped to Neo Performance Materials Group (NPM)'s Silmet plant in Estonia, where they are converted into rare earth oxides and metals. The Silmet plant is the only commercial-scale RE separation plant operating in the EU. In June 2023, construction began on a new magnet manufacturing facility in Narva, Estonia, which is expected to be fully operational by 2025, enabling the local production of high-performance rare-earth magnets in Estonia (CeriumRocks 2023). Currently, the NPM Silmet plant has an annual production capacity of approximately 3,000 tonnes of rare earth oxides (REOs). Once the new magnet manufacturing facility in Narva is operational, this capacity will support the production of magnets for around 1.5 million electric vehicles (EVs), meeting around 80% of the RE demand for newly registered EVs (BEV + PHEV) in the European Union in 2022 (EEA, 2022). Neo's planned Phase 2 expansion, anticipated within the next 2–3 years, aims to increase REO production to 5,000 tonnes annually, which would support magnet production for approximately 4.5 million EVs by 2030.

- **Solvay - La Rochelle (France)**
  Another promising supply chain development involves the Belgian chemical group Solvay, which has announced plans to upgrade its La Rochelle facility in France to separate rare earths, thereby contributing to the strengthening of Europe's rare earth supply chain. This facility is expected to begin operations in 2025, with an annual production capacity of 4000 tonnes of rare earth oxides (REO). Currently, the primary upstream feedstock for La Rochelle comes from Cyclic Materials in Canada, and the shipment will begin at the end of 2024 (Solvay and Cyclic Materials sign supply agreement for recycled mixed rare earth oxide 2024).

However, increased investment in domestic refining capacity suggests that the EU could become at least partially self-sufficient, if not fully independent, in rare earth production over the long term. Significant expansion in processing and refining capacity is expected within the EU, including the establishment of a rare earth separation plant in Puławy, Poland, funded by Mkango Resources and supplied with materials from the Songwe Hill project in Malawi. In addition, more environmentally friendly processing facilities for the Per Geijer ores are being developed by Swedish mining firm LKAB in collaboration with REETec. REETec also has a partnership with the Australian firm Vital Metals to separate and purify rare earth carbonates from Vital's Saskatoon mine. Together, these efforts are expected to contribute approximately 18400 tonnes of rare earth oxides (REO) per year, a fraction of the 298,000 tonnes currently produced by China.

2.4.4 Changes in location - trade

In the absence of disaggregated trade data specifically for neodymium, this analysis focuses on global RE trade flows in 2022, the data retrieved from the BACI database (Gaulier and Zignago 2010) and Chatham House (Chatham House 2024).

Globally, the total weight of RE trade (RE equivalent) in 2022 is 232 kt (Chatham House 2024). The scope of this section includes RE compounds (HS code: 284690), RE metals (HS code: 280530), permanent magnets (HS code: 850511) and rare earth waste (Commodity: Rare

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earths/metals nes, unwrought/waste of scrap), covering key stages in the value chain - extraction, refining and manufacturing.

Since 2010, trade data for RE waste, together with the corresponding HS codes, are not included in the UN Comtrade database (UN Comtrade 2024) or the BACI database. Instead, this data was obtained from Chatham House. Cerium compounds (HS: 284610) are excluded from this report as they are not related to the production of magnets.

RE compounds

In 2022, the top exporters of the RE compounds were China, Myanmar, Malaysia, and Russia, see Figure 51. The largest trade flow of RE compounds was Myanmar's export of approximately 23,000 tonnes to China (as shown in Figure 52). Germany and France are the leading importers of rare earth compounds in Europe, totaling around 13 kilotonnes.

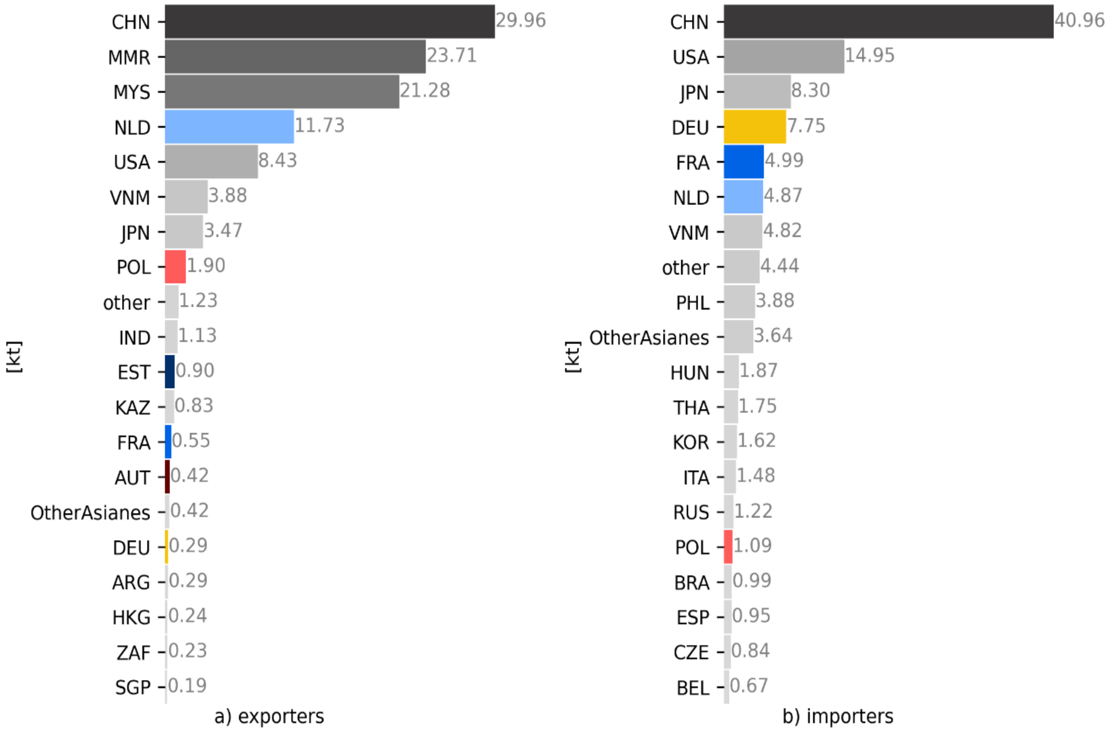

Figure 51: Top-20 (a) exporters and (b) importers of RE compounds in 2022. Based on: CEPII-BACI database, version 202301, updated in February 2023 (Gaulier & Zignago, 2010).

The trade flows between the countries, represented in Figure 52, show that the top three importers from Germany were the Netherlands, China, and Japan, while the top three importers from France were Malaysia, China, and Japan. Meanwhile, the Netherlands emerged as the largest exporter of rare earth compounds, primarily shipping them to Germany, Hungary, and Italy, other major exporting countries in Europe, such as Poland and Belgium, primarily export rare earth compounds to the Philippines.

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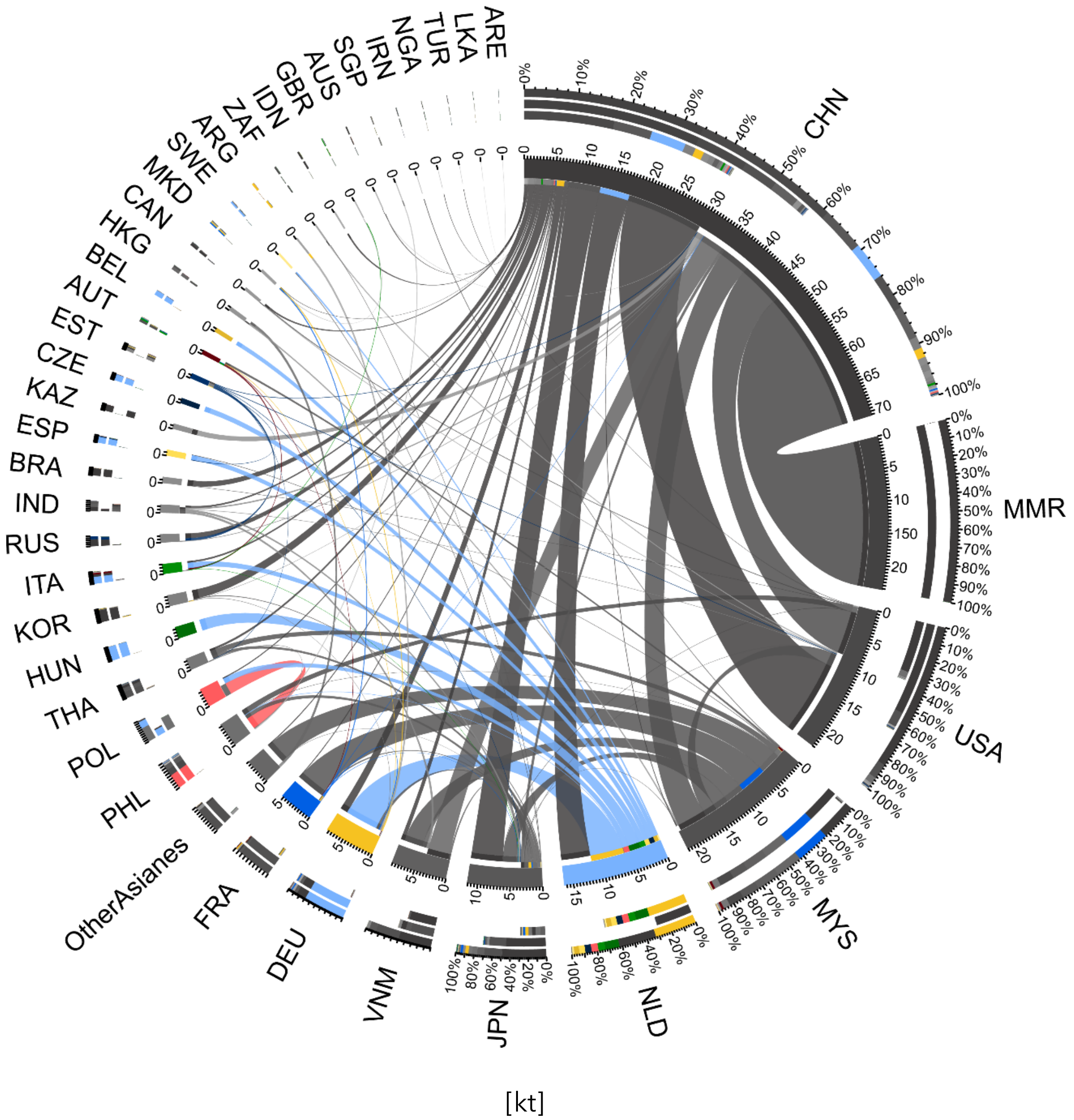

Figure 52: Trade of RE compounds in 2022 represented in a chord diagram (Gaulier and Zignago 2010).

RE metal

Figure 53 presents the top importers and exporters of RE metals in 2022. In that year, Australia's rare earth metal exports to Malaysia, as shown in Figure 54, represented more than half of the global trade in rare earth metals. Followed by China, which exports to Japan around 5000 metric tonnes.

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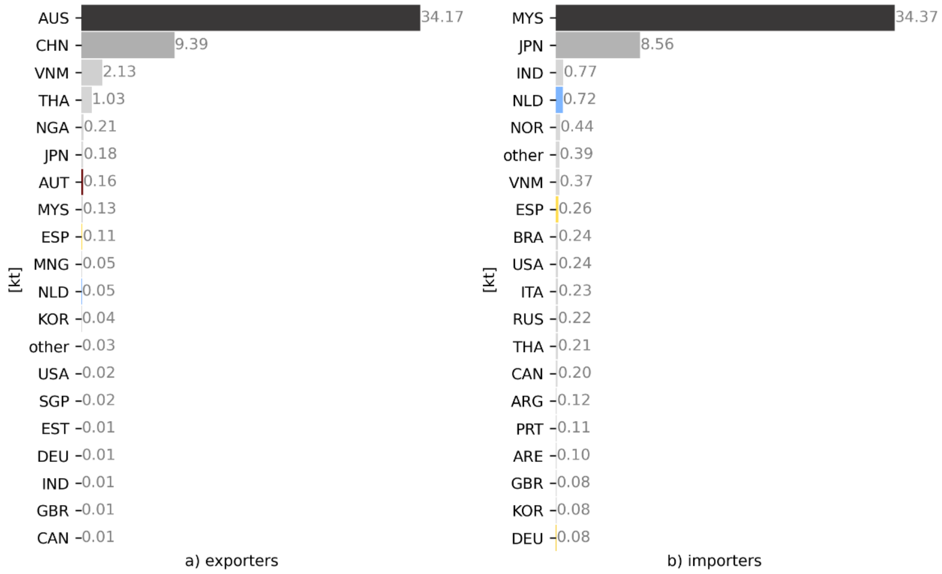

Figure 53: Top-20 (a) exporters and (b) importers of RE metals in 2022. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

Figure 54 presents the trade flows of RE metal between countries. The figure shows that the largest trade flows are indeed between Australia and Malaysia, followed by the export from China to Japan and from Vietnam to Japan. In 2022, Japan imported RE metals from 11 different sources. The Netherlands imported RE metals from China and 27 other countries, including Thailand, Austria, Germany, and Belgium. Spain imported mostly from China and Austria. Other EU countries traded RE metals, including Italy, Portugal, and France, among others.

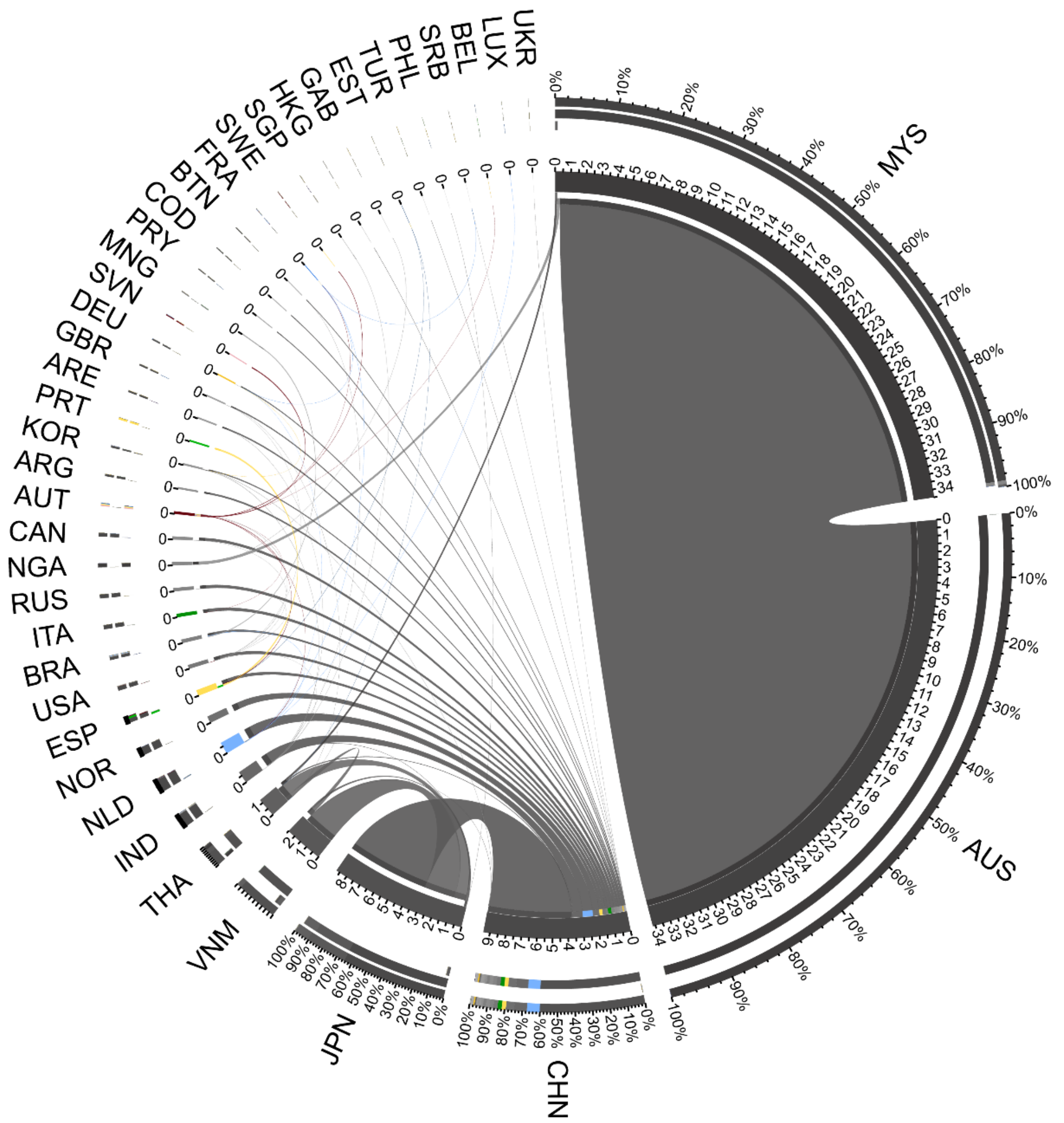

Figure 54: Trade of RE metal in 2022 represented in a chord diagram. (Gaulier and Zignago 2010).

Magnets

China is responsible for approximately 90% of the global magnets production in 2022, the rest mainly comes from Japan (DOE, 2024). The ranks of the top importers and exporters are listed in Figure 55. In 2022, China exported more than 123 kilotonnes of permanent magnets, more than the combined exports of all the rest of the exporting countries.

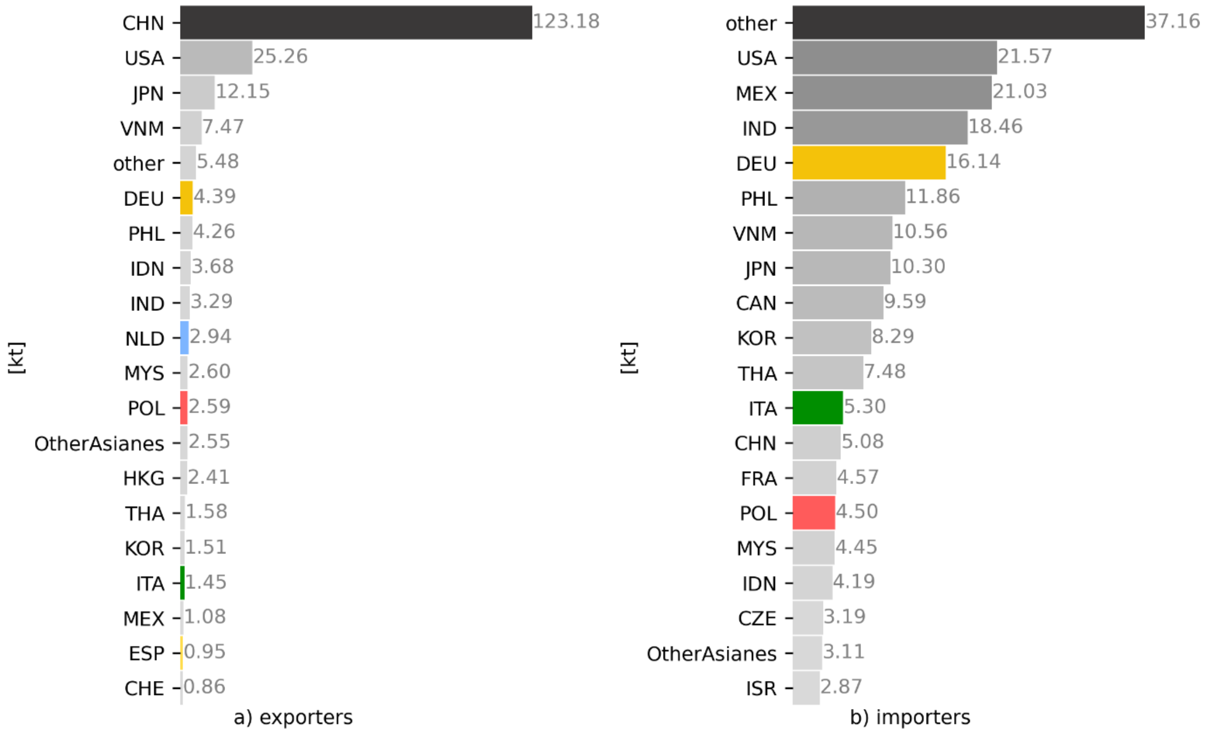

Figure 55: Top-20 (a) exporters and (b) importers of permanent magnets in 2022. Based on: CEPII-BACI database, version 202301, updated in February 2023 (Gaulier & Zignago, 2010).

For the importers, the United States, India, and Germany are the top three importers of individual countries. In 2022, the EU-27 recorded a net import of approximately 34.7 kilotonnes (kt) of magnets, with total imports reaching 50.9 kt and exports totalling 16.2 kt. Of these imports, 75% originated from non-EU countries, predominantly from China (68%), followed by Japan (1.3%) and the United Kingdom (1.29%), as shown in Figure 56. The remaining 25% of imports were sourced from within the EU.

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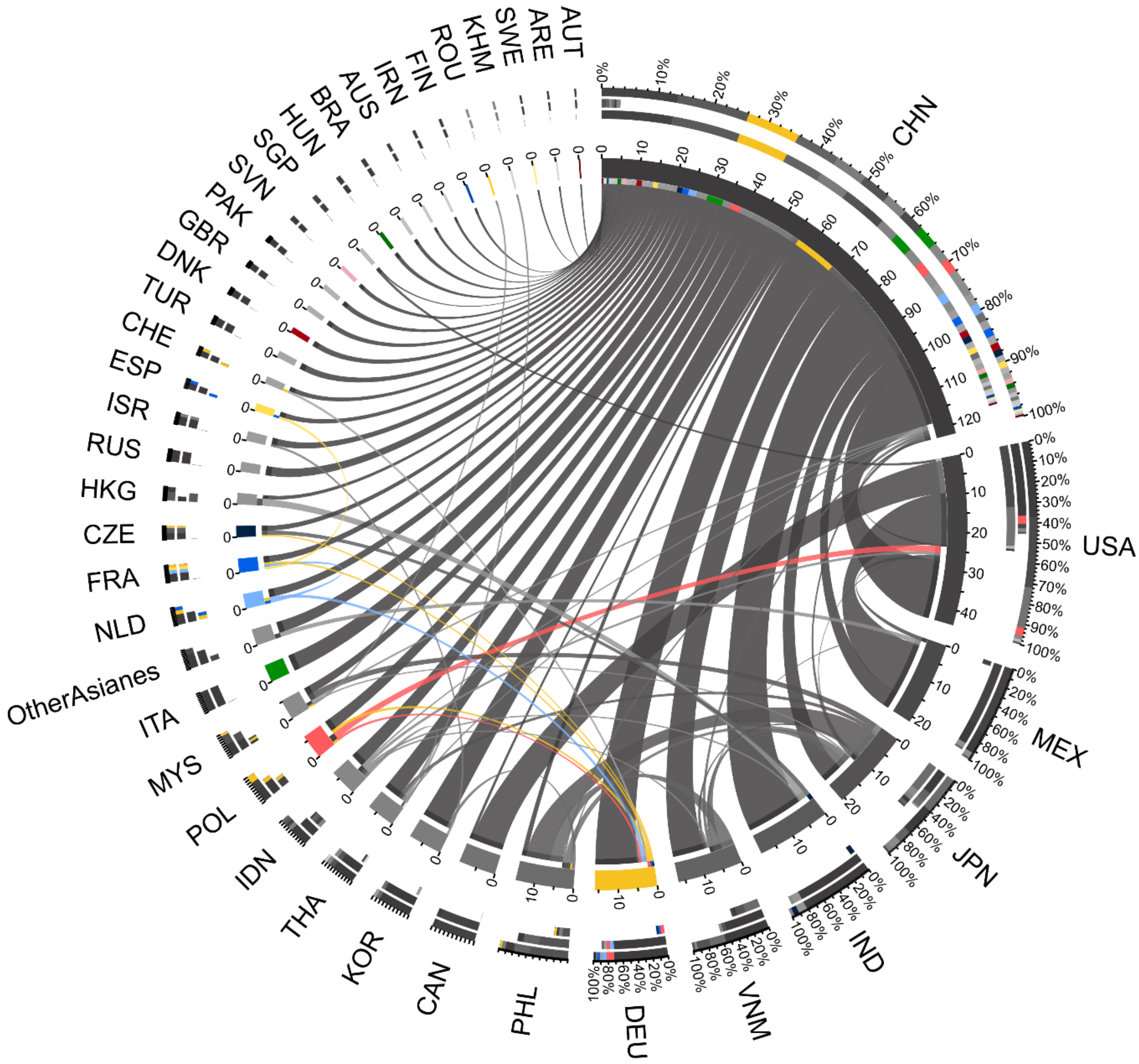

Figure 56: Permanent magnets trade in 2022, HS code: 850511(Gaulier and Zignago 2010).

Only 26% of the EU's magnet exports were destined for non-EU countries (EUROSTAT, 2023). The trade data represented in Figure 56 shows that within the EU, Germany, France, Poland, and Belgium were the primary destinations for these exports. Among non-EU countries, the United States (2.16 kt), China (0.3 kt), and the United Kingdom (0.27 kt) were the leading export destinations. For the EU countries, Poland and the Netherlands have very little net imports/exports, and they play the role of import re-exporters. Poland imports magnets from China and then re-exports them to the United States. Germany is the Netherlands' main trading partner for re-exporting magnets. Italy and Germany are the main net importers of NdFeB magnets, due to their leading position in the automotive and wind turbine industries.

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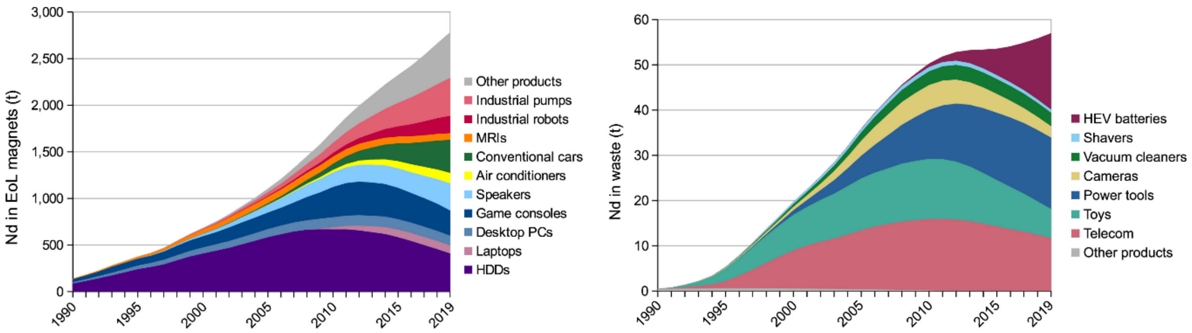
2.4.5 Secondary sources and flows

2.4.5.1 RE recycling potential

Figure 57 and Figure 58 and show the secondary supply potential of Neodymium of Europe. Currently, consumer electronics are the primary source of Neodymium in waste. Compared to other European countries, Germany and the United Kingdom have a large amount of total waste Neodymium, but countries like the Netherlands and Belgium have a higher Neodymium density. In contrast to the rising demand for Neodymium in magnets used in wind turbines and electric vehicle (EV) motors, these categories are currently underrepresented in Neodymium waste streams. This discrepancy is largely attributed to the time lag between the inflow and outflow of Nd, with substantial waste streams expected to materialize in the coming decades as many products reach their end-of-life stage.

The future Neodymium waste streams could be regarded as an urban mine, presenting opportunities for resource extraction. However, the recyclability of Neodymium differs across products; for example, magnets in wind turbines are generally larger and easier to collect than those in electric motors.

There is currently no specific waste code or HS code for magnet scrap, which means that the trade of magnet waste and scrap can to be evaluated. The assessment of the secondary Neodymium potential currently relies entirely on modeling and calculation rather than formal tracking.



(a) Neodymium contained in EoL magnets. (b) Neodymium contained in EoL batteries and catalysts.

Figure 57: Neodymium waste flow among EU-27 and UK from 1990-2019 (van Nielen et al. 2023).

Currently, the recycling rate of rare earth elements is less than one percent. However, as the energy transition progresses, a significant number of permanent magnets used in renewable energy technologies, such as those in EV motors and wind turbines, will reach the end-of-life. This presents a substantial recycling potential and offers an opportunity to alleviate the rare earth supply shortage.

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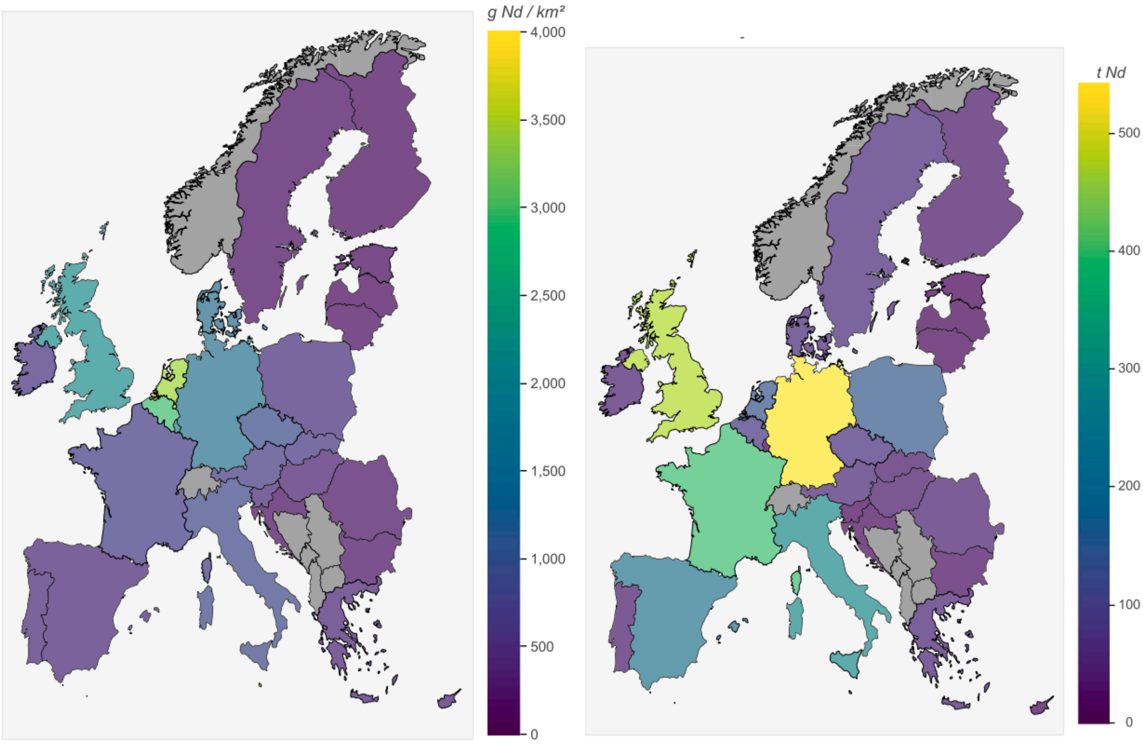

(a) Waste flow density. (b) Total waste flow.

Figure 58: The neodymium in waste per European country in 2019 (van Nielen et al. 2023)

2.4.5.2 Recycling actors

The current recycling rate for RE elements is below 1%. However, more and more RE recycling projects are being launched globally, including in Europe. Here, we highlight the main RE recycling (pilot) projects involving European companies (Table 5).

Name	Country	Capacity (ton/ yr)	Ramp-up	Note
Caremag	France	2000 (waste)	N.A.	1000 tonnes of EoL magnet per year and 1000 tonnes of swarfs
Hypromag	UK, USA, Germany	700-1150 (output of alloy)	2024	Synergies with primary supply projects
Orano	France	7		4 tonnes in 2024, 7 in 2026 (hydrogen)
MagREEsource	France	1000	2029	50 tonne pilot launched in 2024
Ionic Rare Earths	UK	30	2024	Pilot
Itelyum Regeneration SpA	Italy	N.A.	2027	The Level I plant will have a dismantling capacity of 1000 tonnes/year of electric rotors, while the Level II plant will treat 2,000 tonnes/year of PMs, resulting in the recovery of about 700 tonnes/year of RE oxalates

Table 5: Select RE recycling project in Europe. Data source: (IEA 2024c; Itelyum 2024)

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2.4.5.3 RE waste flows

The total global trade flow of waste REs in 2022 is around 7.8 kt, as shown in Figure 59. Its accounts for around 3% of all the RE trade (Chatham House 2024). The top two trade flows are from Brazil to the U.S. and China, respectively. For EU members, this type of trade occurs between Italy, Germany and Belgium.

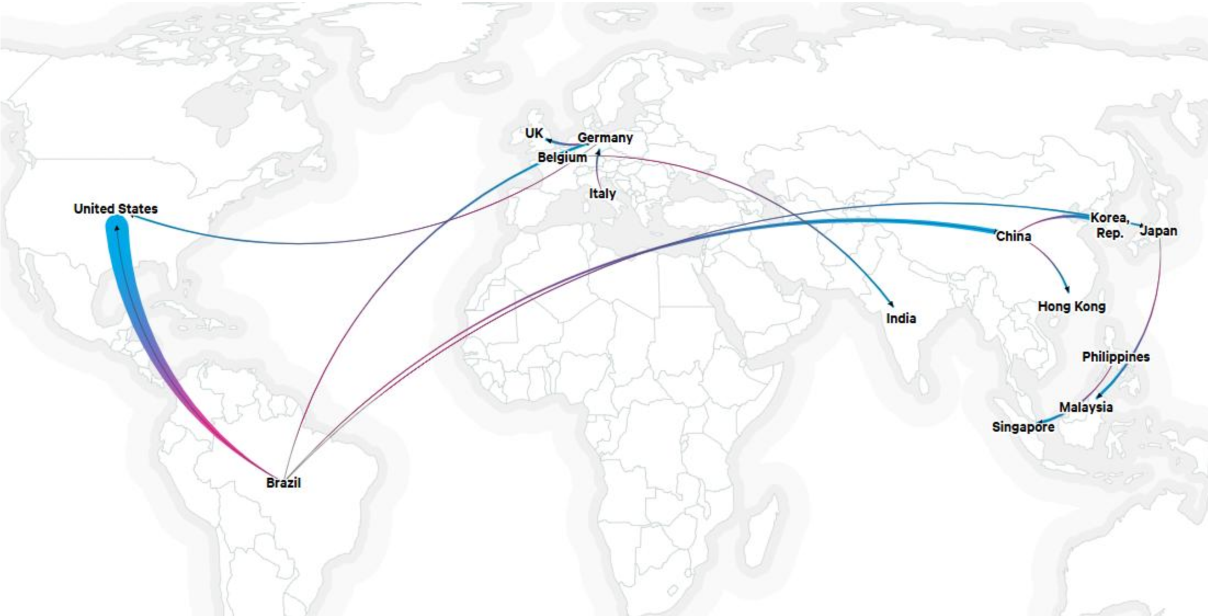

Figure 59: Global trade of RE scrap in 2022. (Commodity: Rare earths/metals nes, unwrought/waste of scrap[3], Data: (Chatham House 2024)

[3] The trade records for this entry at both UN Comtrade and BACI are only pre-2010, and after consulting with Chatham House, they explain that the calculation is done by subscribing to the Bulk API from UN Comtrade, which integrates different versions of the HS code.)

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3 Leverage points for traceability technologies

In this report, we define leverage points as the specific junctures in the supply chain where the deployment of traceability technology can contribute the most to the traceability of the materials, thus verifying their provenance and avoiding fraud. By focusing on these strategic areas and employing the right tools, we can ensure that small, well-placed interventions result in substantial improvements in supply chain transparency and traceability. A set of three criteria to identify these strategic points of the supply chain was selected:

- Transformations in material state and chemical modifications
- Changes in ownership
- Changes in location.

Transformations in material state and chemical modifications

Changes in chemistry, mixing, and splitting refer to any physicochemical transformation occurring to materials throughout their supply chain (from extraction to end-of-life products). Any process that can affect the material and its traceability, like changes in chemistry, mixing, and splitting, needs to be considered in the choice of leverage points in order to ensure the reliability of the chemical and digital tracing of the materials. Figure 60 illustrates the processes that the selected materials explored in this project are subject to.

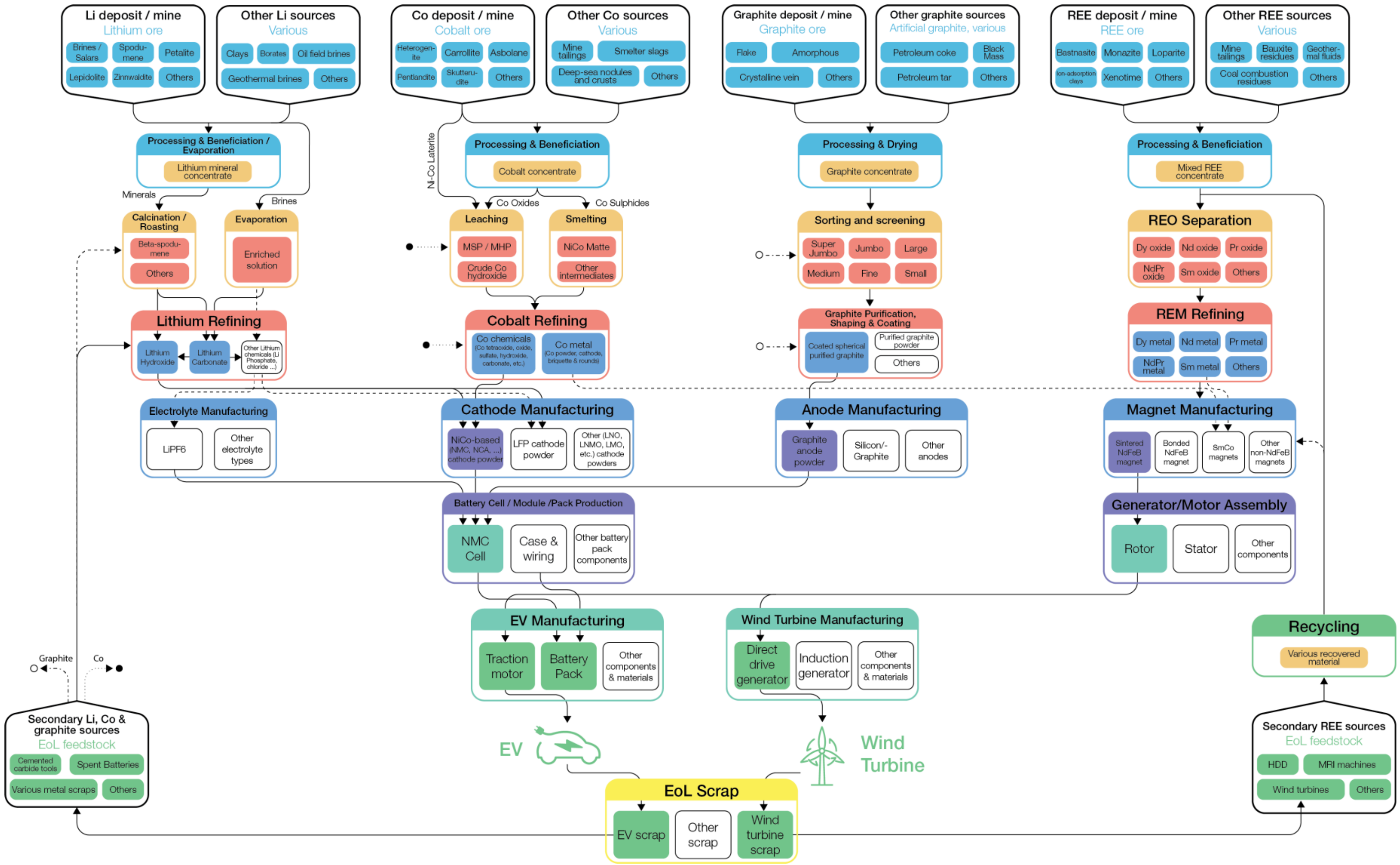

Figure 60: Process-level mapping of lithium, cobalt, natural graphite, and REs for EVs and wind turbine manufacturing. Retrieved from: D2.1, MaDiTraCe project (Donnelly et al., 2023).

Changes in ownership and vertical integration of supply chains

Changes in ownership encompass the legal procedures through which a company or stakeholder officially becomes the new owner of raw materials or products. Considering supply chain traceability, monitoring changes in ownership involves identifying material and title transfers, as well as adhering to the Chain of Custody. Furthermore, vertical integration might occur when a company or stakeholder operates in one or more stages in the supply chain. Glencore, for example, conducts its activities in mining and refining, which implies an integrated business with ownership across supply chain stages.

Within the EU, assessing changes in ownership and vertical integration of supply chains can be facilitated through various reliable sources of information. For example, the European Business Register (EBR) provides detailed company ownership data (European e-Justice Portal, 2023). Identifying changes in ownership for companies outside the EU can be challenging due to the accessibility of their registration information (Open Corporates, 2023). However, specialized corporate intelligence databases can offer pertinent data on company ownership, serving as a reliable indicator of changes in ownership events (S&P Global, 2023).

Changes in locations

These are the points that coincide with processes that can influence traceability. Examples of these strategic points are ports of entry in the EU, where the authenticity of materials is meticulously verified. These pivotal points serve as checkpoints, ensuring the accuracy and reliability of digital product passports (DPPs) and chemical traceability to ensure material authenticity and transparency throughout the supply chain.

This chapter explores potential strategic leverage points in Europe, as well as in high-risk areas worldwide, for the four materials covered in MadiTraCe.

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3.1 Overview of European leverage points for traceability technologies

The three types of leverage points were considered within the European context. The transformations in material state and chemical modifications were analyzed by mapping the countries in the EU + Norway that either already extract or process Co, Li, Nd, or natural graphite in 2022, or are potential future producing countries. Additionally, the main manufacturing and recycling countries of Li-ion batteries and neodymium were also identified. The changes and links in ownership were analyzed through the identification of companies that own mines outside the EU and refineries or smelters within the EU. Finally, the European leverage points based on location changes were identified based on the European imports of the 4 materials.

3.1.1 Transformations in material state and chemical modifications

In this section, an overview is provided of the European countries that mine and/or process cobalt, lithium, natural graphite, and neodymium (in 2022 or prospected in the future), see Table 6. Table 7 includes a list of manufacturing and recycling companies of Li-ion batteries and Neodymium.

- Cobalt: In 2022 there was cobalt mining in Finland. Changes in material state and chemical composition possibly took place at smelters and refineries in Finland, Belgium and Norway (British Geological Survey 2024), and possibly in France, Spain(CIC energiGUNE 2022), and the Netherlands (their cobalt production in 2022 is unknown).
- Lithium: In 2022 there was lithium production in Portugal (mines), in the future according to current exploration mining projects it could be expected in Finland, Germany, France, Serbia, Italy, Spain, Czech Republic, Bosnia and Herzegovina, Austria and Portugal. Changes in lithium transformations in material state and chemical modification are in Germany, lithium processing plants are also in development in Finland, Germany and France. Several strategic projects were selected by the European Commission in 2025, covering extraction and refining.
- Natural graphite: In 2022, there are natural graphite mines in the EU (Sweden). There is also an active graphite mining project in Norway in 2022. For the natural graphite processing, the active processing plants are located in Finland and Norway, according to the S&P (S&P Capital IQ 2025).
- Rare earths, Neodymium: In 2022, there was no domestic extraction of rare earth elements in the EU. Currently, the only commercial rare earth processing plant in the EU is located in Estonia. However, Poland may play a role in rare earth processing in the future as well as France. For rare earth recycling, several start-up and pilot plants have already been established in Germany and France.

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	Mining countries (2022)	Pot. Future mining countries	Processing countries	Pot. Future processing countries
Cobalt	• Finland (Terrafame and Kevitsa)	• Spain (Aguablanca)	• Finland (Kokkola refinery, Talvivaara refinery) • Belgium (Balen and Olen Umicore zinc) • France (Sandouville) • Netherlands (Budel Dorplein Refinery)	• France (GALLICAM, 2027) • Finland (Sakatti Project, 2030)
Lithium	• Portugal (Alvarrões)	• Finland (Keliber – Kokkola mine) • Germany (Vulcan, Zinnwald) • France (EMILI mine, Alsace geothermal brines) • Serbia (Jadar) • Italy (Lazio) • Spain (Alberta II, San Jose) • Czech Republic (Cinovec) • Bosnia and Herzegovina (Lopare) • Austria (Wolfsberg), • Portugal (Mina do Barroso)	• Germany (AMG Lithium GmbH and Langelsheim Albemarle)	• Finland (Keliber - Kokkola refinery, 2025) • Germany (Vulcan refinery Frankfurt, Ruben refinery, Bitterfeld Refinery) • France (EMILI plant, 2028, and Viridian Lithium 2028, GALLICAM, 2027) • Portugal (Estarreja Refinery)
Natural graphite	• Greenland (Amitsoq) • Norway (Traelen) • Sweden (Vittangi and Woxna) • Ukraine (Zavalievsky, pre-war, no EU) • Czech Republic (Český Krumlov, not for battery)	• Romania (SALROM Baia de Fier) • Sweden (Talga Natural Graphite ONE)	• Czech Republic • Finland (GAMP Plant) Norway (Active Anode Material Plant Plant) • Sweden (Vittangi Graphite Project, pilot in 2022)	• France (BAM4EVER, 2026; GALLICAM,2027; NGC Battery Materials,2028) • Estonia (CO2 Graphite, 2025) • Finland (Hycamite TCD Technologies Ltd)

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	Mining countries (2022)	Pot. Future mining countries	Processing countries	Pot. Future processing countries
Neodymium		• Sweden (ReeMAP) • Norway (Fen)	• Estonia (Neo) • France (Solvay)	• Poland (Pulawy Rare Earths Separation Plant, 2027) • France (CAREMAG, Q4 2026) • Italy (LIFE-22-ENV- IT-INSPIREE, 2027) • Sweden (ReeMAP, 2026)

Table 6: European countries that mine and/or process cobalt, lithium, natural graphite, and neodymium (in 2022 or prospected in the future)

Lithium-ion batteries are produced in Germany, Hungary, Poland, Sweden and the Czech republic and are projected to be produced in Norway, Italy, France and Slovakia in 2030. They are recycled in Belgium, Germany, France, Finland and Norway, see also Table 7 (European Commission. 2025; IEA 2024c).

	Manufacturing	Recycling
Li-ion batteries	Germany Hungary Poland Sweden Czech Republic	Belgium Germany France Finland Norway
Neodymium	Slovenia Germany France Estonia	France Germany Italy

Table 7: Countries in the European Union that manufacture or recycle Li-ion batteries (cobalt and lithium) and neodymium.

3.1.2 Changes and links in ownership

Several links were found between smelters or refineries in the European Union with mines outside the European Union through company ownership, which are presented in Table 8. These links and yje changes in ownership and here described for cobalt, lithium, Natural graphite and Neodymium.

Cobalt

Three companies have ownership in cobalt mines as well as in smelters or refineries in Europe. Possibly these companies are exporting (some of) their cobalt to their own smelters or refineries (SoRs) in Europe. Jervois Global Limited owns a cobalt mine in the USA and a refinery in Finland, Sibanye Stillwater Limited owns a refinery in France and possesses mines as well in Australia, Canada, South Africa, and Zimbabwe. Glencore plc possesses a refining

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plant in Norway (Nikkelverk) and mines on all continents, including copper-cobalt mines in the DRC and Zambia.

Six of the mine operator companies have headquarters in the European Union (Switzerland, France, Finland, Sweden, and Belgium) and four in the United Kingdom. Eight of the owner companies have headquarters in the European Union (Belgium, France, Finland, Luxembourg, Switzerland, Sweden) and three in the United Kingdom.

Lithium

The map of lithium companies having mining and refining activities in Europe and outside Europe is very limited, as the European lithium ecosystem is under development.

AMG Lithium (2024) is building an integrated supply chain starting with hard rock mining in the Mibra mine in Brazil, which would be processed to lithium hydroxide monohydrate in Bitterfeld, Germany, where the plant is being commissioned.

Eramet SA possesses lithium mining properties in Argentina and Chile and is the promoter of geothermal brine extraction in France. However, lithium refining in South America takes place there and not in France.

April 2025 HELM AG announced the opening of a new Lithium Chloride Solution production plant of its subsidiary LevertonHELM, a UK-based manufacturer of high-quality Lithium chemicals (HELM AG 2025). The new plant turns the technical grade Lithium Carbonate into Lithium Chloride Solution and increases the production capacity from 3,000 tonnes to 10,000 tonnes of Lithium Chloride Solution per year. However, this company has no mining properties.

The headquarters of lithium mining European operating companies are located in Ireland, Portugal, and the Netherlands.

Natural Graphite

AMG Graphite operates its own mine and processing plant of natural graphite in Germany, also it has owned the natural graphite mine in Sri Lanka since 2008.

	Ownership links with the EU	Mines outside the EU	Refinery in Europe
Cobalt	Glencore PLC	DRC, Zambia, Australia and Canada	Norway (non-EU)
	Jervois Global Limited	United States	Finland
	Sibanye Stillwater Limited	Zimbabwe, South Africa, Australia, Canada	France
Lithium	AMG Lithium Eramet	Brazil Argentina, Chile	Germany Eramet (R&D in France)
Natural graphite	AMG graphites	Sri Lanka	Germany
Neodymium	LKAB Frontier Rare Earths Ltd.	South Africa	Norway(non-EU)

Table 8: Identified links through ownership of a refinery within the European Union with mines outside the EU (cobalt, lithium, natural graphite and neodymium)

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Neodymium

Swedish company LKAB operates a processing plant in Herøya, Norway. In addition, Frontier Rare Earths Ltd owns a rare earth deposit in South Africa and plans to conduct the separation process domestically, further contributing to localized processing capacity.

3.1.3 Changes in location

Imports of cobalt in the European Union

The total quantity of cobalt ores and concentrates, mattes, intermediate products, and chemicals imported into the EU in 2022 is relatively small (50 kt) compared to the global trade (604 kt). Of the imports in the EU, 29 kt are exported from outside the EU, and 21 kt is traded within the EU, see Table 15 in Appendix 8.3.

The largest importing countries in the EU of cobalt ores and concentrates are Spain, the Netherlands, and Italy; the largest importers of cobalt mattes and intermediate products are the Netherlands, Belgium, and Germany; and the largest importers of cobalt chemicals are Finland, the Netherlands, and Germany. Of these countries, Finland has cobalt mines and refineries, while Belgium and the Netherlands have zinc smelters that have produced cobalt. In contrast, Germany and Italy have no reported cobalt mines or refineries. The importing countries can also be entry points in Europe and only trade in cobalt. The Netherlands, Belgium, and Germany have the most significant points in Europe and could therefore serve as main entry points (Rotterdam, Antwerp, and Hamburg).

The largest exporter of cobalt ores and concentrates (of non-EU countries) to the EU is South Africa (0.08 kt), of mattes and other articles, the United States (2 kt), and of chemicals, Namibia (6.8 kt). South Africa has cobalt mines and a cobalt refinery, and the United States has two cobalt mines.

With regards to the import of cobalt waste (cobalt, waste, and scrap), the central importing countries in the EU are (from non-EU countries): the Netherlands, Germany, and Belgium. Belgium and Germany are included in the list of Li-ion battery recyclers (see also Table 13, appendix 8.1).

Imports of lithium in the European Union

The total quantity of lithium ores and concentrates, oxides and hydroxides, and carbonates imported in European countries is relatively small (39 kt) compared to the total trade (404 kt). Of the imports in the EU, 23 kt is exported from non-EU countries, and 16 kt is traded within the EU, see Table 20 in appendix 8.6.

The largest importing countries in the EU of lithium carbonates are Belgium, Germany, and the Netherlands, and of lithium oxides and hydroxides, Poland, Belgium and Sweden see Table 15 in appendix 8.6. Of these countries, Germany plans to launch Europe's first lithium hydroxide refinery (AMG Critical Materials N.V. 2024), Poland and Sweden are manufacturing Li-ion batteries. Poland was globally the second largest exporter of battery packs in 2022 (United Nations Conference on Trade and Development (UNCTAD) 2023). Belgium and Germany are recycling lithium. As discussed in the cobalt case study, Belgium, Germany, and the Netherlands have the largest ports and could therefore serve as entry points in Europe.

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Among non-EU countries, the largest exporters of lithium carbonate are Chile, Argentina, and the United Kingdom. For lithium oxides and hydroxides, the leading exporters are the United States, Russia, and China. Of these countries, Argentina, Chile, China, and the United States possess both lithium mining and refining capacities.

With regards to the imports of lithium waste (waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells, spent primary batteries and spent electric accumulators), the main importing countries in the EU (from non-EU countries) are Germany, Spain and Belgium. Belgium and Germany are included in the list of Li-ion battery recyclers (see also Table 13, appendix 8.1).

Imports of natural graphite in the European Union

In 2022, the EU imported a total of 129.8 kt of natural graphite in various forms—including flake, powder, and other types—from non-EU countries. The main importers of flake and powder natural graphite within the EU were Germany, the Netherlands, and Slovenia, while for other forms, the leading importers were Germany, the Netherlands, and Poland (see also Table 22, Appendix 8.9).

Currently, no significant waste flows of natural graphite from end-of-life batteries are traced, as it remains challenging to distinguish and recover natural from synthetic graphite in spent battery materials. However, with the expected increase in battery recycling volumes, a substantial waste graphite stream is anticipated in the near future.

Imports of rare earth the European Union

In 2022, the EU imported a total of 12.9 kt of rare earth (RE) compounds and 1.2 kt of RE metals from non-EU countries. Intra-EU trade amounted to 12.5 kt of RE compounds and 0.3 kt of RE metals.

The largest importing countries in the EU for RE compounds were France, the Netherlands, and Germany, while for RE metals, the main importers were the Netherlands, Estonia, and Italy (see Table 23 in Appendix 8.10). Germany, Italy and Poland are the top three countries of magnet imports. Among these, only Estonia hosts rare earth separation facilities. France have strategic projects covering different transformation stages including recycling (Solvay, Carester, MagREEsource, Less Common Metals and Orano). Germany is also actively involved in the development of permanent magnets and recycling. As noted in the lithium case study, Germany, the Netherlands, and Belgium have major ports, making them key entry points for strategic materials into Europe (European Commission. 2025; IEA 2024c).

The leading non-EU exporters of rare earth oxides were China, Myanmar, and Malaysia, while the main exporters of rare earth metals were China, Australia, and Vietnam. Among these, China and Malaysia possess both mining and refining capacities for rare earth elements.

In terms of rare earth-containing scrap, the primary EU importers from outside the EU were Germany, France, and Italy. (Chatham House 2024).

3.2 Leverage points in high-risk areas

The previous sections showed how the supply chains of the materials studied in this report, like for many other critical materials, come from various countries, and can even be associated to conditions that can cause harm to human health and the environment, as is the case of cobalt, or to militia-operated activities where human rights may not be protected. It

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is then relevant identify possible exposure to risks to human health, human rights, negative environmental impacts or operations that can be linked to armed conflicts, for example. Several efforts have been made to either guide companies on how to do due their diligence to avoid such risks, which has also resulted in lists of countries where the exposure to these risks may be higher, or more likely. This section reviews some of these initiatives, takes the lists of countries where exposure to risk may be higher and cross checks it the supply chains mapped in the previous section.

The 2011 OECD Due Diligence Guidance and the CAHRAs

The 2011 OECD Due Diligence Guidance introduced a risk-based framework for responsible mineral sourcing (OECD 2025; RAND Europe 2025). The guidance defines "risks" in relation to the potentially adverse impacts of a company's operations, which result from a company's own activities or its relationships with third parties, including suppliers and other entities in the supply chain. The adverse impacts can be both internal and external and include harm to people, reputational damage, or legal liability. Given the nature of mineral extraction activities, trade, and handling, companies face risks in their mineral supply chains, such as indirectly contributing to the fuelling of conflicts. This is why companies need to conduct due diligence. The five steps of the due diligence process proposed by the 2011 OECD Due Diligence Guidance include identifying and assessing risks in the supply chain and designing and implementing a strategy to respond to the identified risks. The guidance also introduces the concept of "conflict-affected and high-risk areas" (CAHRAs). CAHRAs are regions marked by armed conflict, violence, or instability, often involving human rights abuses and legal violations. Sourcing minerals from these areas carries an increased risk of contributing to armed conflict, human rights abuses, and serious breaches of national or international law.

Regulation (EU) 2017/821

Regulation (EU) 2017/821 directly builds on the 2011 OECD Due Diligence Guidance by transposing its standards into EU law: it requires Union importers of tin, tantalum, tungsten, and gold to carry out OECD-style due diligence, with enhanced scrutiny and mitigation measures precisely for supplies originating in CAHRAs (RAND Europe 2025). In doing so, the Regulation ensures that the OECD's voluntary best practices become mandatory obligations for EU operators, breaking the link between mineral trade and conflict in those high-risk areas. The CAHRAs identified for tin, tantalum, tungsten, and gold, together with other countries that mine these materials are represented on the left-side map of Figure 61.

The OECD Environmental Due Diligence in Mineral Supply Chains

In 2023, the OECD introduced the Environmental Due Diligence in Mineral Supply Chains, which guides enterprises on how to identify, prevent, and mitigate environmental risks and adverse impacts across mineral supply chains, while recognizing that both primary and secondary sources are critical to sustainable development and the low-carbon transition (OECD 2025). Artisanal and Small-Scale Mining is also addressed in the guidance, as it can present unique risks, yet avoiding it altogether can worsen conditions.

The adverse impacts encompass a broad range, including climate change, biodiversity loss and degradation, pollution, waste mismanagement, noise, damage to cultural heritage sites and aesthetics, and water depletion. This OECD document proposes a six-step due diligence approach that includes steps such as identifying and assessing adverse impacts, ceasing, preventing, or mitigating adverse impacts, and tracking implementation and results. There are no lists of companies, regions, or countries where the risk of these adverse impacts is

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higher. However, several mining companies provide sustainability reports, which can facilitate the identification of potential leverage points associated with environmental risks.

The FATF "black"and "grey"lists

The Financial Action Task Force (FATF) is an intergovernmental policy-making body established by the G7 in 1989 to set and promote global standards for combating money laundering, terrorist financing and proliferation financing. As part of its activities, the FATF published two sets of lists of jurisdictions with weak measures to combat money laundering and terrorist financing - the "black and grey" lists[4] (Financial Action Task Force 2025b, 2025a). The "black list" corresponds to high-risk jurisdictions subject to a Call for Action, and the "grey list" corresponds to jurisdictions under Increased Monitoring. Both lists are represented on the right-side map of Figure 61.

Methodology for the identification of leverage points associated with "high-risk" areas

The supply chains mapped under MaDiTraCe were compared against the CAHRAs list and the "black and grey" lists from the FATF to identify possible sources of risk in the supply chains of the case study materials. First, the mining and refining countries identified in section 2 are cross-checked with the lists represented in Figure 61. This comparison identifies countries/jurisdictions with mining and refining activities where there is possible exposure to activities linked to the risks that were considered for the lists - armed conflict, violence, or instability, often involving human rights abuses and legal violations, and possible money laundering and terrorist financing.

It should be taken into consideration that no conclusions can be drawn without careful assessment of the activities of the organization itself. Not only is the CAHRAs list used here not developed for the case study materials, it has also been developed regionally, but the analysis presented in this section was made at the country level. It should also be noted that countries can be part of these supply chains but are not part of the supply chains of tin, tantalum, tungsten, or gold, about which no insight can be provided. The left map of Figure 61 identifies countries in the CAHRAs list and countries that mine tin, tantalum, tungsten and gold but are not in the CAHRAs list (3Ts&AU (not in the CAHRAs).

There are 41 countries where the 4 MadiTrace case-study minerals have reserves, are mined, or are refined. Out of these 41 countries, 6 are not part of any of the high-risk areas or part of the tin, tantalum, tungsten, or gold mining countries, meaning that they cannot be evaluated. These countries or territories include Belgium, Norway, Greenland, Sri Lanka, New Caledonia, and Cuba. Sri Lanka mines graphite, while New Caledonia and Cuba make small contributions to the cobalt supply chain.

[4] The FATF lists considered in these report were those published on the 21st of February 2025. The lists are updated frequently and a new lists were already available at the time of completion of this report.

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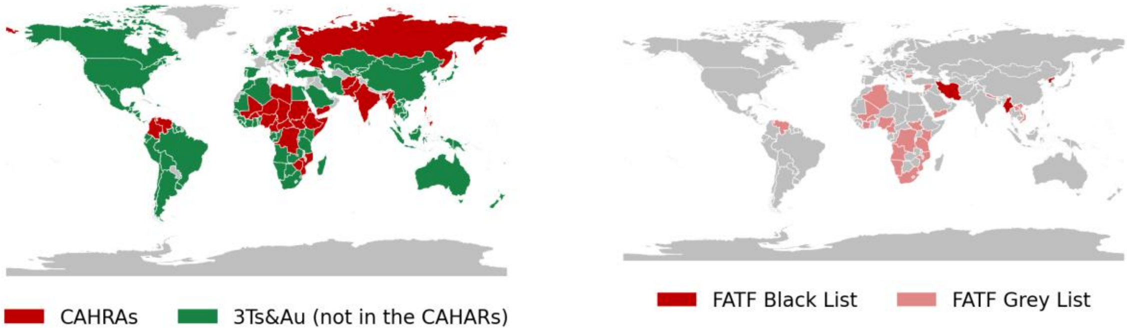

Figure 61: Countries that are in the CAHRAs list and countries that mine tin, tantalum, tungsten and gold (3Ts&Au) but that are not part of the CAHRAs list (left).Countries that are in the FATF's "Black and grey" lists (right).

The second step of the analysis accounts for trade. As shown by the trade of materials in the previous chapter, supply chains can be quite complex. There are production hubs like China which can trade with several different countries or importing/exporting countries with no production like the Netherlands. It is then relevant to assess who imports and exports the materials extracted, processed, or stocked in high-risk countries. In addition to this, secondary importers (importers of high-risk areas) were also assessed to illustrate how the complexity of the supply chains can hinder the identification or tracing of materials with risky provenance.

A classification with levels of risk exposure is proposed in Figure 62 to account for how "distant" a trader is to the source of high-risk areas. As shown in the figure, a country that imports at least one unit of material from a country in one of the considered lists is assigned a risk level of 1. A country that imports at least one unit from a level 1 area is assigned a level 2, and so on. For example, an area that imports two tonnes from a level 1 area and 200 tonnes from a level 3 area is assigned a level 2 classification, and any area that imports from that area will have a level 3 or higher.

The comparison of the CAHRAs and the "black and grey" lists with the supply chains of cobalt, lithium, natural graphite, and neodymium does not provide an exhaustive list of leverage points or a definitive analysis of where the risk is in the supply chain, it shows regions where a more detailed analysis can be relevant and how through trade the origin of a material could be lost if not tracked with solutions such as digital product passports, and proper chain of custody methods.

Figure 62: Proposed risk level classification for evaluation of leverage points in trade flows. The same colors are used for each risk level in all the figures using the classification.

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The following subsections of the section 0 present an illustrative example of the analysis of possible leverage points associated with flows of cobalt ore from countries in CAHRAs and FATF lists, followed by two subsections that present the results of the same analysis for the four case-study elements and some of their intermediate products – one with a focus on possible leverage points in mining and refining countries, and a another one covering other potential leverage points when considering European imports.

3.2.1 Example: leverage points in high-risk areas for cobalt ore

As described in the previous section, the first step of the evaluation of the high-risk ares is the comparison of the countries in the CAHRAs and FATF lists with the mining and refining countries. In this example for cobalt ore, we compare the lists with the list of countries that mined cobalt in 2022, as shown in Figure 4.

Figure 64 shows the countries that are both part of the CAHRAs or FATF lists and that mine cobalt in red, that are not part of the lists and mine tin, tantalum, tungsten, or gold in green, and the ones that mine cobalt but are not part of the lists or and mine tin, tantalum, tungsten or gold, in blue. The comparison of the values in the section 2.1.2.2 with the risk lists, which is illustrated in Figure 64 shows that 75% of the cobalt extracted and documented by S&P Global for 2022, originated in high-risk areas. These areas could present potential leverage points for traceability technology and are: The DRC, Russia, Zimbabwe, South Africa, and the Philippines.

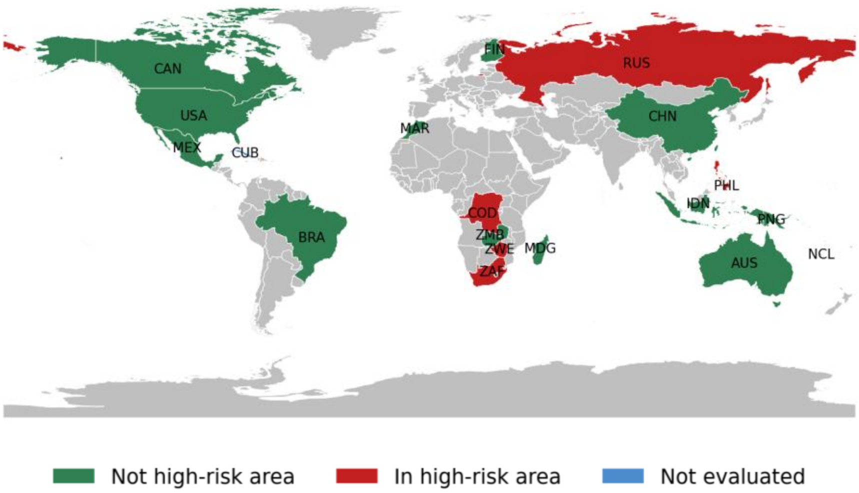

Figure 63: Cobalt extracting countries of 2022 in the CAHRAs and FATF “black and grey” lists

Figure 64 colors countries and flows according to the risk classification in Figure 62. Several countries appear as “no data” in Figure 64 a), those are countries that did not import cobalt ore in 2022, and therefore have no risk level associated. When taking trade into account, Figure 64 a) shows that in addition to the high-risk areas that extract cobalt, others trade it, such as India. To better understand the significance of these flows, the amounts traded are represented in Figure 64 c), which shows that the most significant flow is exported from the DRC into China and Morocco. There are also some relatively significant flows exchanged between European countries (Finland, Austria, Belgium, and France) that have a level 2 assigned, which means that these European countries imported some amount of cobalt ore from countries that sourced it from “high-risk” areas. Finland, for example, imported 1309 tonnes from Austria, 187 tonnes from Germany, 0.155 tonnes from the Netherlands, and

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0.015 tonnes from China, all "Risk level 1" areas according to the BACI HS92 data (Gaulier and Zignago 2010).

Figure 64 b) shows the European imports per country colored according to the risk classification of the exporter, and allows for an analysis of possible EU leverage points. Belgium, Spain, Finland, France, the United Kingdom, Italy, and the Netherlands all import cobalt ore. Spain, in particular, imported the largest amount from a "high-risk" area directly (80.7 tonnes from South Africa), which doesn't necessarily mean that Spain is importing flows linked to ESG risks, but that there is a chance that it is, and should therefore be checked under a more detailed analysis.

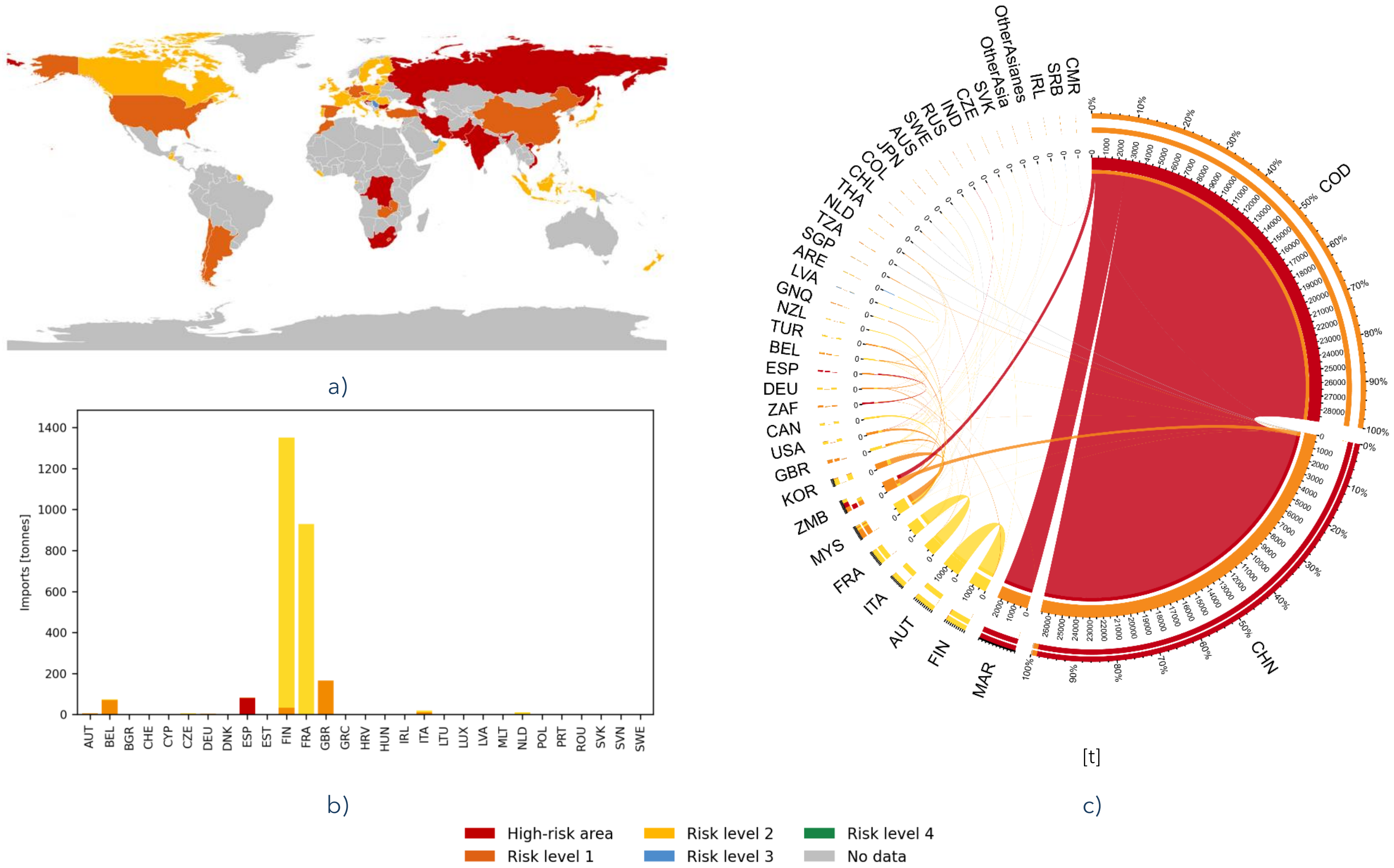

Figure 64: Risk of human rights infringement, or financing of armed conflicts or terrorism linked to the extraction and trade of cobalt ore, based on the supply chain data for 2022, with countries colored according to the proposed risk level classification. a) Global exporters of cobalt ore. b) Imports of cobalt ore into Europe .c) Trade flows between countries.

3.2.2 Leverage points in high-risk areas - transformations in material state and chemical modifications

The countries that are part of the CAHRAs or the FATF "black and grey"lists that have reserves, mine, or refined any of the case study materials in accordance with the data of Chapter 2 are presented in Table 9. European countries and territories like Belgium, Norway and Greenland were included in the list of countries not evaluated as they are not present in any of the considered lists, or in the lists of countries that mine tin, tantalum, tungsten or gold. However, these European countries should not pose any immediate concern compared to other high-risk areas.

The DRC, the Philippines, Russia, Zimbabwe, and South Africa are potential leverage points for cobalt. There were no high-risk areas identified that refine lithium, as the data considered was that of 2022. For another reference year there could be production from Russia, which would then pose as a potential leverage point. Zimbabwe is a potential leverage point for unrefined lithium. Potential leverage points for natural graphite include India, Mozambique, Russia, Dem. P. R. of Korea, Tanzania, Vietnam, and Ukraine. For Neodymium or REOs, potential leverage points are India, Myanmar, Russia, Tanzania, Vietnam, and South Africa.

	CAHRAs	FATF Black List	FATF Grey List	Not evaluated
Cobalt reserves	DRC Philippines Russia		DRC	Cuba
Cobalt extraction	DRC Philippines Russia Zimbabwe		DRC South Africa	Cuba New Caledonia
Refined Cobalt	Russia		South Africa	Belgium Norway
Lithium reserves	Zimbabwe			
Lithium extraction	Zimbabwe			
Refined Lithium				
Natural graphite reserves	India Mozambique Russia	Dem. P.R. of Korea	Mozambique Tanzania	Sri Lanka Norway
Natural graphite extraction	India Mozambique Russia Ukraine	Dem. P.R. of Korea	Mozambique Vietnam	Sri Lanka Norway
Neodymium reserves	India Russia		Tanzania Vietnam South Africa	Greenland
REO production	India Myanmar Russia	Myanmar	Tanzania Vietnam South Africa	Greenland

Table 9: Countries and territories that have reserves, extracted, or refined the case-study materials in 2022 and that are part of the CAHRAs or the FATF lists. Countries that could

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not be evaluated because they are not in the lists or extract tin, tantalum, tungsten or gold, were included in the last column as “Not evaluated”

As mentioned, this analysis does not mean that, for example, all cobalt extracted or refined in the DRC is somehow contributing to armed conflicts or associated with human rights abuses. Umpula and Dummet, (Umpula and Dummett 2024) for example, discuss how small-scale, ‘artisanal’ producers and the government in the DRC are working on a roadmap for ending child labor and improving working conditions, and how engaging in such activities should be prioritized over disengaging altogether from small producers who rely on this industry for their livelihood. The Responsible Minerals Initiative, for example, proposes standards for smelters and refiners that participate in the Responsible Minerals Assurance Process (Responsible Minerals Initiative 2025).

3.2.3 Changes in location

To assess possible European leverage points related to high-risk areas, the trade data previously presented was analyzed, and each trade was classified according to Figure 62 and they is presented in the following chord diagrams. As mentioned, Figure 62 presents a scale for risk exposure, where the level of risk increases with the proximity to the areas considered high-risk (areas in the CAHRAs and the FATF “black and grey” lists). The classification by country is per product, meaning that a country can have different classification for different products.

The schematic chord diagrams of the following figures represent the high-risk area associated with the country in the outer rink, in the color blocks next to the country codes. The flows adjacent to the color blocks represent exports from that country, colored according to the risk classification of the exporting country. The flows with a small white space between the country's color block and the flow are the imported flows. The traded flows of cobalt ores and concentrates are presented again in Figure 65, which, given the description in the previous example of this chapter, should serve to facilitate the interpretation of the diagrams.

It should be noted that, on the one hand, the CAHRAs list was developed for due diligence in the supply chains of tin, tantalum, tungsten, and gold, and has been adapted for use with cobalt, lithium, natural graphite, and neodymium in this report. The list was also developed for regions; however, it is applied at the country level, which may obscure significant regional variations and company-specific practices. Additionally, the lists represent countries where there is a higher risk, indicating that mining and refining activities are not necessarily linked to human rights violations or the financing of armed conflicts and terrorism. The FATF list is also very dynamic and updated frequently, so the identified countries can change from the ones presented here. The analysis highlights points in the supply chain where the risk is higher and where the implementation of traceability technology can facilitate due diligence efforts. While this analysis provides a starting point for identifying leverage points, more granular, site-specific data is essential to avoid overgeneralisation and ensure context-sensitive traceability strategies.

Cobalt

Figure 65 presents the schematic representation of the import flows of cobalt ores and concentrates in 2022. The figure is similar to Figure 64 c), and follows the same coloring

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logic, but here only the imported flows into Europe are represented, and the values were omitted for simplicity, as the focus of the analysis is on the level of risk of the imported flows, their relative significance and their origin. The chords show that the most significant flows of ores traded in Europe were exported by Austria and Italy and imported by Finland and France, respectively.

The flows associated with a higher level of risk were the Spanish imports from South Africa, followed by the imports of the United Kingdom from Zambia, and the exports from Germany to Finland, Belgium and Austria. Both Germany and the Netherlands have a level 1 risk classification, but have no significant flows from high-risk areas visible in the figure, which means that they must import very small shares from the considered high-risk areas.

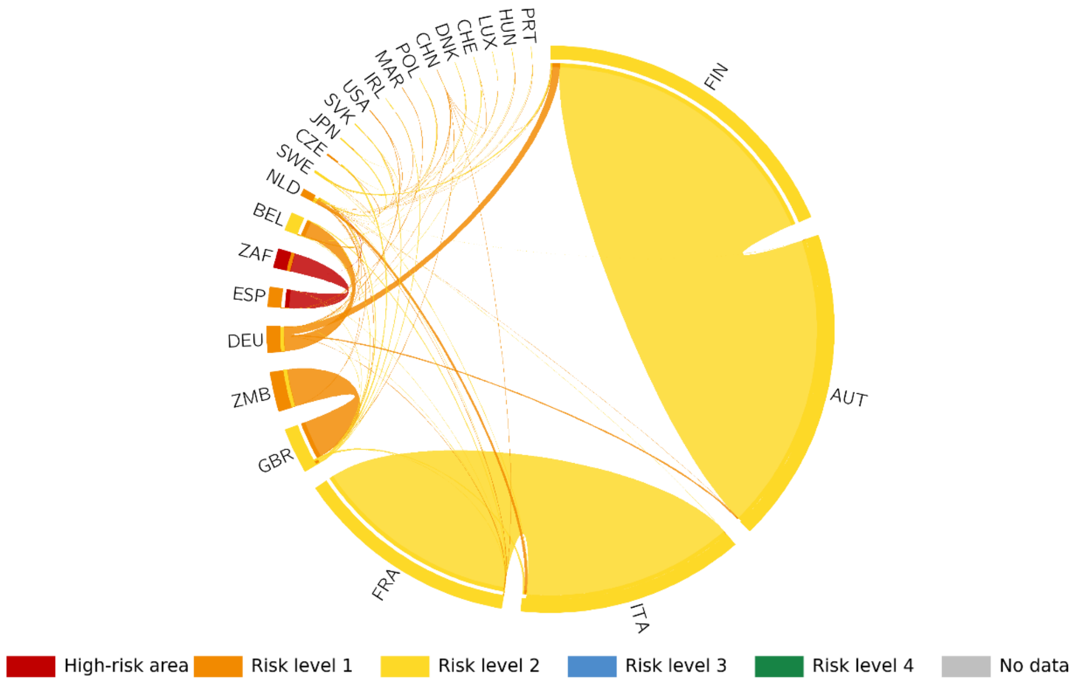

Figure 65: Schematic representation of the European imports of *cobalt ores and concentrates (HS 260500)* in 2022 in a chord diagram. Countries are represented in the outer ring by their risk classification, and flows are colored according to the classification of the exporter.

The imports of the cobalt products illustrated in Figure 66 - mattes and other intermediate products of cobalt metallurgy, unwrought cobalt, waste and scrap, powders (HS 810510) and articles n.e.s. in heading no. 8105 (HS 810590) – show a higher level of complexity than the flows of cobalt ores and concentrates. Most European countries have a level 1 classification attributed, which means that even if the majority of the imported flows have a level 1 classification, these countries are also importing shares, even if relatively small, from high-risk areas.

There are several European countries that both import and export these flows, particularly to other European countries, including the Netherlands, Belgium, Germany, and the United Kingdom. While all of the level 1 countries can be relevant leverage points for traceability technology, The Netherlands, in particular, could represent a strategic option as it imports products from countries of various risk levels outside of Europe, including from high-risk areas (Russia and South Africa), from level 1 areas like China, Germany, or Canada, and

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level 2 areas like Madagascar. It then exports products under the same classification to countries like Belgium, Germany, the United Kingdom, and France. I will schedule some time for us to connect.

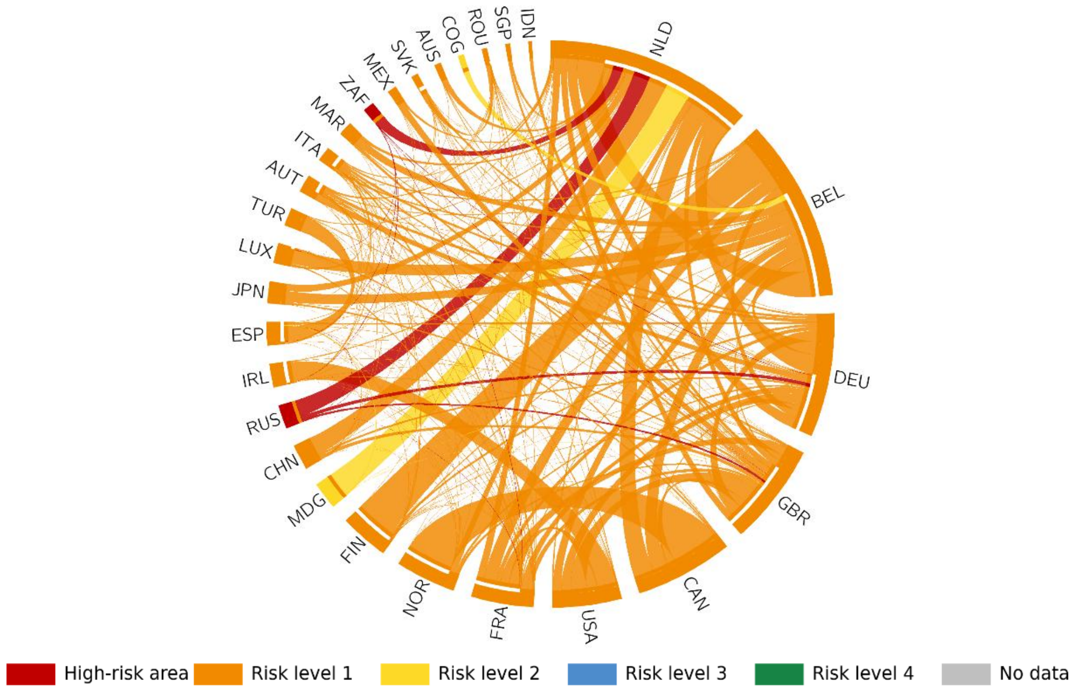

Figure 66: Schematic representation of the European imports of *mattes and other intermediate products of cobalt metallurgy, unwrought cobalt, waste and scrap, powders (HS 810510) and articles n.e.s. in heading no. 8105 (HS 810590)* in 2022 in a chord diagram. Countries are represented in the outer ring by their risk classification, and flows are colored according to the classification of the exporter.

Figure 67 illustrates the trade of three other sets of cobalt products:

- Cobalt: Chlorides: of cobalt' (HS 282734),
- Cobalt oxides and hydroxides: commercial cobalt oxides (HS 282200),
- Acids: saturated acyclic monocarboxylic acids: cobalt acetates (HS 291523).

The flows for these three imported products in Europe show a third different *profile*. For these products, the flows from high-risk areas are pretty significant. Finland imports quite significant amounts from Namibia and South Africa. It then exports to other European countries, including Belgium, Germany, Spain, and the Netherlands. Belgium also exports to other European countries. These materials, which could have been imported originally from high-risk areas into Europe, increase the distance of the flow to its high-risk origin, while still potentially presenting risk. Given these trade dynamics, Finland is a possible strategic leverage point for traceability technology for these cobalt products. Germany is also importing from South Africa, the Netherlands, Namibia, and Switzerland, from a high-risk area – the DRC.

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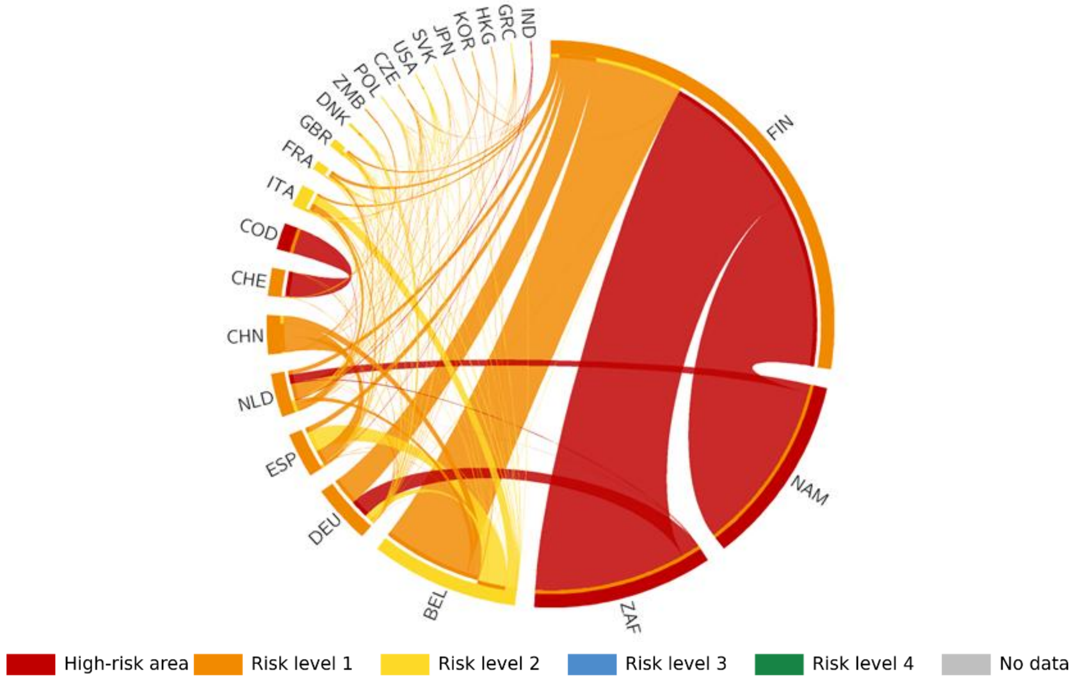

Figure 67: Schematic representation of the European imports of *Chlorides: of cobalt (HS 282734), Cobalt oxides and hydroxides: commercial cobalt oxides (HS 282200) and Acids: saturated acyclic monocarboxylic acids: cobalt acetates (HS 291523)* in 2022 in a chord diagram. Countries are represented in the outer ring by their risk classification, and flows are colored according to the classification of the exporter.

The schematic representation of the imports of cobalt waste and scrap (HS 810530) by European countries can be found in Figure 79. Several European countries trade these flows, with the majority originating from level 1 or level 2 countries. The largest importers are Germany, the Netherlands, the United Kingdom, France, Italy, and Belgium, among others. The United Kingdom and Germany are not only the largest importers, but they also export significantly less than they import. A similar thing can be observed for Belgium, at a smaller scale. This could suggest that these countries valorize this waste by either stocking it or processing it. Several non-European countries also export these flows, such as the USA, Japan, China, Brazil, and Singapore.

The only significant flows from high-risk areas are the imports from India to Belgium, the United Kingdom, Germany, and the Netherlands, with these last two being relatively small. Belgium also imports a significant share from the United Kingdom and Italy, and exports mostly to France, which has a level 2 classification. Given the variety of countries, risk levels, and sources, there are several potential leverage points in Europe for these waste products.

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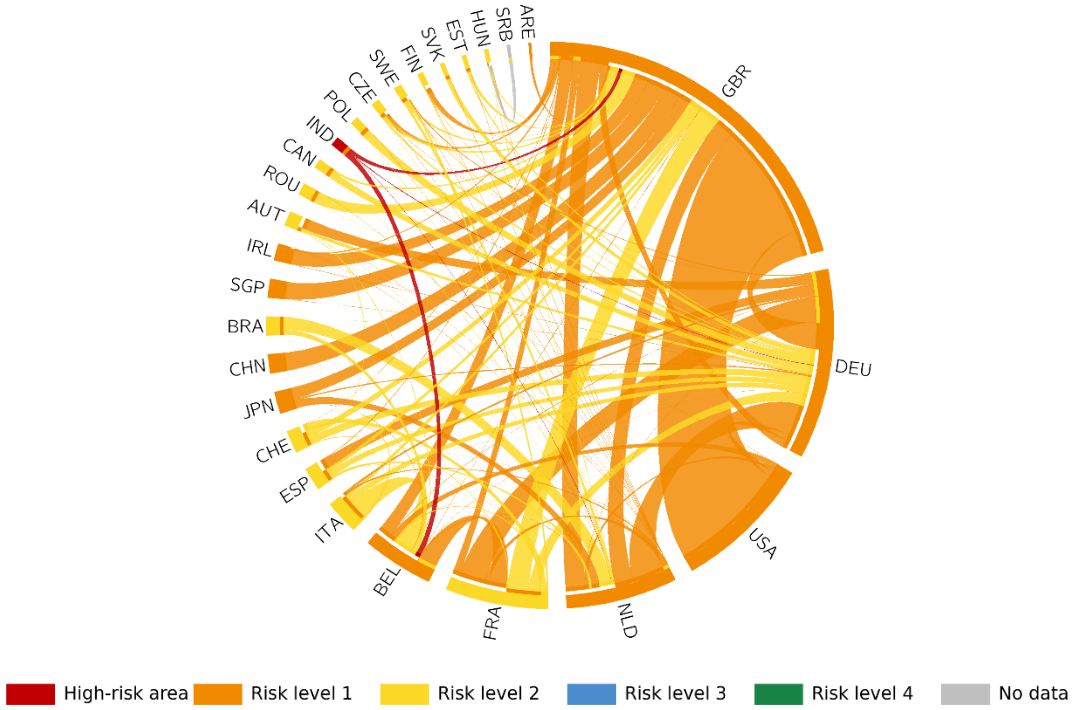

Figure 68: Schematic representation of the European imports of *cobalt waste and scrap (HS 810530)* in 2022 in a chord diagram. Countries are represented in the outer ring by their risk classification, and flows are colored according to the classification of the exporter.

Lithium

The relative imports of lithium oxides and hydroxides (HS 282520) and lithium carbonates (HS 283691) by European countries, identified by their risk level, are represented in Figure 69. The largest exporters to Europe are Chile, the Netherlands, the USA, Russia, and China. Belgium is the leading importer of these lithium intermediate products, followed by Germany, and other smaller importers, like the Netherlands, the United Kingdom, France, Spain, Poland, and Sweden.

Chile, a level 2 risk country, is Europe's top exporter, so some European countries should show a level 3 classification. However, this is not reflected in the figure. The majority of European countries have a level 1 risk, indicating they import from high-risk areas, albeit in small quantities. The leading high-risk area importing to Europe is Russia, which mostly exports to Belgium, the United Kingdom, Poland, and the Netherlands. Zimbabwe is also a high-risk area that exports a relatively small flow to the Czech Republic. Given these flows, Belgium, the Netherlands, the United Kingdom, Poland, and the Czech Republic are all potential relevant leverage points as they import from areas of different risk, including directly from high-risk areas.

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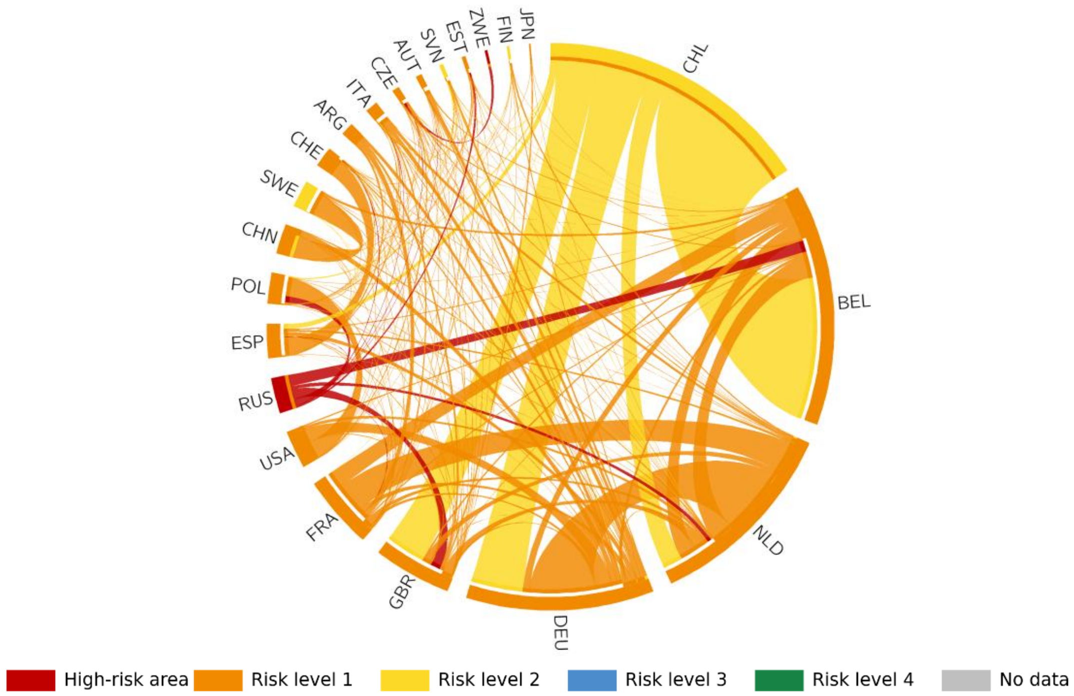

Figure 69: Schematic representation of the European imports of *lithium oxides and hydroxides (HS 282520) and lithium carbonates (HS 283691)* in 2022 in a chord diagram. Countries are represented in the outer ring by their risk classification, and flows are colored according to the classification of the exporter.

Figure 70 illustrates European imports of waste and scrap of primary cells, primary batteries, and electric accumulators; spent primary cells, spent primary batteries, and spent electric accumulators (HS 854810), here referred to as battery-related waste . The figure shows a complex net of imported flows in Europe, with most originating from level 1 and level 2 countries. Most of the flows are imported from other European countries - France and the Netherlands. Both export relatively large amounts to Germany. France also exports to Spain, Belgium, and the United Kingdom, among other countries. The Netherlands, in addition to Germany, also exports significant shares to Belgium and Poland. Germany is the largest importer among European countries, followed by Spain and Belgium.

There are a few high-risk imports of battery-related waste. However, these originate in countries – Bulgaria and Croatia - that are only identified in the FATF "grey" list. These two countries could be potential leverage points, as there are no significant non-European countries closely related to high-risk areas exporting significant flows to Europe. The imports of battery-related waste by European countries, based on 2022 trade data, seem to be very small.

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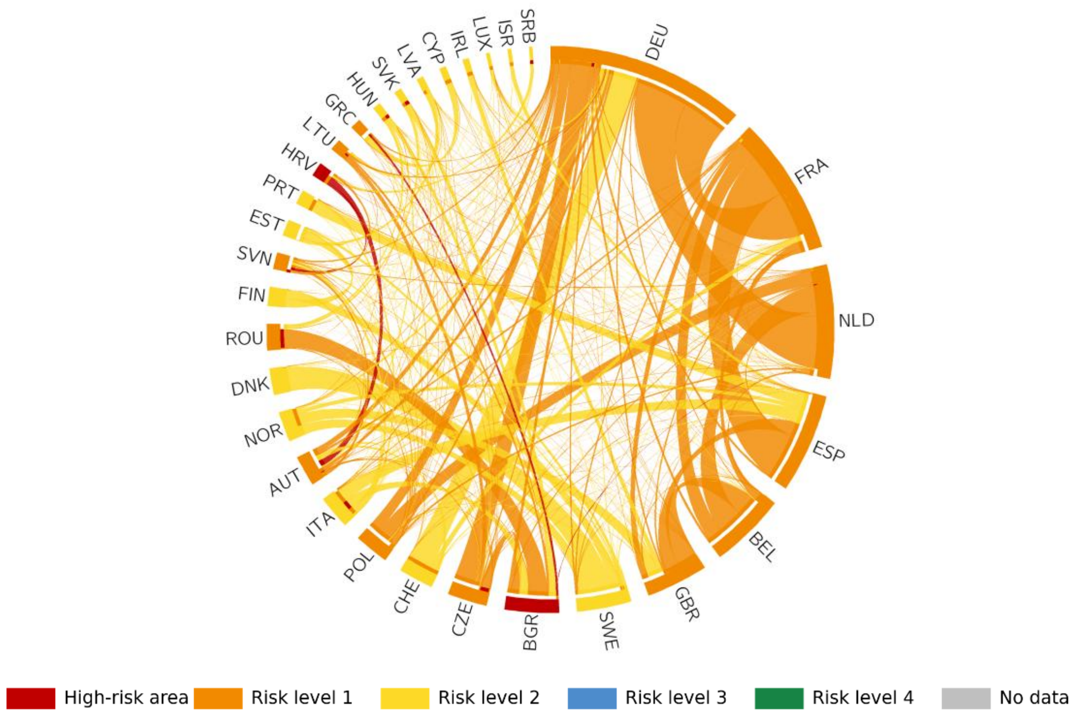

Figure 70: Schematic representation of the European imports of *waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells, spent primary batteries and spent electric accumulators (HS 854810)* in 2022 in a chord diagram. Countries are represented in the outer ring by their risk classification, and flows are colored according to the classification of the exporter.

Natural Graphite

The European imports of natural graphite in powder or in flakes (HS 250410) and in other forms (HS 250490) are schematically represented in Figure 71. Germany, the Netherlands, Austria, Poland, Slovenia, Belgium, the Czech Republic, The United Kingdom, Italy, Spain, France, and Slovakia are all level 1 importers. This means that these countries all import from the only high-risk are exporting to Europe – Mozambique, which is also the leading one. Other non-European exporters to Europe , are China, Madagascar, Brazil, and South Korea. Madagascar has no risk level attributed because it is not a high-risk area, and did not import any of these graphite products in 2022. Norway is also a significant European trader – the country mostly imports and exports with the Netherlands.

Most of the European importers, import from countries of varied risk classifications, hence they could all be potential leverage points. Based on the relative amounts and the level of risk, Germany, and the Netherlands, as well as Austria, Poland, Slovenia, Belgium and the United Kingdom, could be some more strategic choices.

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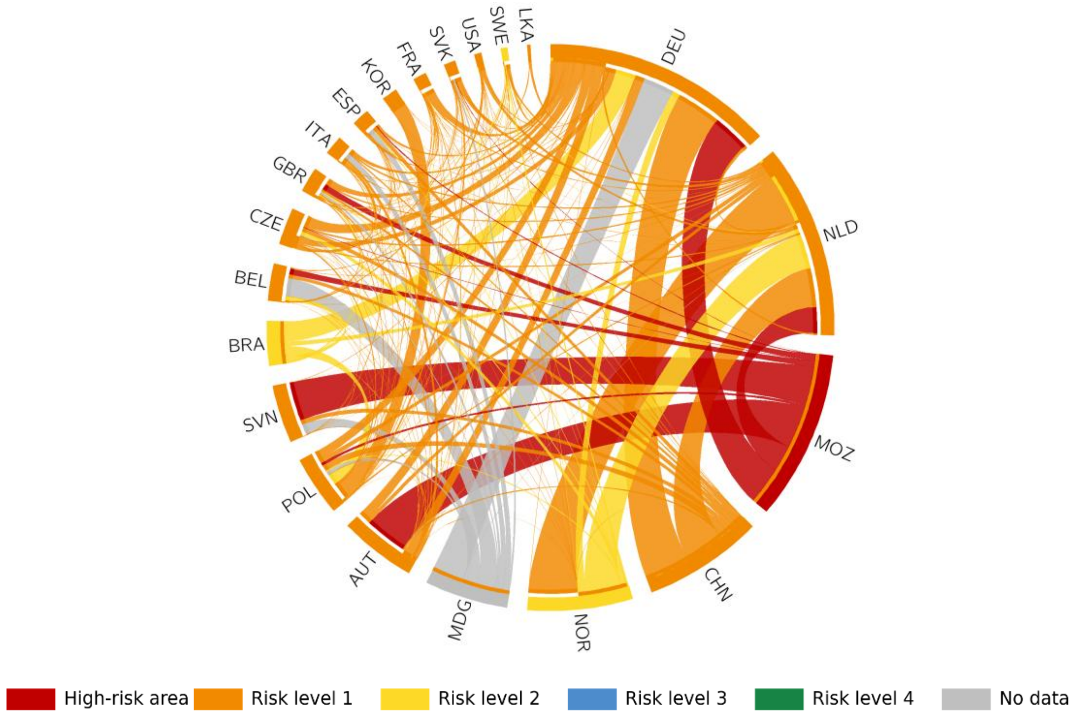

Figure 71: Schematic representation of the European imports of natural graphite in powder or in flakes (HS 250410) and in other forms (HS 250490) in 2022 in a chord diagram. Countries are represented in the outer ring by their risk classification, and flows are colored according to the classification of the exporter.

Rare Earths (Neodymium and others)

There are no HS codes dedicated explicitly to the tracking of Neodymium flows, but there are those for Res. The European imports of REs compounds, inorganic or organic (excluding cerium), of rare-earth metals, of yttrium, scandium, or of mixtures of these metals (HS 284690), referred to as REs compounds for short, are presented in Figure 72. This figure presents a configuration and classification of flows different from the previous ones. Almost all European importers were classified as Risk level 1, as were most of the flows, which also originate in risk level 1 regions: The Netherlands, China, Malaysia, and Japan. The Netherlands, Germany, and France have the level 1 classification due to relatively small flows from India, with Italy being their leading European importer.

The strategy for selecting risk-related leverage points could involve targeting key European importers/exporters, such as the Netherlands, Germany, or France, which import significant quantities from non-European countries. Alternatively, it could involve countries like Italy, where risk exposure is higher. It would also be essential to assess the risks associated with these flows in India.

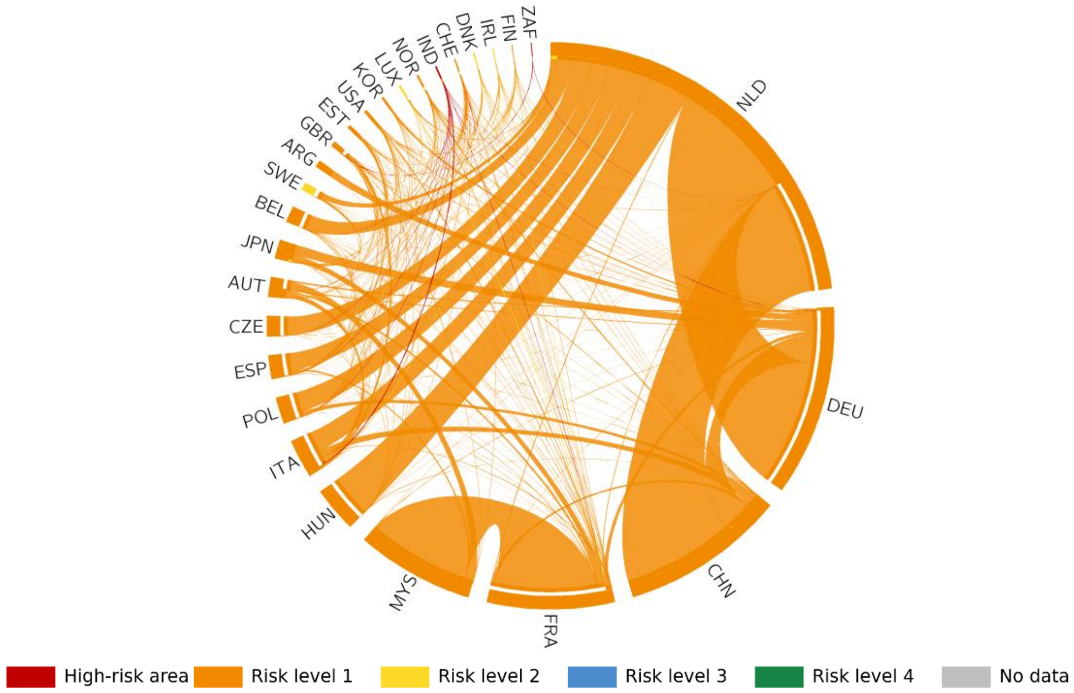

Figure 72: Schematic representation of the European imports of *REs compounds, inorganic or organic (excluding cerium), of rare-earth metals, of yttrium, scandium or of mixtures of these metals (HS 284690)* in 2022 in a chord diagram. Countries are represented in the outer ring by their risk classification, and flows are colored according to the classification of the exporter.

Unlike the flows of the REs compounds, the European flows of Earth-metals, rare: scandium and yttrium, whether or not intermixed or interalloyed (HS 280530), referred to as REs metals for short, present only one very large exporter: China. Most European countries import and do not have significant exports of RE compounds, such as the Netherlands, Norway, Italy, Portugal, the United Kingdom, Germany, and Slovenia, among others. Spain, which imports from China, also exports to Portugal and Austria, and is mainly an exporter.

There is, however, one similar aspect to the imports of RE compounds: there is no major exporter to Europe that is a high-risk area. Yet, countries like the Netherlands, the United Kingdom, and Germany have a level 1 classification. This is attributed to relatively very small imports from Vietnam. Given China's significant role as an exporter to Europe and its level 1 classification, assessing the origin of materials from high-risk areas imported into China could provide a better understanding of the associated risks with European imports. This could be very relevant information in determining the ESG risk-associated strategic leverage points for REs metal imports.

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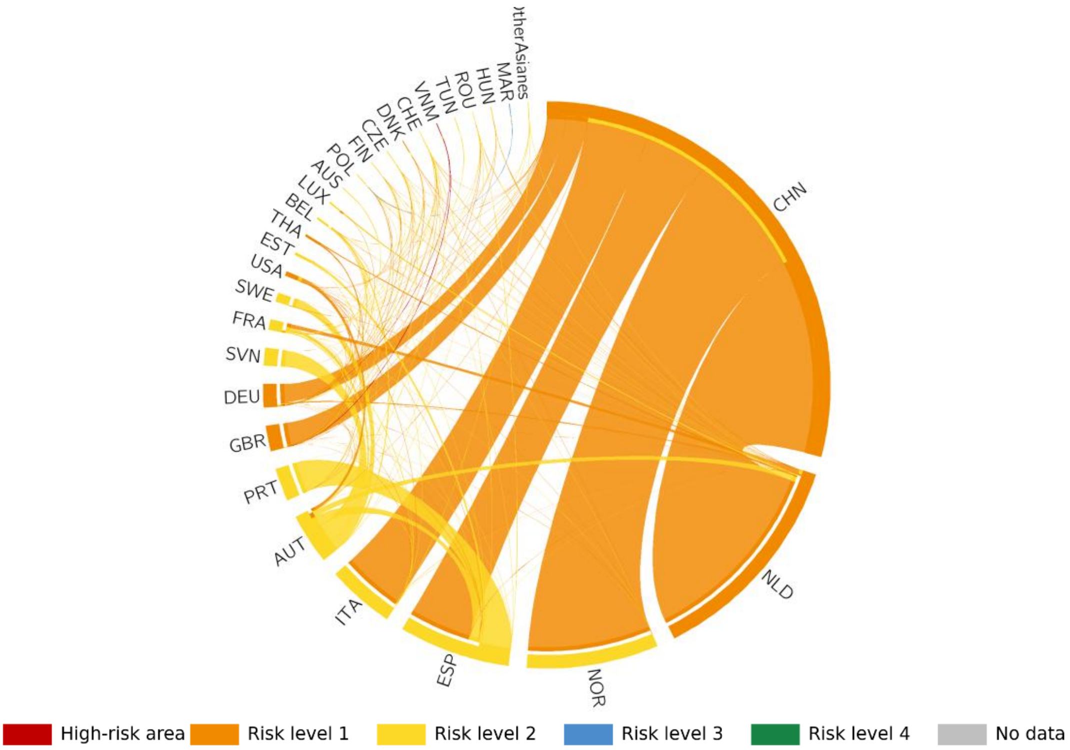

Figure 73: Schematic representation of the European imports of *earth-metals, rare: scandium and yttrium, whether or not intermixed or interalloyed (HS 280530)* in 2022 in a chord diagram. Countries are represented in the outer ring by their risk classification, and flows are colored according to the classification of the exporter.

The schematic representation of the imports of permanent magnets and articles intended to become permanent magnets after magnetisation, of metal (HS 850511), referred to as permanent magnets, in Figure 74 shows that all European importers have a risk-level classification, yet, like for REs metals, most permanent magnets are imported from China. Some smaller shares of permanent magnets are imported from non-European high-risk areas by all European countries. These high-risk areas are India and the Philippines. The most significant high-risk imports are from India to the Czech Republic and Germany, which also have the most significant imports from the Philippines, followed by France. Imports from India by Italy and Poland are also visible in the figure.

The countries with the most significant imports from high-risk areas may be the most strategic leverage points, especially Germany, which imports from two high-risk areas and exports to several other European countries. However, if upon closer analysis, there is no risk associated with the activities of the companies exporting permanent magnets from high-risk areas to Europe, or on the flows originating from China, then the risk associated with permanent magnets could be very small.

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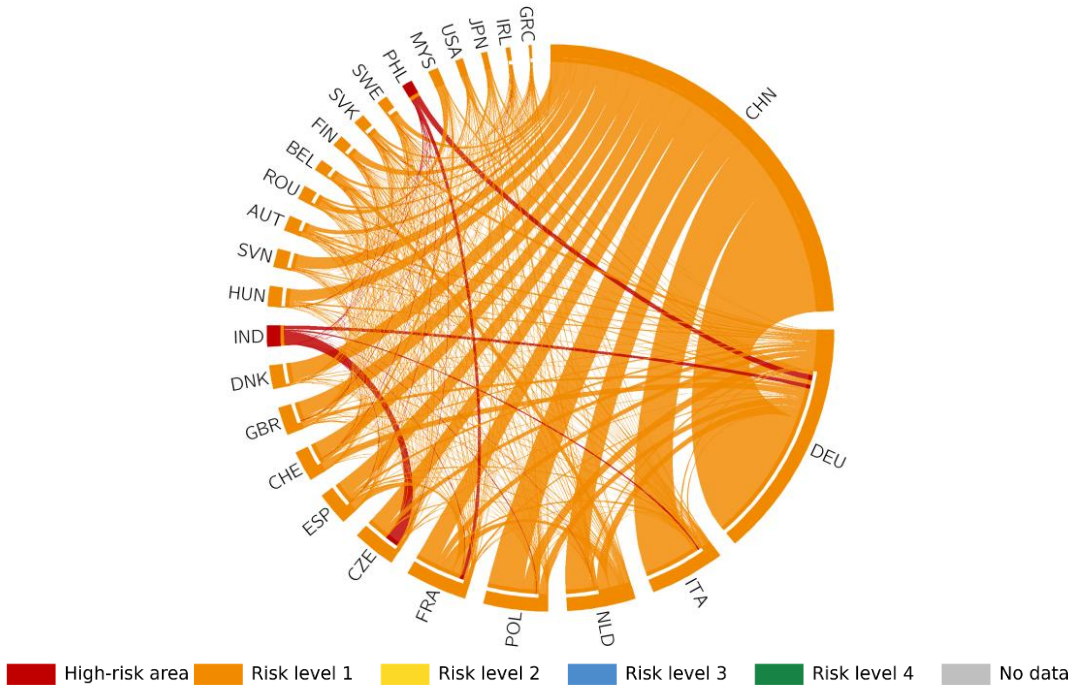

Figure 74: Schematic representation of the European imports of permanent magnets and articles intended to become permanent magnets after magnetisation, of metal (HS 850511) in 2022 in a chord diagram.
Countries are represented in the outer ring by their risk classification, and flows are colored according to the classification of the exporter.

4 Requirements, elicitation, and classification for Digital Product Passport

In this chapter, we focus on the fundamental elements for developing a robust DPP. Building upon the groundwork in previous sections, chapter 4 focuses on requirements, elicitations, and classification for the integration of DPP. Considering supply chain mapping, strategic leverage point identification, and the exploration of CoC models, the endeavor is to define a comprehensive DPP methodology. This methodology should integrate data vocabulary, attributes, and accessibility parameters, ensuring rigorous adherence to the CERA 4in1 standard.

4.1 Data attributes, requirements, and accessibility

An attribute, in the context of DPPs, refers to a specific piece of information or characteristic associated with raw material. At this stage of the Maditrace project, we consolidated an initial set of core attributes considered essential for inclusion in raw material DPPs. This list builds upon earlier exploratory work and has evolved based on stakeholder input, technical assessments, and regulatory alignment.

Data Attributes

Raw Material Passports are essential for transparent and trustworthy data exchange across supply chains, due diligence compliance with regulations, identification of critical and strategic raw materials, supporting circular economy through disclosure of secondary material origin, and enabling data interoperability within European data spaces and ecosystems. The attributes listed below aim to provide the information in the CRM supply chain stages for these use cases:

- Product Information: Product Information contains key identifiers and descriptive attributes that uniquely define the raw material and its specifications. This includes the product name, GTIN (Global Trade Item Number), CAS number, and chemical formula, which ensure global identification and classification. Batch-related data such as the production and expiry dates, as well as the batch number, are essential for traceability and quality control.
- Manufacturer Details: This includes the manufacturer's name, registered address, and contact information, which are critical for accountability, supply chain transparency, and regulatory reporting
- Input composition: The exact composition of the raw material at the entry of a process, including percentages of individual elements or compounds.
- Output composition: The exact composition of the raw material at the output of a process (after being processed), including percentages of individual elements or compounds.
- Material origin: Information about where the material was sourced, including geographic location and mining details.
- Process:
  - Details about how the raw material is processed and transformed into intermediate or final products. These should be provided in alignment with UN Transparency Protocol, i.e., digital traceability events.
  - Environmental impact of the process: Information regarding the environmental consequences of the processing stages, such as energy consumption, emissions, and waste generation.
  - Processing and Logistics: It encompasses the transformation steps and transportation activities the raw material undergoes from extraction to delivery. This includes the physical location of processing facilities, the modes of transport used (e.g., sea freight, road), and classifications such as UN hazard codes that inform safety and regulatory compliance during transit.
  - Certification of the company responsible for the process: Certification and compliance data for the company or entity overseeing the processing stages, ensuring adherence to industry standards and regulations.

Requirements

Specific requirements include:

- Compliance with certification schemes (e.g., CERA 4in1 Standard): DPP should adhere to the CERA 4in1 standard, ensuring that data attributes and reporting formats align with the requirements set forth in this industry-specific standard. More details about CERA 4in1 and other certification standards can be found in Deliverable 1.2 from MaDiTraCe project (Fernández et al. 2024).
- Adherence to European Battery regulation: DPP should fully comply with the European Battery Regulation. Ensuring compliance with this regulation is essential for maintaining legal and environmental standards within the European market.
- Data accuracy: Ensuring that the information included in the DPP is accurate and up to date through regular updates and validation processes.

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- Interoperability: Ensuring that the DPP can be integrated with other systems and databases for seamless data exchange.
- Accessibility: Making DPP accessible to authorized stakeholders within the supply chain while ensuring data security and privacy.

4.2 Data vocabulary

This section provides the vocabulary for describing and categorizing data within the DPP (see Table 10). This helps ensure consistency and clarity in data representation and makes it easier for different stakeholders to understand and use the information.

Term	Definition
Control Methods	Procedures and measures implemented to ensure quality, compliance, and accountability at various stages of the material's journey.
Data Interoperability	Address how data elements will be structured and formatted to ensure interoperability with other systems and standards.
Data Security and Privacy	Outline measures and protocols to ensure data security and privacy, especially when dealing with sensitive information.
Data Usage Permissions	Describe how data access and usage permissions will be managed to control who can view, edit, or share information within the digital material passport system.
Data Validation Criteria	Specify the criteria and rules that will be applied to validate and verify the accuracy and completeness of data within the digital material passport.
Digital Material Passport	A digital record or certificate that provides comprehensive information about the origin, processing, and characteristics of a specific raw material.
Hazardous Substances	Identifies dangerous components with GHS classification, safety data sheets, and handling instructions.
Manufacturer Identification	Manufacturer details including name, trade name, address, and contact details.
Material Identifier	A unique alphanumeric code is assigned to each type of raw material for tracking and identification.
Origin Location	The geographic location (e.g., mining site) where the raw material was extracted.
Physical Properties	Provides technical characteristics such as purity, appearance, melting point, and moisture content.
Processing and Logistics	Describes the processing location, transportation method, and hazard classification for safe and traceable handling.
Product Information	Describes the raw material through name, GTIN, CAS number, chemical formula, batch number, and classification.
Quality Control Checkpoint	A specific point in the supply chain where quality checks are conducted.
Raw Material Sources	Details the original input materials, their countries of origin, and respective suppliers.
Sustainability Metrics	Includes carbon footprint, energy and water usage, recycled content, and waste management practices.
Traceability	The ability to track and trace the movement of raw materials throughout the supply chain, from mining to production.

Table 10. Data vocabulary for DPP methodology.

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4.2.1 Metadata

Metadata plays a pivotal role in providing essential context and comprehensive information about the data within the DPP. Properly curated metadata ensures the accuracy and reliability of the DPP, offering stakeholders a deeper understanding of the product's journey. Here are specific metadata categories vital for enhancing the DPP:

Metadata for Material Composition

- Date of Analysis: This metadata records the date when material composition data was last updated. Keeping this information current is essential for accurately reflecting the most recent analysis results.
- Laboratory Information: Details about the laboratory (i.e., whether a laboratory is certified or not) or the facility that conducted the material analysis are crucial. Including information about the methodology and standards used enhances the credibility of the composition data.

Metadata for Material Origin

- Mining Permit Information: It brings pertinent details related to the mining permits associated with the material source. It includes information about the permit issuance date, the authorized duration, and the regulatory body overseeing the mining activity. This data ensures transparency regarding the legality (according to national legislation) of the materials' origin.
- Environmental Impact Assessment: Assessments of environmental data along the supply chain. This includes evaluations of the site's ecological impact, biodiversity assessments, and any remediation efforts implemented. This metadata provides valuable insights into the environmental sustainability of the material source, enabling informed decisions regarding its usage in products. Methodologically, Life Cycle Assessment (LCA) allows the assessment of the environmental impacts of products and services, from the mining stage to their end of life, including multiple impact categories such as climate change potential, acidification, eutrophication, land use, and biodiversity.

4.3 Compliance with CERA 4in1

With the advent of Regulation (EU) 2023/1542 concerning batteries and waste batteries, attention has shifted to the entire battery supply chain – from mining to recycling – to ensure that the industry abides by the strict environmental and human rights standards. Apart from sustainability, safety and recyclability are also key areas of focus.

One way to ease the achievement of the requirements is by introducing the digital product passport (DPP). Through the DPP, product-related data, such as recycled content, performance, reparability, ESG, etc., can be shared among the supply chain actors. It is mandated that organizations will have to implement a DPP system within less than 2 years from now. Within this short timeframe, they must establish systems capable of generating the necessary ESG and traceability information, among other data.

The CERA 4in1 standard system uniquely addresses ESG and traceability-related concerns across all areas of the supply chain, enabling organizations to remain compliant regardless of their location, the material being handled, or their size. With the requirement of a DPP system by regulation, so far, the CERA Performance Standard Downstream (CPS-II) and the CERA Chain of Custody Standard (CCS) are considering the integration of DPP-related

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information management in the standard development. The objective is to ensure that all the processes and procedures are in place to avoid any gaps that might arise related to product information throughout its lifecycle.

Accordingly, future auditing procedures will include assessments, such as:

Whether the organization is taking the necessary steps to collaborate with their suppliers to obtain the required data.

Whether protocols exist to verify the completeness and reliability of the information.

Whether the training of their employees includes topics related to DPP security and management, etc.

Therefore, considering the changes that will be brought in by the battery regulation, the CPS downstream and CCS have incorporated these aspects in standard development and into the auditing procedures. All the requirements are also designed to align with the commitment, assessment, monitoring, and disclosure (CAMD) structure, which underpins the CERA standards.

Commitment	The organization devises policies, sets objectives, designs strategies, and allocates the necessary resources.
Assessment	The organization implements risk and opportunity management.
Monitoring	The organization must maintain a constant oversight of the efficiency and effectiveness of risk and opportunity management.
Disclosure	The organization must report on the efficiency and effectiveness of risk and opportunity management and strive to constantly improve its performance by integrating stakeholder feedback

Table 11: Overview of the CAMD structure (Nowaz et al. 2025)

Importantly, it is to be noted that compliance with the CERA 4in1 standards does not necessarily verify the accuracy of the data itself. Still, it assesses whether the organization has the capacity to generate this information to be integrated into the DPP.

4.4 Methodology for developing the Digital Product Passport

Considering the data vocabulary, attributes, and parameters (including compliance with CERA 4in1 standard) from sections 4.1 -4.3, this information can be integrated to establish the key aspects of developing a comprehensive methodology for DPP. Identifying the key aspects of a DPP methodology addresses the sub-question four proposed in this report (in Chapter 1), which is: *what are the key prerequisites, procedures, and methodologies needed to establish a digital material passport, ensuring compliance with CERA 4in1 standards through data vocabulary, attributes, and accessibility?*

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In this section, we first describe our methodology to develop a DPP for a certain product segment. As announced by the European Commission, the following product segments are high-ranked and will obtain a DPP under the respective delegated act. Each of those product segments will have different requirements with respect to the reuse, repair, and recycling of products that imply different environmental and social impacts. However, the DPP methodology should be the same for each product segment. Thus, we propose ten key aspects to consider in the development of the DPP methodology for a product segment:

1. Impact Analysis: Identify or reconfirm product-specific negative environmental and social impacts.
2. Mitigation Plan: Identify and describe in detail the countermeasures, procedures, and processes to reduce the negative impact.
3. Data needs: Identify the data that is required to implement and measure the above-mentioned impact as well as countermeasures, procedures, and processes.
4. Value Chain Analysis: Analyse and understand the product-specific value chain with all its actors.
5. Data sources: Identify which actor can provide which (parts of the) data, which is defined in point 3. Furthermore, compliance with regulations requires defining the level of detail for data granularity.
6. Existing IT infrastructure: Identify the existing infrastructure and preferred IT technology stacks, identification schemes, etc. Likewise, it is necessary to assess the data that is currently available and determine what new data needs to be generated.
7. Business needs: Understand the needs of supply chain actors, including their business confidentiality concerns and their preferences for data sharing.
8. Specify the DPP: Define the final DPP content, the sources, and recommendations for DPP.
9. Explore Ecosystem: Identify and engage existing industry stakeholders who are capable of discussing the DPP requirements, sharing best practices, and further developing technical standards.
10. Support Ecosystem: Enable industry consortia (where needed) to interpret the legal text, further develop and maintain the DPP specifications, and establish and enforce industry governance frameworks.

After completing these steps defined in the methodology, DPP implementation occurs by following the steps indicated below:

Stakeholder Onboarding and Agreement Setup: Identify all relevant supply chain participants (e.g., miners, processors, transporters) and formalize collaboration via legal agreements, data-sharing policies, and onboarding procedures.

Establish Digital Identity Infrastructure: Assign each organization and relevant asset a decentralized identifier (DID) to enable verifiable identity. This supports authentication and trust across all DPP interactions.

Define Standardized Data Model: Develop a structured data model containing key attributes related to raw material identity, composition, processing, logistics, sustainability, compliance, and lifecycle events.

Issue Verifiable Credentials: Each stakeholder issues digitally signed credentials containing validated data for their stage of the material's lifecycle. These credentials follow W3C VC standards for interoperability and trust.

Integrate Storage and Data Access Systems: Implement decentralized or hybrid storage solutions to host the DPP data. Enable access via APIs for querying, updating, and verifying credentials.

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Link Digital Passport to Physical Product: Generate a QR code or other machine-readable identifier that connects the physical material or packaging with its digital passport, enabling on-site or downstream access.
Control Access and Data Visibility: Apply access control mechanisms based on roles, permissions, and DIDs to ensure that sensitive data is only available to authorized parties while maintaining transparency where needed.
Monitor and Update DPP Records: Maintain the DPP as a living document. Record changes, updates, and additional credentials as materials move through the supply chain or are reprocessed.
Enable API-Based Interactions: Provide RESTful APIs or integration points (e.g., via Postman collections) for technical teams to create, update, and retrieve DPPs programmatically.
Ensure Regulatory and Conformity Alignment: Validate that all recorded data complies with relevant standards (e.g., EU Battery Regulation, REACH). Build in auditability and reporting mechanisms.

5 State of practices of control methods and tracing solutions

This chapter focuses on the chain of custody (CoC) system, which helps traceability by tracking the journey of materials, using physical or electronic evidence, from the extraction of raw materials to the final product. The evidence is a CoC document or equivalent, which accompanies the material at each stage of the supply chain and contains information regarding the product, supplier and any additional details related to sustainability, like carbon footprint, along with objective evidence. On receiving the materials, they should conduct a thorough assessment and verification of the physical characteristics of the material against those stated in the document.

The tracking is done by implementing CoC models, comprising no-mixing and mixing approaches. No mixing approaches include Identity Preserved (IP) and Segregation models, where the certified materials cannot be mixed with non-certified materials, see Figure 75. Certified materials indicate that the organisation handling them has fulfilled the CoC standard requirements and has received certification against it, and is allowed to make claims based on the CoC model employed. In the case of IP, the controls are comparatively more stringent as they do not allow mixing materials from different certified origins. Such no-mixing models are generally preferred by organisations procuring materials from conflict-affected and high-risk areas (Van den Brink et al. 2019).

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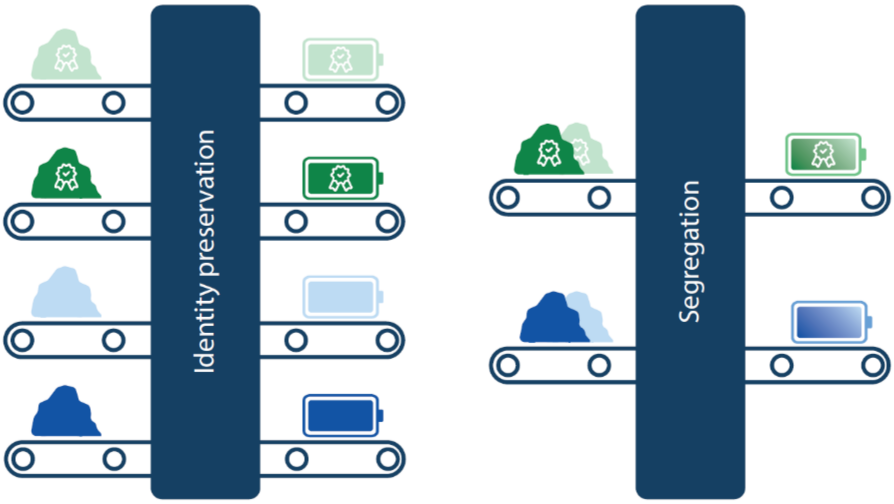

Figure 75: Illustration of the identity preservation and segregation CoC methods.

The controlled blending (CB) and mass balance (MB) models allow the mixing of certified and non-certified materials, see Figure 76. In case of CB, the exact percentage of the certified materials is always determined in inputs and outputs, so the amount of certified materials for the end-product is known. MB is a simpler approach and requires a less demanding infrastructure. The types of MB approaches are the rolling average percentage method and credit allocation. For both approaches, the inputs and outputs should be reconciled within the designated claim period (ISO/DIS 22095 2019). The book and claim model is not strictly a CoC model, as there is no link between the physical flow of the materials and administrative records, see Figure 76. Nonetheless, ISO/ DIS 22095 (2019), ISEAL Alliance (SEAL Alliance 2016) and IRMA CoC Standard(IRMA 2024a) include the book and claim model due to its advantages, such as not having the availability of CoC materials in their supply chain, but are still interested in contributing to responsible sourcing practices or the reduction of carbon footprint by procuring CoC materials sourced from a distant location.

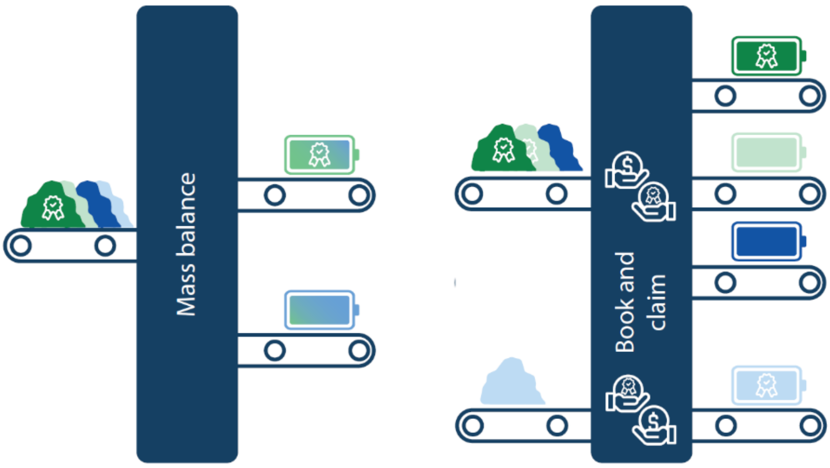

Figure 76: Illustration of the mass balance and book and claim CoC methods.

By implementing these models, the organisation can make claims regarding their product to the subsequent player in the supply chain or the end-consumer. An overview of the type of claims is provided in the Table 12.

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CoC model	Claim type
Identity Preserved	Origin of the material (from mine X)
Segregation	The entire material can be claimed to be certified (100%)
Controlled blending	A certain percentage of the material can be claimed to be certified.
Mass balance	Sustainable sourcing of the percentage of certified material (although the product may or may not contain certified materials)
Book and claim	Claims related to supporting responsible sourcing practices

Table 12: Claims following the CoC model employed (ASI 2022; IRMA 2024b; The Copper Mark 2022)

At each stage of material handling, the administrative records should clearly reflect the status of physical materials, for instance, the amount of raw materials still in storage, processed materials in storage, etc. As they are processed, the conversion factors, change in batch numbers, and other information related to the material modification must be recorded to track the materials and foster traceability. Notably, the organisations must ensure that the certified output does not exceed the quantity of the certified input, considering the conversion factor.

$$Certified\ Output\ \leq Certified\ Input\ \times Conversion\ Factor$$

The CERA CCS standard will include all the critical control points that need to be addressed under the management system prerequisites for the input, handling and output of the materials.

6 Conclusions

The main goal of this deliverable of the MaDiTraCe Project was to map the supply chains of the selected raw materials and use that data to identify leverage points for the traceability technologies. Data attributes, requirements, accessibility, and the data vocabulary for the digital product passport were also covered, as was compliance of the DPP with CER4in1. The report also includes a description of the methodology for developing DPPs and an overview of the state of practices on control methods and tracing solutions.

Chapter 2 focused on the supply chain mapping of the selected raw materials – cobalt, lithium, natural graphite, and neodymium – based on the proposed criteria for leverage point identification – covering transformations in material state (deposits and reserves, extraction, and refining), ownership (mining operators, owner companies, and a network analysis for those materials that had the information available), and location (trade of the ore, refined materials, and waste for the materials for which information was available). Secondary flows were also included depending on available information.

Cobalt, mainly extracted as a by-product of copper in the DRC and refined predominantly in China, is essential for batteries and is expected to face a 190% demand surge by 2030 (IEA 2024a). Artisanal and small-scale mining in the DRC raises significant environmental and human health concerns. However, efforts to address these issues are underway through initiatives from the government, companies, and organizations such as the Fair Cobalt Alliance. A few multinational companies control a large share of the market, and a significant number of organizations are vertically integrated across mining and refining.

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While cobalt recycling is limited, the recycling potential is expected to increase fivefold by 2028. Europe has minimal production capacity and depends heavily on imports, especially of cobalt chemicals—mainly through Finland—making traceability increasingly critical as battery cell manufacturing expands.

Lithium is a strategic resource for the energy transition, given its applications for batteries. Production is highly concentrated in Australia, Chile, and China, with China also dominating processing. Although several EU countries are developing mining and refining capacity, Europe remains reliant on imports and plays a limited role in primary production. A few companies control most of the global supply, like for cobalt, and several organizations are vertically integrated across mining and processing. Europe is involved primarily as an importer and processor, with countries like the Netherlands serving as trade hubs. Recycling is still limited, but EU policies on recovery and recycled content are expected to boost recovery from spent batteries.

Graphite presents unique traceability challenges due to the coexistence of natural and synthetic sources. Demand is expected to triple by 2030 due to the growing use in EVs and energy storage systems. While efforts are underway to diversify production, including projects in Mozambique, Brazil, and Europe, global capacity for battery-grade processing outside of China remains limited. In Europe, domestic supply is projected to grow, with the Nordic countries playing a key role. However, the graphite supply chain faces significant traceability challenges, including limited transparency in processing stages, indistinguishability between natural and synthetic graphite once refined, and a lack of granularity in trade classifications. Ensuring traceability across the graphite value chain requires improved data systems and integration with battery recycling infrastructure.

Neodymium, largely used in NdFeB magnets, is similarly marked by a high degree of concentration in China. Global demand for NdFeB magnets is expected to almost quadruple by 2030, creating a projected supply gap. While Europe holds some resources in Greenland, Norway, and Sweden, these have yet to translate into active production. Europe is focusing on processing and recycling, with several strategic projects underway, remaining heavily dependent on imports of intermediate and final products. Traceability remains a significant challenge due to the complex supply chain coupled with limited data transparency, especially in trade and recycling flows.

Section 3 builds on the supply chain mapping to identify leverage points for traceability technologies in both Europe and high-risk areas, using three main criteria: changes in material state, ownership, and location. Within Europe, extraction and refining sites in Finland, Portugal, and France, and key entry points such as Germany, Belgium, and the Netherlands, offer promising opportunities for data verification and control. These locations are well-suited for verifying DPP data through methods like chemical fingerprinting, though challenges remain, particularly for finished products, whose flows can be challenging to map, as trade data do not well cover them. Europe's growing role in recycling, especially in Germany and Belgium, also offers opportunities for traceability interventions. In high-risk areas, where material extraction activities have been identified as contributing to armed conflicts, terrorism financing, human rights abuses, and money laundering, were also compared with the supply chain mapping, in order to assess where in the supply chains of these materials there could be possible exposure to such risks. The areas considered were those in the CAHRAs and the FATF "black and grey" lists. Despite its limitations, the analysis helped identify parts of the supply chain linked to elevated risks of human rights abuse or financial crime. It showed how risk can spread in complex supply chains. In addition to the risks considered by these lists, it would also be relevant to consider

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environmental and social risks, which could be assessed through the analysis of sustainability reports that some companies publish.

With complex supply chains, where countries can import materials from various sources, the mixing of materials from responsible and irresponsible sources can occur. The analysis in this report revealed that, in all the supply chains of the four materials assessed, there was possible exposure to ESG violations in some part of the supply chain. Hence, all four commodities should be traced. Cobalt is mainly mined in the DRC, including by artisanal miners, posing serious environmental and health risks. Smaller but relevant shares of lithium are extracted in high-risk regions/countries such as Zimbabwe, and certain Chinese companies are flagged due to forced labour practices with Uyghur population (U.S. Department of Homeland Security 2024). The natural graphite supply chain lacks transparency and is sourced from countries flagged by CAHRAs and the FATF. Unregulated operators in China and Myanmar mine a small share of REs, primarily heavy REs extracted from areas under militia control—the quantities of which cannot be reliably assessed here. Trade data shows that even without direct imports from high-risk areas, European countries may still receive materials originating from such regions, especially when sourcing from large refining hubs like China. Material fingerprinting can help verify provenance at the point of entry, but its effectiveness is limited by the widespread use of upstream mixing and mass-balance chain-of-custody methods.

Chapter 4 has outlined the essential data attributes, requirements, and classification systems vital for implementing DPPs for critical raw materials. Building on prior supply chain mapping and leverage point analysis, it establishes a structured methodology aligned with both the CERA 4in1 standard and EU regulatory frameworks. Through the integration of standardized vocabularies, metadata, and a ten-step implementation process, the chapter provides a robust foundation for traceability, interoperability, and sustainability. Collectively, these elements position DPPs as a pivotal tool for enhancing transparency and supporting the responsible management of critical raw materials.

Chapter 5 builds on this data framework by examining practical control methods that enable traceability in real-world supply chains. It reviews different CoC models, ranging from strict segregation to mass balance and book-and-claim, and supports credible traceability claims across supply chains. These models provide operational mechanisms to verify and record material flows, enabling the effective implementation of DPPs in line with regulatory and certification standards.

Ultimately, this deliverable lays a foundation for improving traceability across CRM supply chains through integrated supply chain analysis, the identification of leverage points, and a structured DPP framework aligned with CERA 4in1 and EU policy requirements. Key recommendations include: (1) enhancing data systems, particularly concerning secondary and recycled material flows, (2) strengthening traceability in strategic and high-risk sourcing regions, and (3) advancing standardised, interoperable solutions. Going ahead, the scope of future work should be extended to include additional materials, pilot the real-world implementation of DPPs and reinforce the link between traceability and sustainability goals.

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8 Appendices

8.1 Cobalt (Li-ion battery) recycling companies

Table 13: Li-ion battery recycling companies, locations and their established and planned capacity (Input lithium-ion batteries/ scrap).

Company	Country	Capacity (tonnes/ year)	Source	Type	Status
Accurec	Germany (Krefeld)	4000	(Baum et al. 2022)	Pyro/hydro combo	Established
Akkuser	Finland (Nivala)	4000	(Baum et al. 2022)	Pyro/hydro combo	Established
Anhua Taisen Recycling Technology Co. Ltd	China	37200	(S&P 2018)	Unknown	Established
Brunp Recycling Technologies	China (Hunan)	100000	(Baum et al. 2022)	Pyro/hydro combo	Established
Dowa Eco-System	Japan (Tsuruga)	6500	(Baum et al. 2022)	Pyro	Established
Envirostream	Australia (Melbourne)	3000	(Baum et al. 2022)	Preprocessing	Established
GEM Co Ltd.	China (Jingmen)	30000	(Baum et al. 2022)	Hydro	Established
Glencore	Switzerland (Baar)	3000	(Baum et al. 2022)	Pyro/hydro combo	Established
Guanghua Sci-Tech	China (Guangdong)	12000	(Baum et al. 2022)	Preprocessing	Established
Inmetco	United States (Elwood, PA)	6000	(Baum et al. 2022)	Pyro	Established
International Metals Reclamation Company LLC (INMETCO)	United States (Elwood City)	6000	(Esmen 2023)	Unknown	Established
JX Nippon Mining	Japan (Tsuruga)	5000	(Baum et al. 2022)	Pyro/hydro combo	Established

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Company	Country	Capacity (tonnes/ year)	Source	Type	Status
Li-Cycle	United States (Rochester, NY)	5000	(Baum et al. 2022)	Hydro	Established
Li-Cycle	Canada (Kingston, ON)	5000	(Baum et al. 2022)	Hydro	Established
Li-cycle Corp	Germany	30000	(Li-Cycle 2023)	Unknown	Established
Lithium Australia, Envirostream	Australia	3000	(Livium Ltd 2023)	Unknown	Established
Quzhou Huayou	China (Quzhou)	40000	(Baum et al. 2022)	Pyro	Established
Recupyl	France (Grenoble)	110	(Baum et al. 2022)	Hydro	Established
Redux recycling owned by Redwood	Germany (Offenbach)	10000	(Recyling Today 2023)	Pyro	Established
Retriev (Toxco)	Canada (Trail, BC)	4500	(Baum et al. 2022)	Hydro	Established
Sumitomo/Sony	Japan (Namie)	150	(Baum et al. 2022)	Pyro	Established
SungEel HiTech	South Korea (Gunsan)	8000	(Baum et al. 2022)	Hydro	Established
Taisen	China (Hunan)	6000	(Baum et al. 2022)	Hydro	Established
Umicore	Belgium	7000	(Recycling Today 2022)	Pyro/hydro combo	Established
Valdi	France (Commentry)	20000	(Baum et al. 2022)	Pyro	Established
Fortum	Germany (Kirchardt), Finland (Harjavalta)	3000	(Fortum 2023)	Unknown	Established and planned (200000 tonnes)
SNAM (Societe Nouvelle d'Affinage des Metaux)	France	1000	(Intersolar 2023)	Unknown	Established and Planned (5000 tonnes)
SK Tes	Locations in Singapore, France and China	15000	(SK tes 2023)	Unknown	Established and planned (to

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Company	Country	Capacity (tonnes/ year)	Source	Type	Status
					expand to 40000 tonnes)
ABT	United States (Fernley, NV)	20000	(Baum et al. 2022)	Unknown	Planned
Aquametals	United States	50000	(Aqua Metals 2023)	Unknown	Planned
Fenix	Whitehall, UK	10000	(Baum et al. 2022)	Hydro	Planned
Ganfeng Li	Sonora, MX		(Baum et al. 2022)	Unknown	Planned
Gotion High-Tech	China (Hefei)		(Baum et al. 2022)	Unknown	Planned
Green Li-ion	Singapore		(Baum et al. 2022)	Unknown	Planned
Li-Cycle	United States (Gilbert, AZ)	10000	(Baum et al. 2022)	Hydro	Planned
Li-Cycle	United States (Tuscaloosa, AL)	10000	(Baum et al. 2022)	Hydro	Planned
Northvolt	Norway (Frederikstad)	8000	(Baum et al. 2022)	Unknown	Planned
Posco Hy Clean Metal	South Korea (Gwangyan)	12000	(Baum et al. 2022)	Unknown	Planned
Tesla	China (Shanghai)		(Baum et al. 2022)	Unknown	Planned
Total established		374460			
Total planned		365000			
Total future production		739460			

8.2 Cobalt List of abbreviations network analysis

Table 14: Abbreviations (abbr.) of countries (COU), companies (Com), mines and smelters or refineries (SoR) in network analysis

Type	Name	Abbr.	Type	Name	Abbr.	Type	Name	Abbr.
Com	Glencore plc	Glencore	Com	Scully Royalty Ltd.	Scully	Mine	South Kambalda	South
Com	Eurasian Group LLP	Eurasian	Com	Scully Royalty Ltd.	Scully	Mine	Sudbury Operations	Sudbury
Com	CMOC Group Limited	CMOC	Com	Severonickel Mining and Metallurgical Complex	Severonickel	Mine	Taganito	Taganito
Com	Gécamines SA	Gécamines	Com	Shanghai Decent Investment (Group) Co., Ltd.	Shanghai	Mine	Tenke Fungurume	Tenke
Com	Zhejiang Huayou Cobalt Co., Ltd	Zhejiang	Com	Shenzhen Zhongjin Lingnan Nonfemet Co. Ltd.	Shenzhen	Mine	Terrafame	Terrafame
Com	Public Joint Stock Company Mining and Metallurgical Company Norilsk Nickel	Public	Com	Societe Miniere du Sud Pacifique SA	Societe	Mine	Trojan	Trojan
Com	China Nonferrous Mining Corporation Limited	China	Com	Solway Investment Group Limited	Solway	Mine	Tulaergen	Tulaergen
Com	Groupe Forrest International S.A.	Groupe	Com	Trafigura Group Pte. Ltd.	Trafigura	Mine	Voisey's Bay	Voisey's
Com	Shalina Resources Ltd	Shalina	Com	Trafigura Group Pte. Ltd.	Trafigura	Mine	Yuanjiang	Yuanjiang m
Com	Jinchuan Group International Resources Co. Ltd	Jinchuan	Com	Umicore SA	Umicore	Mine	Zimplats	Zimplats
Com	Norin Mining (Hong Kong) Limited	Norin	Com	Unnamed Owner	Unnamed	Mine	Piaui	Piaui

Type	Name	Abbr.	Type	Name	Abbr.	Type	Name	Abbr.
Com	JinChuan Group Co.,Ltd	JinChuan	Com	Unnamed Owner	Unnamed	SoR	Codemin Smelter	Codemin
Com	Nickel Asia Corporation	Nickel	Com	Votorantim S.A.	Votorantim	SoR	Barro Alto Smelter	Barro
Com	Prony Resources New Caledonia consortium	Prony	COU	Australia	AUS	SoR	Kolwesi Smelter	Kolwesi
Com	Zijin Mining Group Company Limited	Zijin	COU	Brazil	BRA	SoR	Canmine Refinery	Canmine
Com	Managem S.A.	Managem	COU	Canada	CAN	SoR	Usoke Plant	Usoke
Com	Sumitomo Corporation	Sumitomo	COU	China	CHN	SoR	Kwinana Refinery	Kwinana
Com	Metallurgical Corporation of China Ltd.	Metallurgical	COU	Cuba	CUB	SoR	Greater Cobalt Refinery	Greater cobalt
Com	General Nickel Company S.A.	General	COU	Dem. Rep. Congo	DRC	SoR	Ipilan Refinery	Ipilan
Com	Sherritt International Corporation	Sherritt	COU	Finland	FIN	SoR	First Cobalt Refinery	First Cobalt
Com	Vale S.A.	Vale	COU	Indonesia	IDN	SoR	Yarwun HPAL Refinery	Yarwun
Com	Pacific Metals Co., Ltd.	Pacific	COU	Madagascar	MDG	SoR	Falcondo Smelter	Falcondo
Com	Terrafame Oy	Terrafame Oy	COU	Mexico	MEX	SoR	Sable Refinery	Sable
Com	BHP Group Limited	BHP	COU	Morocco	MAR	SoR	TTL Plant	TTL
Com	First Quantum Minerals Ltd.	First	COU	New Caledonia	NCL	SoR	Pomalaa Smelter	Pomalaa
Com	IGO Limited	IGO	COU	Papua New Guinea	PNG	SoR	Blue Sparking Plant	Blue
Com	Eurasian Resources Group S.à r.l.	Eurasian	COU	Philippines	PHL	SoR	Halmahera Persada Lygend Plant	Halmahera
Com	PT Vale Indonesia Tbk	PT	COU	Russia	RUS	SoR	Indotama HPAL Plant	Indotama
Com	Jervois Global Limited	Jervois	COU	South Africa	ZAF	SoR	Gebe Industry Plant	Gebe

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Type	Name	Abbr.	Type	Name	Abbr.	Type	Name	Abbr.
Com	Korean Consortium	Korean	COU	USA	USA	SoR	Refining Shop and Nickel Electrolysis Shop Plant	Refining
Com	Boliden AB (publ)	Boliden	COU	Zambia	ZMB	SoR	Talnakh Concentrator	Talnakh
Com	Lundin Mining Corporation	Lundin	COU	Zimbabwe	ZWE	SoR	Ufaleynickel Refinery	Ufaleynickel
Com	Vedanta Incorporated	Vedanta	COU	Dominican Republic	DOM	SoR	Townsville Refinery	Townsville
Com	Cubaniquel	Cubaniquel	COU	Uganda	UGA	SoR	Yabulu Refinery	Yabulu
Com	Xinjiang Xinxin Mining	Xinjiang	COU	Guatemala	GTM	SoR	Kasese Plant	Kasese
Com	African Rainbow Minerals Limited	African	COU	Netherlands	NLD	SoR	Kasese Refinery	Kasese
Com	POSCO Holdings Inc.	POSCO	COU	Norway	NOR	SoR	Monchegorsk Refinery	Monchegorsk
Com	Ji Lin Ji En Nickel Industry Co., Ltd.	Ji	COU	India	IND	SoR	Excelsior Plant	Excelsior
Com	JiuQuan Iron and Steel (Group) Co.,Ltd	JiuQuan	Mine	Alex	Alex	SoR	Danxia Smelter	Danxia
Com	Panoramic Resources Limited	Panoramic	Mine	Ambatovy	Ambatovy	SoR	Koniambo Smelter	Koniambo
Com	Appian Capital Advisory LLP	Appian	Mine	Avebury	Avebury	SoR	Exmibal Smelter	Exmibal
Com	Nickel 28 Capital Corp.	Nickel	Mine	Boleo	Boleo	SoR	Balen/Overpelt Smelter	Balen
Com	Wyloo Pty Ltd	Wyloo	Mine	Bou-Azzer	Bou-azzer	SoR	Budel Dorplein Refinery	Budel
Com	China State-Owned Mining Enterprise	China	Mine	Chambishi	Chambishi	SoR	Kokkola Refinery	Kokkola

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Type	Name	Abbr.	Type	Name	Abbr.	Type	Name	Abbr.
Com	Bindura Nickel Corporation Limited	Bindura	Mine	Deerni	Deerni	SoR	Springs Refinery	Springs
Com	ERAMET S.A.	ERAMET	Mine	Eagle	Eagle	SoR	Ndola Smelter	Ndola
Com	Impala Platinum Holdings Limited	Impala	Mine	East Yellow Mountain	East	SoR	Tocantins HPAL Refinery	Tocantins
Com	Societe de Participation Miniere du Sud Caledonia SAS	Societe	Mine	Etoile	Etoile	SoR	Kambalda Concentrator	Kambalda
Com	Mineral Resources Development Corp	Mineral	Mine	Forrestania	Forrestania	SoR	Bindura Smelter	Bindura
Com	Société Territoriale Calédonienne de Participation Industrielle	Société	Mine	Goro	Goro	SoR	Lualaba Smelter	Lualaba
Com	Sojitz Corporation	Sojitz	Mine	Huachin	Huachin	SoR	Chambishi Smelter	Chambishi
Com	Sibanye Stillwater Limited	Sibanye	Mine	Idaho Cobalt Operations	Idaho	SoR	Sonic Bay Plant	Sonic
Com	Yuanjiang Nickel	Yuanjiang	Mine	Impala Bafokeng	Impala	SoR	Weda Bay Plant	Weda
Com	Zimplats Holdings Limited	Zimplats H	Mine	Jinchuan	Jinchuan	SoR	Chambishi Refinery	Chambishi
Com	Huachin SPRL	Huachin	Mine	Kalatongke	Kalatongke	SoR	Gecamines Refinery	Gecamines
Com	Camrova Resources Inc.	Camrova	Mine	Kambove	Kambove	SoR	Lubumbashi Refinery	Lubumbashi
Com	Nippon Steel Nisshin Co., Ltd.	Nippon	Mine	Kamoto	Kamoto	SoR	Nikkelverk Refinery	Nikkelverk
Com	Mallee Resources Limited	Mallee	Mine	Kevitsa	Kevitsa	SoR	Murrin Murrin Refinery	Murrin
Com	Brazilian Nickel Plc	Brazilian	Mine	Kola Division	Kola	SoR	Sudbury Smelter	Sudbury
Com	Korea Mine Rehabilitation and Mineral Resources Corporation	Korea	Mine	Kolwezi	Kolwezi	SoR	Luilu Refinery	Luilu

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Type	Name	Abbr.	Type	Name	Abbr.	Type	Name	Abbr.
Com	Moa Nickel S.A.	Moa	Mine	Lubumbashi Slag Hill	Lubumbash i	SoR	Nkana Refinery	Nkana
Com	Rio Tuba Nickel Mining Corporation	Rio	Mine	Luiswishi	Luiswishi	SoR	Nkana Smelter	Nkana
Com	Sino-Platinum Metals Co.,Ltd	Sino	Mine	Manitoba Division	Manitoba	SoR	Impala Refinery	Impala
Com	Taganito Mining Corporation	Taganito	Mine	Maslovskoe	Maslovskoe	SoR	Kokkola Refinery	Kokkola
Com	Anglo American Brasil Limitada (Codemin)	Anglo	Mine	Metalkol RTR	Metalkol	SoR	Sao Miguel Paulista Refinery	Sao
Com	Anglo American plc	Anglo	Mine	Mimosa	Mimosa	SoR	Jinchuan Refinery	Jinchuan
Com	AuKing Mining Limited	AuKing	Mine	Moa Bay	Moa	SoR	Jinchuan Smelter	Jinchuan
Com	Blue Earth Refineries Inc.	Blue	Mine	Murrin Murrin	Murrin	SoR	Marrakesh Refinery	Marrakesh
Com	Chemaf SPRL (Shalina Resources)	Chemaf	Mine	Mutanda	Mutanda	SoR	Basamuk Plant	Basamuk
Com	Cobalt Blue Holdings Limited	Cobalt blue	Mine	Nchanga	Nchanga	SoR	Hachinohe Smelter	Hachinohe
Com	Cobalt One Limited	Cobalt one	Mine	Nickel West	Nickel	SoR	Goro HPAL Plant	Goro
Com	DMCI Holdings, Inc.	DMCI	Mine	Nkomati	Nkomati	SoR	Fort Saskatchewan Refinery	Fort
Com	Electra Battery Materials Corporation	Electra	Mine	Nova-Bollinger	Nova	SoR	Ernesto Guevara HPAL Refinery	Ernesto
Com	Gladstone Pacific Nickel Ltd.	Gladstone	Mine	Ontario Division	Ontario	SoR	Sandouville Refinery	Sandouville
Com	Global Special Opportunities Ltd.	Global	Mine	Polar Division	Polar	SoR	Ambatovy Refinery	Ambatovy
Com	Jubilee Metals Group PLC	Jubilee	Mine	Pumpi	Pumpi	SoR	Niihama Refinery	Niihama
Com	Nord Precious Metals Mining Inc.	Nord	Mine	Punta Gorda	Punta	SoR	Coral Bay HPAL Plant	Coral

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Type	Name	Abbr.	Type	Name	Abbr.	Type	Name	Abbr.
Com	PT Aneka Tambang Tbk	PT Aneka	Mine	Raglan	Raglan	SoR	Taganito HPAL Plant	Taganito
Com	PT Harum Energy Tbk	PT Harum	Mine	Ramu	Ramu	SoR	Talvivaara Plant	Talvivaara
Com	PT Trimegah Bangun Persada Tbk	Trimegah	Mine	Ravensthorpe	Ravensthorpe	SoR	Copper Cliff Refinery	Copper
Com	PT. Ceria Nugraha Indotama	PT Ceria	Mine	Rio Tuba	Rio	SoR	Long Harbour Refinery	Long
Com	Pt. Gebe Industry Nickel	Pt Gebe	Mine	Ruashi	Ruashi	SoR	Port Colborne Refinery	Port
Com	Public Joint Stock Company Mining and Metallurgical Company Norilsk Nickel	Norilsk Nickel	Mine	Santa Rita	Santa	SoR	Nicomet Plant	Nicomet
Com	Public Joint Stock Company Mining and Metallurgical Company Norilsk Nickel	Norilsk Nickel	Mine	Savannah	Savannah	SoR	Nchanga Smelter	Nchanga
Com	Public Joint Stock Company Ufaleynickel	Ufaleynickel	Mine	Sichuan La-La	Sichuan	SoR	Fukang Smelter	Fukang
Com	QPM Energy Limited	QPM	Mine	SLN	SLN	SoR	Zhejiang Plant	Zhejiang
Com	Queensland Nickel Pty Ltd.	Queensland	Mine	Sorowako	Sorowako	SoR	HNC HPAL Smelter	HNC

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8.3 Cobalt imports in the European Union

Table 15: Cobalt imports in the European Union

	Countries in the EU exporting within the EU	Total import (tonnes)	Countries outside the EU exporting to the EU	Total import (tonnes)
Cobalt ores and concentrates	Austria, Belgium, Bulgaria, Croatia, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, The Netherlands	2375	Canada, Chile, China, Democratic Republic of The Congo, Hong Kong, China, India, Japan, Korea, Morocco, Philippines, South Africa, Switzerland, Turkey, Ukraine, United Kingdom, USA, Zambia	113
Cobalt: mattes and other intermediate products of cobalt metallurgy, unwrought cobalt, waste and scrap, powders	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, The Netherlands	11320	Albania, Argentina, Australia, Bosnia Herzegovina, Brazil, Cambodia, Canada, China, China, Macao Special Administrative Region, Colombia, Congo, Costa Rica, Hong Kong, China, India, Israel, Japan, Kazakhstan, Kenya, Korea, Kyrgyzstan, Madagascar, Malaysia, Mexico, Montenegro, Morocco, New Zealand, Norway, Svalbard and Jan Mayen, Oman, Peru, Philippines, Republic of Moldova, Russia, Saudi Arabia, Serbia, Singapore, South Africa, Sri Lanka, Switzerland, Thailand, Tunisia, Turkey, Uganda, Ukraine, United Arab Emirates, United Kingdom, USA, Venezuela, Vietnam, Zambia	14124
Cobalt oxides and hydroxides: commercial cobalt oxides	Austria,Belgium,Bulgaria,Croatia,Cyprus,Czechia,Denmark,Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, The Netherlands	7045	Australia ,Brazil, Canada, China, Democratic Republic of the Congo, Hong Kong, China, India, Japan, Korea, Mexico, Namibia, Norway, Svalbard and Jan Mayen, Russia, Singapore, South Africa, Switzerland, Thailand, Turkey, United Kingdom, USA, Zambia	14706

	Countries in the EU exporting within the EU	Total import (tonnes)	Countries outside the EU exporting to the EU	Total import (tonnes)
Cobalt; waste and scrap	Austria,Belgium,Bulgaria,Cyprus,Czechia,Denmark,Estonia,Finland, France, Germany, Greece, Hungary, Ireland ,Italy, Latvia, Lithuania, Malta, Poland, Portugal ,Romania, Slovakia, Slovenia, Spain, Sweden, The Netherlands	866	Brazil,Canada,China,Colombia,India,Israel,Japan,Kazakhstan,Kyrgyzstan,New Zealand, Oman, Serbia, Singapore, South Africa, Switzerland, Thailand, Ukraine, United Kingdom, USA, Venezuela	632

8.4 Lithium mines and deposits

Table 16. Conversion factor to lithium carbon equivalent. Based on (British Geological Survey 2016)

Lithium compound	Chemical formula	Conversion factor to LCE
Lithium	Li	5.323
Lithium oxide	Li2O	2.473
Lithium carbonate	Li2CO3	1
Lithium chloride	LiCL	0.871
Lithium hydroxide monohydrate	LiOH.H2O	0.880
Butyllithium	C4HgLi	0.576

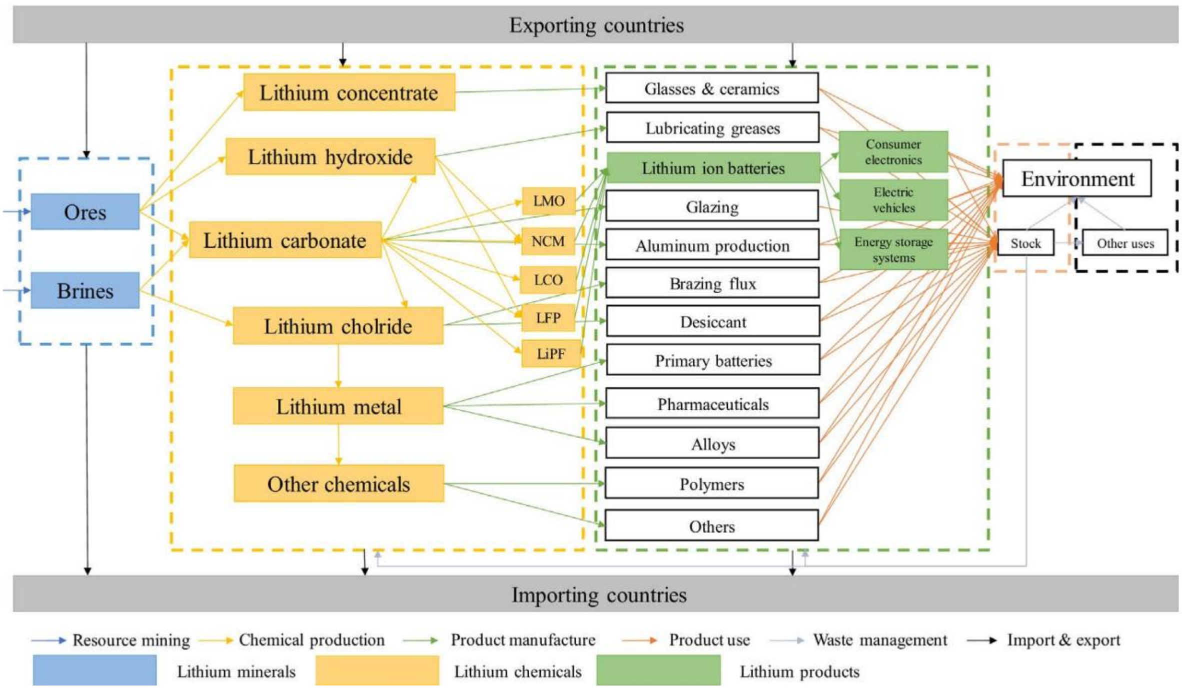

Figure 77: Lithium flows and product throughout the lithium life cycle (abbreviations LMO = Lithium Manganese Oxide, NCM = lithium Nickel, Cobalt, Manganese oxide, LCO = Lithium Cobalt Oxide, LFP = Lithium Iron Phosphate, LiPF =Lithium hexafluorophosphate) (Sun et al. 2017)

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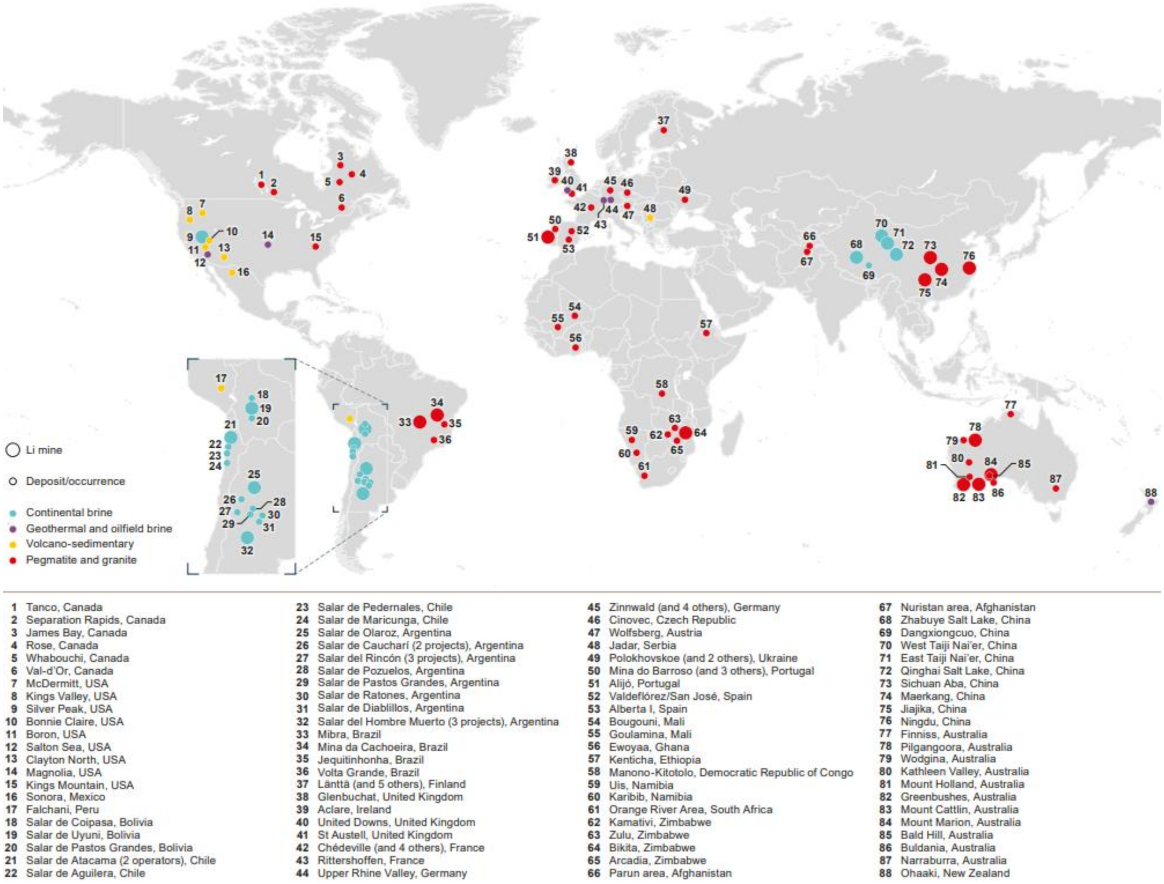

Figure 78: Global lithium mines, deposits and occurrences (Shaw 2021).

Table 17: Lithium reserves and resources (USGS 2024)

	Resources (tonnes)	Reserves (tonnes)
Chile	11000000	9300000
Australia	8700000	6200000
Argentina	22000000	3600000
China	6800000	3000000
Canada	3000000	930000
Brazil	800000	390000
Zimbabwe	690000	310000
Portugal	270000	60000
Bolivia	23000000	
Germany	3800000	
DRC	3000000	
Mexico	1700000	
Czechia	1300000	
Serbia	1200000	
Peru	1000000	

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	Resources (tonnes)	Reserves (tonnes)
Russia	1000000	
Mali	890000	
Spain	320000	
Namibia	230000	
Ghana	200000	
Finland	68000	
Austria	60000	
Kazakhstan	50000	
Other countries		2800000
USA		1100000

Table 18: Lithium projects 2022, country, production and operators/owner companies. The mines are ranked by production from highest to lowest.

Mine (project)	Abbreviation used for Figure	Country	Operator/owner company	References
Greenbushes	Greenbushes	Australia	Talison Lithium (Operator), Albemarle (49%), IGO (25%), Tianqi Lithium (26,01%)	(Albemarle 2024a; IGO 2024; S&P Capital IQ 2024a; Talison Lithium 2021)
Salar de atacama (del Carmen)	Atacama (DC) M	Chile	Sociedad química y minera de chile s.a (100%)	(S&P Capital IQ 2024a; SQM 2023)
Pilgangoora	Pilgangoora	Australia	Pilbara minerals (100%)	(Mining 2024; Pilbara Minerals 2021; S&P Capital IQ 2024a)
Mount Marion	Mt Marion	Australia	Mineral Resources Ltd. (50%), Jiangxi Ganfeng Lithium Co. Ltd (50%)	(Ganfeng Lithium 2020; S&P Capital IQ 2024a)
Salar de atacama	Atacama M	Chile	Albemarle (100%)	(Albemarle 2024a) (S&P Capital IQ 2024a)
Chaerhan	Chaer M	China	Qinghai Salt Lake Industry Co., Ltd. (100%)	(Qinghai Salt Lake Industry Co. Ltd. 2024; S&P Capital IQ 2024a; Wood Mackenzie 2024)
Wodgina	Wodgina	Australia	Albemarle (50%), Mineral Resources Ltd. (50%)	(Albemarle 2023a, 2024a; S&P Capital IQ 2024a)
Salar Del Hombre Muerto	Hombre M	Argentina	Minera del Altiplano S.A. (MdA) (operator), Arcadium Lithium (100%)	(S&P Capital IQ 2024a)(Arcadium Lithium 2024)
Yichun Tantalum Niobium Mine	Yichun T M	China	Ningxia Non-Ferrous Metals (Operator), Yichun Tantalum Niobium Mine Co., Ltd. (Jiangxi	(Asian Metal 2024; S&P Capital IQ 2024a)

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Mine (project)	Abbreviation used for Figure	Country	Operator/owner company	References
			Tungsten Industry holding Group Co., Ltd.,) (100%)	
Mt Cattlin	Mt Cattlin	Australia	Arcadium Lithium (merger of Allkem and Livent) (100%)	(Arcadium Lithium 2024; S&P Capital IQ 2024a)
Salar de Olaroz	Olarez M	Argentina	Orocobre Limited (australia) (operator), Arcadium Lithium (66.5%), Toyota Tsusho Corp. (25%), Jujuy Energia y Mineria Sociedad del Estado (8.5%)	(S&P Capital IQ 2024a; Toyota Tsusho Corporation 2021)
Mibra	Mibra	Brazil	AMG Brasil. S.A. (Operator), AMG Critical Materials N.V. (100%)	(AMG Brasil 2024; AMG Lithium 2023; S&P Capital IQ 2024a)
Bikita	Bikita	Zimbabwe	Bikita Minerals (Private) Limited (operator), Sinomine Resource Grp Co Ltd (74%), Tantalum Mining Corporation of Canada Limited (26%)	(Sinomine Resource Group Co. Ltd. 2021a; S&P Capital IQ 2024a)
Cauchari-Olaroz	C-Olarez M	Argentina	Minera Exar (operator), Ganfeng Lithium (46.67%), Lithium Americas (Argentina (44.8%), Jujuy Energia y Mineria Sociedad del Estado (8.5%)	(Ganfeng Lithium 2020; Lithium Argentina 2024a; S&P Capital IQ 2024a)
East Taijinair	E-Taji M	China	Qinghai East Taijinair Lithium Resources Co. Ltd (Operator), Western Mining Group Co. Ltld. (operator/owner*)	(S&P Capital IQ 2024a; USGS 2024)
Altura	Altura	Australia	Pilbara minerals (100%)	(Pilbara Minerals 2021; S&P Capital IQ 2024a)
Qarhan lake	Qarhan M	China	Golmud Zangge Lithium Co., Ltd. (Operator), Zangger Mining Co. Ltd. (100%)	(S&P Capital IQ 2024a; ZGM 2024)
Silver Peak mine	Silver M	United States	Albemarle	(Carbon Credits 2024; S&P Capital IQ 2024a)
Jiajika	Jiajika	China	Youngy Invt Hldg Grp Co.Ltd. (Operator), YoungyCo (100%)	(Reuters 2020; S&P Capital IQ 2024a)
Yiliping (Qinghai)	Yiliping M	China	China MinMetals Corp. (51%), Ganfeng Lithium (49%)	(Ganfeng Lithium 2020; S&P Capital IQ 2024a; S&P Global 2021)

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Mine (project)	Abbreviation used for Figure	Country	Operator/owner company	References
Pastos Grandes	Pastos G M	Argentina	Lithium Argentina (Operator), Lithium Americas Corp. (100%)	(Lithium Argentina 2024b; S&P Capital IQ 2024a)
West Tajinai Lake	W-Taji M	China	Qinghai Hengxin Rong Lithium Technology Co., Ltd. (100%)	SMM (2021)(S&P Capital IQ 2024a)
Zhabuye	Zhabuye M	China	Tibet Xigaze Zhabuye Lithium High-Tech Co (80%), Tianqi Lithium (20%), Tibet Mineral Dev. Co. LTD* BYD Co*	(China Daily 2010; S&P Capital IQ 2024a)
Tanco	Tanco	Canada	Tantalum Mining Corporation of Canada Limited (Operator), Sinomine Resource Grp Co Ltd (100%)	(Sinomine Resource Group Co. Ltd. 2021b, 2021b; S&P Capital IQ 2024a)
West Tajinair	Not included	China	Unknown	(S&P Capital IQ 2024a)
Sal de los Angelos	Angelos M	Argentina	NextView New Energy Lion HK (Operator), Revotech Asia Ltd. (46%), Tibet Summit Resources Co. (46%), Leading Resources Global Ltd. (venturer) (9%)	(S&P Capital IQ 2024a)
Cachoeira	Cachoeira	Brazil	Companhia Brasileira de Lítio (100%)	(S&P Capital IQ 2024a)
Alvarrões	Alvarroes	Portugal	Grupo Mota (100%)	(Lepidico 2018; S&P Capital IQ 2024a)
Jinaier	Jinai M	China	Qinghai Dongtai Jinaier Salt Lake Lithium Resources Co. Ltd. (Operator/owner 100%)	(Asian Metal 2018; S&P Capital IQ 2024a)
Finniss	Finniss	Australia	Core Lithium (100%), Ganfeng Lithium *	(CORE Lithium 2024; Ganfeng Lithium 2020; S&P Capital IQ 2024a; Talison Lithium 2021)

8.5 Lithium production companies

Table 19: Companies: producers and owners of lithium mines and plants and production by shares

Company	Mine Production by shares	Mines and shares	Plant production by shares	Plants and shares	References
Albemarle (ALB)	175884	Greenbushes (49%), Silver Peak (100%), Wodgina (50%), Salar de Atacama (50%)	260000	Kemerton (100%), Kings Mountain (100%), La Negra (100%), Meishan (100%), Langelsheim (100%), New Johnsonville (100%), Silver Peak (100%), Tianyuan (100%, Xinyu/Qinzhou (100%)	(IGO 2024) (Talison Lithium 2021) (Albemarle 2024a) (Albemarle 2024b), (Albemarle 2023b, 2023a, 2024f, 2024c, 2024a, 2024d) (Carbon Credits 2024; Greencarcongress 2022; United States Securities and Exchange Commission 2022)
Sociedad química y minera de chile s.a (SQM)	152500	Salar de Atacama (100%)	152500	Salar de Atacama (100%)	(SQM 2023)
Pilbara minerals (PILM)	84284	Altura (100%), Pilgangoora (100%)	3870	POSCO (18%)	(Mining 2024; Pilbara Minerals 2021) (Reuters 2021; The Korea Economic Daily 2023)
Tianqi lithium Corp (TIAL)	55600	Greenbushes (26.01%), Zhabuye (20%)	90280	Anju Sichuan (100%), Shehong Sichuan (100%), Tongliang Chonqing (100%), Zhangjiagang Jiangsu (0%), Zhabuye (20%), Kwinana (51%)	(IGO 2024) (Albemarle 2024a) (Talison Lithium 2021) (China Daily 2010; Tianqi Lithium 2018)

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Company	Mine Production by shares	Mines and shares	Plant production by shares	Plants and shares	References
IGO	52500	Greenbushes (25%)	23520	Kwinana (49%)	(IGO 2024), (Albemarle 2024a; Talison Lithium 2021)
Arcadium Lithium (ARCL)	44569	Mount Cattlin (100%), Salar de Olaroz (66.5%), Salar del Hombre Muerto (100%)	85370	Bessemer City (100%), Naraha (75%), Olaroz Lithium (66.5%), Rugao and Zheujiang (100%), Salar Del Hombre Muerto (100%)	(Arcadium Lithium 2024) (Livent 2024; Orocobre 2024; Toyota Tsusho Corporation 2021)
Mineral Resources Ltd. (MIR)	38044	Mount Marion (50%), Wodgina (50%)			(Albemarle 2023b, 2024a; Ganfeng Lithium 2020)
Ganfeng Lithium (GANF)	34534	Cauchari-Olaroz (46.67%), Yiliping Qinghai (49%), Mount Marion (50%)	138118	Basic Lithium (100%), Cauchari Olaroz (46.67%), Fengxin Ganfeng (100%), Hebei Ganfeng (100%), Ningdu (100%), Xinyu Ganfeng (100%), Yichun Ganfeng (100%), Yiliping Qinghai (49%)	(Ganfeng Lithium 2020) (Lithium Argentina 2024a) (S&P Global 2021)
QINGHAI SALT LAKE INDUSTRY CO., LTD. (QSLI)	30831	Chaerhan (100%)	39831	Chaerhan (100%)	(Qinghai Salt Lake Industry Co. Ltd. 2024)
Yichun Tantalum Niobium Mine Co., Ltd. (Jiangxi Tungsten Industry holding	14788	Yichun tantalum (100%)		Yichun Solver (0%)	(Asian Metal 2018)

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Company	Mine Production by shares	Mines and shares	Plant production by shares	Plants and shares	References
Group Co., Ltd.,) (YTNM)					
Sinomine Resource Grp Co Ltd (SRG)	12698	Bikita (74%), Tanco (100%)			(Sinomine Resource Group Co. Ltd. 2021a; Tancomine 2022)
AMG Critical Materials N.V. and AMG Brasil. S.A. (AMGB, AMG)	12686	Mibra (100%)	20000	AMG Lithium (100%)	(AMG Brasil 2024; AMG Lithium 2023, 2024; GEA Group 2021)
Western Mining Group Co. Ltld. (WMG)	11942	East Taijinair (100%)	11942	East Tajinair (100%)	(U.S. Geological Survey 2020)
Lithium Americas, Lithium Argentina (LAC,LACA)	11605	Cauchari-Olaroz (44.84% and 44.8%), Pastos Grandes	11600	Cauchari-Olaroz (44.8%), Pastos Grandes (100%)	(Ganfeng Lithium 2020; Lithium Argentina 2024a)
Zangger Mining Co. Ltd. (ZMC)	10537	Qarhan lake (100%)	10537	Qarhan lake (100%)	(ZGM 2024)
Youngy Co, Youngy Invt Hldg Grp Co.Ltd. (YOU)	8160	Jiajika (100%)	4800	Youngy (100%)	(Reuters 2020)
Qinghai Hengxin Rong Lithium Technology Co., Ltd. (QHRL)	5000	West Tajinai Lake (100%)	5000	West Tajinai Lake (100%)	(Shanghai Metals Market 2021)
China MinMetals Corp. (CMMC)	4060	Yiliping Qinghai (51%)	4060	Yiliping Qinghai (51%)	(Ganfeng Lithium 2020; S&P Global 2021)
Tibet Xigaze Zhabuye Lithium	4000	Zhabuye (80%)	4000	Zhabuye (80%)	(China Daily 2010; Tianqi Lithium 2021)

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Company	Mine Production by shares	Mines and shares	Plant production by shares	Plants and shares	References
High-Tech Co					
Toyota Tsusho Corp. (TTC)	3490	Salar de Olaroz (25%)	3490	Olaroz Lithium (25%)	(Toyota Tsusho Corporation 2021) (Arcadium Lithium 2024; Lithium Argentina 2024a)
Tantalum Mining Corporation of Canada Limite (TMCC)	3241	Bikita (26%), Tanco			(Sinomine Resource Group Co. Ltd. 2021b; Tancomine 2022)
Companhia Brasileira de Lítio (CBL)	2210	Cachoeira (100%)	1500	Divisa Alegre (100%)	(Companhia Brasileira de Lítio (CBL) 2024; Global Business Reports (GBR) 2023)
Jujuy Energia y Mineria Sociedad del Estado (JEMS)	2202	Cauchari-Olaroz (8.5%), Salar de Olaroz (8.5%)	2202	Cauchari-Olaroz (8.5%), Olaroz Lithium (8.5%)	(Ganfeng Lithium 2020; Lithium Argentina 2024b; Toyota Tsusho Corporation 2021) (Arcadium Lithium 2024)
Revotech Asia Ltd. (REVA)	1150	Sal de los Angelos (46%)	1150	Sal de los Angelos (46%)	(S&P Global 2023)
Tibet Summit Resources Co. (TSRC)	1125	Sal de los Angelos (45%)	1125	Sal de los Angelos (45%)	(S&P Global 2023)
Grupo Mota (MOTE)	1020	Alvarrões (100%)			(Lepidico 2018)
Qinghai Dongtai Jinaier Salt Lake Lithium Resources Co. Ltd. (QDJS)	1000	Jinaier (100%)	1000	Jinaier (100%)	(Asian Metal 2018)

Company	Mine Production by shares	Mines and shares	Plant production by shares	Plants and shares	References
Core Lithium (CORE)	500	Finniss (100%)			(CORE Lithium 2024; Ganfeng Lithium 2020; Talison Lithium 2021)
Leading Resources Global Ltd. (venturer) (LRG)	225	Sal de los Angelos (9%)	225	Sal de los Angelos (9%)	(S&P Global 2023)
NextView New Energy Lion HK (NVNE)	0	Sal de los Angelos	0	Sal de los Angelos	(S&P Global 2023))
Orocobre Limited (australia) (OROC)	0	Salar de Olaroz	0	Naraha, Olaroz Lithium	(Toyota Tsusho Corporation 2021) (Arcadium Lithium 2024; S&P Global 2023)
Bikita Minerals (Private) Limited (BKM)	0	Bikita			(Sinomine Resource Group Co. Ltd. 2021a)
Golmud Zangge Lithium Co., Ltd. (GZL)	0	Qarhan lake		Qarhan lake (0%)	(ZGM 2024)
Minera del Altiplano S.A. (MDA)	0	Salar Del Hombre Muerto		Salar Del Hombre Muerto (0%)	(Arcadium Lithium 2024)
Minera Exar (MEX)	0	Cauchari-Olaroz		Cauchari-Olaroz	(Ganfeng Lithium 2020) (Lithium Argentina 2024b)
Ningxia Non-Ferrous Metals (NNFM)	0	Yichun Tantalum			(Asian Metal 2024)
Qinghai East Taijinair Lithium Resources Co. Ltd (QETK)	0	East Tajinair			(U.S. Geological Survey 2020)
Talison Lithium (TALL)	0	Greenbushes			(IGO 2024), (Albemarle 2024a; Talison Lithium 2021)

Company	Mine Production by shares	Mines and shares	Plant production by shares	Plants and shares	References
Jiangxi Dongpeng New Material Co. Ltd. (JDNM)			6000	Jiangxi Dongpeng (100%)	(Sinomine Resource Group Co. Ltd. 2021a)
Jiangte Motor (JIAM)			3000	Yichun Silver (100%)	(Jiangte 2024; YiChun Yin Li New Energy Co. 2014)
BYD Co		Zhabuye (0%)	0		(China Daily 2010; Tianqi Lithium 2021)
Tibet Mineral Dev. Co. LTD (TMDC)			0	Zhabuye (0%)	(China Daily 2010; Tianqi Lithium 2021)
POSCO				POSCO (82%)	(Reuters 2021; The Korea Economic Daily 2023)

8.6 Lithium trade flows and imports in the European Union

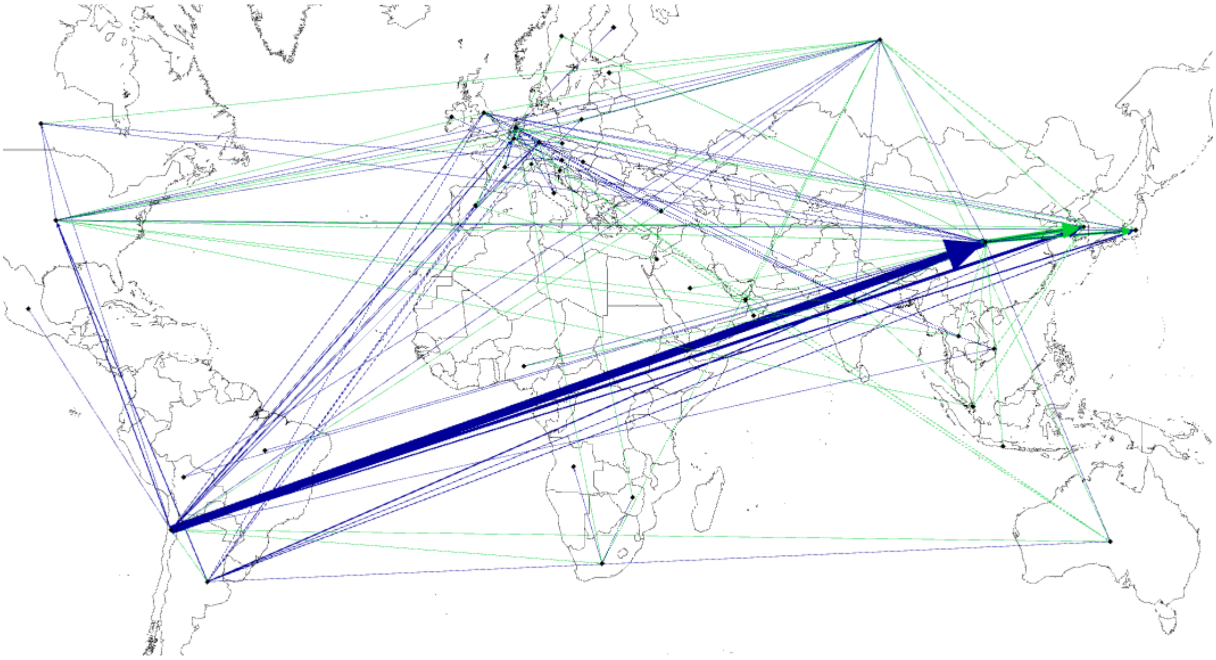

Figure 79: Geographic map Lithium trade flows 2022. HS 282520 (lithium oxides and hydroxides) in green and HS 283691 (lithium carbonates) in blue.

Table 20: Lithium imports in the EU from within the EU and countries (or territories) outside the EU.

	Countries in the EU exporting within the EU	Total import (tonnes)	Countries outside the EU exporting to the EU	Total import (tonnes)
Lithium carbonate	Austria, Belgium, Bulgaria, Cyprus, Czechia, Germany, Denmark, Spain, Estonia, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden	7243	Argentina, Bolivia, Plurinational State of., Brazil, Canada, Switzerland, Chile, China, United Kingdom, Hong Kong, India, Iceland, Japan, Korea, Republic of., Nigeria, Norway, New Zealand, OtherAsianes, Russian Federation, Singapore, Thailand, United States, Viet Nam	15877
Lithium oxides and hydroxides	Austria, Belgium, Bulgaria, Cyprus, Czechia, Germany, Denmark, Spain, Estonia, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden	8729	Australia, Canada, Switzerland, Chile, China, United Kingdom, India, Japan, Korea, Republic of., OtherAsianes, Russian Federation, Singapore, Serbia, Türkiye, United States, Zimbabwe	7520

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	Countries in the EU exporting within the EU	Total import (tonnes)	Countries outside the EU exporting to the EU	Total import (tonnes)
lithium; waste and scrap	Austria, Belgium, Bulgaria, Cyprus, Czechia, Germany, Denmark, Spain, Estonia, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden	360315	Aruba, Andorra, Bosnia and Herzegovina, Canada, Switzerland, China, Colombia, Curaçao, Ethiopia, United Kingdom, Greenland, Hong Kong, Honduras, Indonesia, India, Iceland, Israel, Jordan, Japan, Kyrgyzstan, Kuwait, Liberia, Moldova, Republic of, Mexico, Marshall Islands, Montenegro, Malaysia, Norway, OtherAsia, Philippines, French Polynesia, Russian Federation, Singapore, Serbia, Sao Tome and Principe, Suriname, Sint Maarten (Dutch part), Togo, Thailand, Tunisia, Türkiye, Ukraine, United States	77772

8.7 Natural graphite reserve in 2023

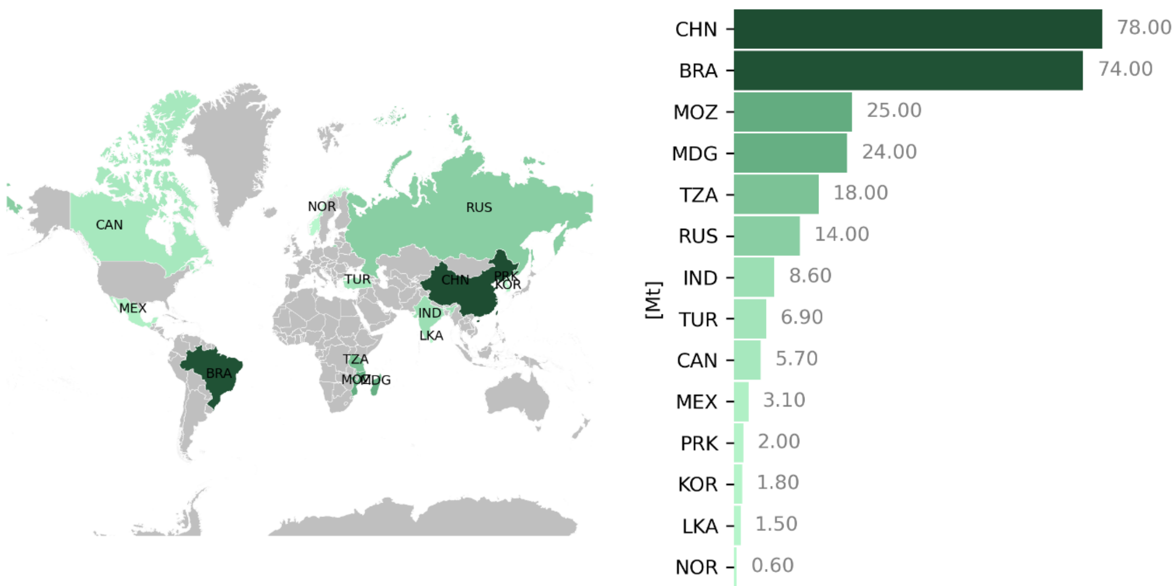

Figure 80: Global natural graphite reserves in 2023 by country.

8.8 Natural graphite content by HS code

Natural graphite commodity	HS code	Estimated percentage of natural graphite	Source
Flakes/powder natural graphite	250410	1	UN Comtrade (UN Comtrade 2024)
Other natural graphite	250490	1	UN Comtrade (UN Comtrade 2024)

Table 21: HS codes natural graphite

8.9 Natural graphite imports in the European Union

	EU to EU (inter-EU)	Total import (tonnes)	Non-EU to EU	Total import (metric tonnes)
Natural graphite (in powder/flack, crystalline)	Austria, Belgium, Bulgaria, Cyprus, Czechia, Germany, Denmark, Spain, Estonia, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden	28159	United Arab Emirates, Australia, Brazil, Canada, Switzerland, China, United Kingdom, Hong Kong, Indonesia, India, Iceland, Japan, Korea, Republic of., Sri Lanka, Morocco, Madagascar, Mexico, Mozambique, Namibia, Nigeria, Norway, OtherAsianes, Russian Federation, Singapore, Thailand, Tunisia, Türkiye, Uganda, Ukraine, United States, South Africa	127797
Natural graphite (other, micronised)	Austria, Belgium, Bulgaria, Czechia, Germany, Denmark, Spain, Estonia, Finland, France, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Netherlands, Poland, Portugal, Romania, Slovenia, Sweden	1648	United Arab Emirates, Australia, Brazil, Canada, Switzerland, China, Colombia, United Kingdom, Indonesia, India, Japan, Kazakhstan, Korea, Republic of., Sri Lanka, Madagascar, Mexico, Mozambique, Norway, OtherAsianes, Pakistan, Philippines, Russian Federation, Türkiye, Ukraine, United States	2029

Table 22: Natural graphite import in the EU

8.10 Rare earth import in the European Union

	EU to EU (inter-EU)	Total import (tonnes)	Non-EU to EU	Total import (tonnes)
Rare earth compounds	Austria, Belgium, Bulgaria, Czechia, Germany, Denmark, Spain, Estonia, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Netherlands, Poland,	12520	United Arab Emirates, Argentina, Australia, Belarus, Canada, Switzerland, China, Colombia, Gabon, United Kingdom, Hong Kong, India, Iran, Islamic Republic of., Israel, Japan, Kazakhstan, Korea, Republic of., North Macedonia, Malaysia, Norway, OtherAsianes, Qatar, Russian Federation, Singapore, Serbia, Thailand, Tunisia, Türkiye, United States, Viet Nam, South Africa	12916

	EU to EU (inter-EU)	Total import (tonnes)	Non-EU to EU	Total import (tonnes)
	Portugal, Romania, Slovakia, Slovenia, Sweden			
Rare earth metal	Austria, Belgium, Czechia, Germany, Denmark, Spain, Estonia, Finland, France, Hungary, Ireland, Italy, Luxembourg, Latvia, Netherlands, Poland, Romania, Slovakia, Sweden	311	Australia, Canada, Switzerland, China, United Kingdom, Hong Kong, India, Israel, Japan, Korea, Republic of., Morocco, OtherAsianes, Thailand, Tunisia, Türkiye, Ukraine, United States, Viet Nam	1224
Permanent magnets	Austria, Belgium, Bulgaria, Cyprus, Czechia, Germany, Denmark, Spain, Estonia, Finland, France, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden	11392	Aruba, United Arab Emirates, Argentina, Armenia, Australia, Azerbaijan, Bahrain, Bosnia and Herzegovina, Belarus, Brazil, Canada, Switzerland, Chile, China, Colombia, Costa Rica, Dominica, Ecuador, Egypt, Ethiopia, United Kingdom, Georgia, Ghana, Guatemala, Hong Kong, Indonesia, India, Iceland, Israel, Japan, Kazakhstan, Kenya, Korea, Republic of., Kuwait, Lebanon, Sri Lanka, Macao, Morocco, Moldova, Republic of., Madagascar, Mexico, North Macedonia, Mali, Myanmar, Mauritius, Malaysia, Nicaragua, Norway, Nepal, New Zealand, Oman, OtherAsianes, Pakistan, Panama, Peru, Philippines, Qatar, Russian Federation, Saudi Arabia, Singapore, Serbia, Thailand, Tunisia, Türkiye, Tuvalu, Tanzania, United Republic of., Ukraine, Uruguay, United States, Uzbekistan, Viet Nam, South Africa	37982

Table 23: Rare earth imports in the EU

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8.11 Lithium processing plants

Table 24: Lithium processing plants, with location, ownership companies, capacity and products.

Processing Plant	Abbreviat-ion	Country of plant/mine	Companies	Capacity /production (LCE Mt)	Notes on production	Lithium Products**	References
AMG Lithium GmbH	AMG Li	Germany	AMG Lithium	20000	Capacity	Hydroxide, sulfidic materials	(AMG Lithium 2024; GEA Group 2021)
Anju Sichuan	Anju S	China	Tianqi lithium	20000	Capacity	Carbonate	(Tianqi Lithium 2018)
Basic lithium plant	Basic Li	China	Ganfeng Lithium	94000	Capacity	Hydroxide, carbonate, chloride, butyl lithium	(AMG Lithium 2024)
Bessemer City	Bessemer	United States	Arcadium Lithium (merger of Allkem and Livent)	15000	Capacity	Lithium hydroxide made of lithium carbonate	(Arcadium Lithium 2024; Livent 2024)
Cauchari-Olaroz plant	C-Olarez P	Argentina	Minera Exar (operator), Ganfeng Lithium (46.67%), Lithium Americas (Argentina (44.8%), Jujuy Energia y Mineria Sociedad del Estado (8.5%)	11942	Based on mine prod.	Carbonate	(Ganfeng Lithium 2020)
Chaerhan plant	Chaer P	China	Qinghai Salt Lake Industry Co., Ltd. (100%)	39831	Based on mine prod.	Carbonate	(Qinghai Salt Lake Industry Co. Ltd. 2024; Wood Mackenzie 2024)
Chemical plant unit Divisa Alegre	Divisa Ale P	Brazil	Companhia Brasileira de Lítio	1,500	Capacity	Carbonate	(Companhia Brasileira de Lítio (CBL) 2024)
East Taijinair plant	E-Taji P	China	Western Mining Group Co. Ltld.	11942	Based on mine prod.	Carbonate	(Qinghai Salt Lake Industry Co. Ltd. 2024; Wood Mackenzie 2024)
Fengxin Ganfeng Renewable Lithium Resources Co., Ltd.	Feng GANF	China	Ganfeng Lithium	640	Capacity	Metal	(Ganfeng Lithium 2020)

Processing Plant	Abbreviat-ion	Country of plant/mine	Companies	Capacity /production (LCE Mt)	Notes on production	Lithium Products**	References
Guangxi Tianyuan New Energy Materials Co., Ltd. (Tianyuan)		China	Albemarle	25000	Capacity	Hydroxide, carbonate	(Albemarle 2024f; Altura Mining Limited 2019)
Hebei Ganfeng	Hebei GANF	China	Ganfeng Lithium	6000	Capacity	Carbonate	(Ganfeng Lithium 2020)
Jiangxi Dongpeng New Material plant	Jiangxi D	China	Jiangxi Dongpeng New Material Co. Ltd. (Sinomine Resource Grp Co Ltd (Owner*)	6000	Capacity	Hydroxide, carbonate, fluoride	(Sinomine Resource Group Co. Ltd. 2021a)
Jinaier plant	Jinai P	China	Qinghai Dongtai Jinaier Salt Lake Lithium Resources Co. Ltd.	1000	Based on mine prod.	Lithium carbonate	(Asian Metal 2018)
Kemerton	Kemerton	Australia	Albemarle	50000	Capacity	Lithium hydroxide	(Albemarle 2023a, 2024a)
Kings Mountain	K Mountain	United States	Albemarle	50000	Capacity	Hydroxide, carbonate, bromide, chloride, metal, alloy powders	(Albemarle 2024g)
Kwinana refinery	Kwinana P	Australia	Talison Lithium (Talison is owned by 51% Tianqi lithium corporation and 51% IGO limited)	48000	Capacity	Hydroxide	(IGO 2024) (Albemarle 2024a; Talison Lithium 2021)
La Negra	La Negra	Chile	Albemarle	50000	Based on mine prod.	Carbonate	(Albemarle 2024b; Greencarcongress 2022)
Langelsheim		Germany	Albemarle		Capacity	Butyllithium, lithium chloride, specialty products, lithium hydrides, cesium and special metals	(Albemarle 2024d)
Meishan		China	Albemarle	50000	Capacity	Hydroxide, carbonate	(Albemarle 2024f, 2024b, 2024a)
Naraha		Japan	Orocobre (Operator), Arcadium Lithium (75% owner*)	10000	Capacity	Hydroxide	(Arcadium Lithium 2024; Orocobre 2024)

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Processing Plant	Abbreviat-ion	Country of plant/mine	Companies	Capacity /production (LCE Mt)	Notes on production	Lithium Products**	References
NEW JOHNSONVILLE	Johnsonville	United States	Albemarle		Capacity	Butyllithium, specialty products	(Albemarle 2024e)
Ningdu	Ningdu	China	Ganfeng Lithium	20000	Capacity	Carbonate	(Ganfeng Lithium 2020)
Olaroz Lithium Facility	Olarez Li	Argentina	Orocobre Limited Australia (Operator), Arcadium Lithium (66.5%), Toyota Tsusho Corp. (25%), Jujuy Energia y Mineria Sociedad del Estado (8.5%)	13959	Based on mine prod.	Carbonate	(Arcadium Lithium 2024) (Lithium Argentina 2024a; Toyota Tsusho Corporation 2021)
Pastos Grandes plant	Pastos G P	Argentina	Lithium Argentina (Operator), Lithium Americas Corp (Owner)	6250	Based on mine prod.	Carbonate, chloride	(Lithium Argentina 2024b)
POSCO - Pilbara Conversion Facility Plant		South Korea	POSCO-Pilbara Lithium Solution Co. (Operator), Pilbara Minerals (18%), POSCO	21500	Capacity	Hydroxide	The Korea Economic Daily (2023) (Reuters 2021)
Qarhan lake plant	Qarhan P	China	Golmud Zangge Lithium Co., Ltd. (Operator), Zangger Mining Co. Ltd. (100%)	10537	Based on mine prod.	Carbonate	(ZGM 2024)
Rugao and Zhejiang	Rug and Zhe	China	Arcadium Lithium (merger of Allkem and Livent)	30000	Capacity	Hydroxide	Livent (2022) (Arcadium Lithium 2024)
Sal de los Angelos plant	Angelos P	Argentina	NextView New Energy Lion HK (Operator), Revotech Asia Ltd. (46%), Tibet Summit Resources Co. (45%), Leading Resources Global Ltd. (venturer) (9%)	2500	Based on mine prod.	Carbonate	(S&P Global 2023)
Salar de atacama (del Carmen) plant	Atacama (DC) P	Chile	Sociedad química y minera de chile s.a (100%)	152500	Based on mine prod.	Carbonate	(SQM 2023)
Salar Del Hombre Muerto Plant	Hombre M P	Argentina	Minera del Altiplano S.A. (MdA) (Operator), Arcadium Lithium (100%)	21087	Based on mine prod.	Carbonate	(Arcadium Lithium 2024)

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Processing Plant	Abbreviat-ion	Country of plant/mine	Companies	Capacity /production (LCE Mt)	Notes on production	Lithium Products**	References
Shehong Sichuan	She Sich	China	Tianqi lithium	24200	Capacity	Carbonate, hydroxide, chloride	(Tianqi Lithium 2018)
Silver Peak plant	Silver P	United States	Albemarle	10000	Production based on mine production	Hydroxide, carbonate	(Carbon Credits 2024)
Taipei	Taipei	Taiwan	Albemarle		Capacity	Butyllithium	(Albemarle 2024f)
Tongliang Chongqing	Tongliang	China	Tianqi lithium	600	Capacity	Metal	(Tianqi Lithium 2018)
West Tajinai Lake plant	W-Taji P	China	Qinghai Hengxin Rong Lithium Technology Co., Ltd. (100%)	5000	Based on mine prod.	Carbonate	(Shanghai Metals Market 2021)
Xinyu Ganfeng	Xinyu GANF	China	Ganfeng Lithium	6500	Capacity	Carbonate, fluoride	(Ganfeng Lithium 2020)
Xinyu/Qinzhou (Guangxi Tianyuan Plant)	Tianyuan P	China	Albemarle	25000	Capacity	Hydroxide, carbonate	(Albemarle 2023a)
Yichun Ganfeng Lithium Co., Ltd.	Yichun GANF	China	Ganfeng Lithium	1500	Capacity	Metal	(Ganfeng Lithium 2020)
Yichun Silver Lithium New Energy Co. Ltd	Yichun Silver	China	Yichun Silver Lithium New Energy Co. Ltd (Operator), Jiangte Motor (100%*)	3000	Capacity	Hydroxide, carbonate	(Jiangte 2024; YiChun Yin Li New Energy Co. 2014)
Yiliping (Qinghai) plant	Yiliping P	China	China MinMetals Corp. (51%), Ganfeng Lithium (49%)	7961	Based on mine prod.	Lithium carbonate	(Ganfeng Lithium 2020; S&P Global Market Intelligence 2021)
Youngy plant	Youngy P	China	Youngy Invt Hldg Grp Co.Ltd. (Operator), YoungyCo (100%)	4800	Capacity	Hydroxide, carbonate	(Reuters 2020)

Processing Plant	Abbreviat-ion	Country of plant/mine	Companies	Capacity /production (LCE Mt)	Notes on producti on	Lithium Products**	References
Zhabuye plant	Zhabuye P	China	Tibet Xigaze Zhabuye Lithium High-Tech Co (80%), Tianqi Lithium Corp. (20%), Tibet Mineral Dev. Co. LTD, BYD Co*	5000	Based on mine prod.	Carbonate	(China Daily 2010; Tianqi Lithium 2021)
Zhangjiagang Jiangsu	Zhangj P	China	Tianqi lithium	20000	Capacity	Carbonate	(Tianqi Lithium 2018)

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Table 25: links between hard rock mines and processing plants

Mine	Owners	Plant	Owner	Link
Altura, Australia	Pilbara minerals	Guangxi Tianyuan, China	Albemarle	Link between Altura and Tinyuan has at least existed in the past (ASX 2019)
Alvarrões, Portugal	Sinomine Resource Group Co . Ltd.	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Bikita, Zimbabwe	Bikita Minerals (Private) Limited, Sinomine Resource Group Co. Ltd., Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Cachoeira, Brazil	Companhia Brasileira de Lítio (100%)	Chemical plant unit Divisa Alegre, Brazil		The same owner
Finniss, Australia	Core Lithium (100%)	Sichuan Yahua and Ganfeng Lithium		Offtake deal: Finniss (CORE) secured long term offtakes with two of the world's largest lithium companies – Sichuan Yahua and Ganfeng Lithium (CORE Lithium 2024)
Greenbushes, Australia	Talison Lithium Albemarle, IGO Tianqi Lithium	Zhangjiagang Jiangsu, China	Tianqi lithium	Ownership link and Route based on (Khakmardan et al. 2023)

Mine	Owners	Plant	Owner	Link
Altura, Australia	Pilbara minerals	Guangxi Tianyuan, China	Albemarle	Link between Altura and Tinyuan has at least existed in the past (ASX 2019)
Alvarrões, Portugal	Sinomine Resource Group Co . Ltd.	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Bikita, Zimbabwe	Bikita Minerals (Private) Limited, Sinomine Resource Group Co. Ltd., Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Cachoeira, Brazil	Companhia Brasileira de Lítio (100%)	Chemical plant unit Divisa Alegre, Brazil		The same owner
Finniss, Australia	Core Lithium (100%)	Sichuan Yahua and Ganfeng Lithium		Offtake deal: Finniss (CORE) secured long term offtakes with two of the world's largest lithium companies – Sichuan Yahua and Ganfeng Lithium (CORE Lithium 2024)
Jiajika, China	Youngy Invt Hldg Grp Co.Ltd., Youngy Co	Youngy plant, China	Youngy Invt Hldg Grp Co.Ltd., Youngy Co	The same owner
Mibra, Brazil	AMG Brasil. S.A. (Operator), AMG Critical Materials N.V. (100%)	AMG Lithium GmbH, Germany	AMG Lithium	(AMG Lithium 2024)

Mine	Owners	Plant	Owner	Link
Altura, Australia	Pilbara minerals	Guangxi Tianyuan, China	Albemarle	Link between Altura and Tinyuan has at least existed in the past (ASX 2019)
Alvarrões, Portugal	Sinomine Resource Group Co . Ltd.	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Bikita, Zimbabwe	Bikita Minerals (Private) Limited, Sinomine Resource Group Co. Ltd., Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Cachoeira, Brazil	Companhia Brasileira de Lítio (100%)	Chemical plant unit Divisa Alegre, Brazil		The same owner
Finniss, Australia	Core Lithium (100%)	Sichuan Yahua and Ganfeng Lithium		Offtake deal: Finniss (CORE) secured long term offtakes with two of the world's largest lithium companies – Sichuan Yahua and Ganfeng Lithium (CORE Lithium 2024)
Mount Marion, Australia	Mineral Resources Ltd. (50%), Jiangxi Ganfeng Lithium Co. Ltd (50%)	Possibly linked to basic lithium plant, fengxin Ganfeng, Hebei Ganfeng, Ningdu, Xinyu Ganfeng and Yichun Ganfeng, through		The same owner

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Mine	Owners	Plant	Owner	Link
Altura, Australia	Pilbara minerals	Guangxi Tianyuan, China	Albemarle	Link between Altura and Tinyuan has at least existed in the past (ASX 2019)
Alvarrões, Portugal	Sinomine Resource Group Co . Ltd.	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Bikita, Zimbabwe	Bikita Minerals (Private) Limited, Sinomine Resource Group Co. Ltd., Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Cachoeira, Brazil	Companhia Brasileira de Lítio (100%)	Chemical plant unit Divisa Alegre, Brazil		The same owner
Finniss, Australia	Core Lithium (100%)	Sichuan Yahua and Ganfeng Lithium		Offtake deal: Finniss (CORE) secured long term offtakes with two of the world's largest lithium companies – Sichuan Yahua and Ganfeng Lithium (CORE Lithium 2024)
		ownership Ganfeng		

Mine	Owners	Plant	Owner	Link
Altura, Australia	Pilbara minerals	Guangxi Tianyuan, China	Albemarle	Link between Altura and Tinyuan has at least existed in the past (ASX 2019)
Alvarrões, Portugal	Sinomine Resource Group Co . Ltd.	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Bikita, Zimbabwe	Bikita Minerals (Private) Limited, Sinomine Resource Group Co. Ltd., Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Cachoeira, Brazil	Companhia Brasileira de Lítio (100%)	Chemical plant unit Divisa Alegre, Brazil		The same owner
Finniss, Australia	Core Lithium (100%)	Sichuan Yahua and Ganfeng Lithium		Offtake deal: Finniss (CORE) secured long term offtakes with two of the world's largest lithium companies – Sichuan Yahua and Ganfeng Lithium (CORE Lithium 2024)
Mount Cattlin, Australia	Arcadium Lithium (merger of Allkem and Livent) (100%)	Zhangjiagang Jiangsu, China	Tianqi lithium	Route based on (Khakmardan et al. 2023)
Pilgangoora, Australia	Pilbara minerals (100%)	Pilgan plant and Ngungaju Plant, Possibly linked to basic lithium plant, fengxin		Offtake deal between Pilbara Minerals and Ganfeng

Mine	Owners	Plant	Owner	Link
Altura, Australia	Pilbara minerals	Guangxi Tianyuan, China	Albemarle	Link between Altura and Tinyuan has at least existed in the past (ASX 2019)
Alvarrões, Portugal	Sinomine Resource Group Co . Ltd.	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Bikita, Zimbabwe	Bikita Minerals (Private) Limited, Sinomine Resource Group Co. Ltd., Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Cachoeira, Brazil	Companhia Brasileira de Lítio (100%)	Chemical plant unit Divisa Alegre, Brazil		The same owner
Finniss, Australia	Core Lithium (100%)	Sichuan Yahua and Ganfeng Lithium		Offtake deal: Finniss (CORE) secured long term offtakes with two of the world's largest lithium companies – Sichuan Yahua and Ganfeng Lithium (CORE Lithium 2024)
		Ganfeng, Hebei Ganfeng, Ningdu, Xinyu Ganfeng and Yichun Ganfeng.		(Mining 2024)
Tanco, Canada	Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Jiangxi Dongpeng New Material Co. Ltd. (Sinomine	The same owner

Mine	Owners	Plant	Owner	Link
Altura, Australia	Pilbara minerals	Guangxi Tianyuan, China	Albemarle	Link between Altura and Tinyuan has at least existed in the past (ASX 2019)
Alvarrões, Portugal	Sinomine Resource Group Co . Ltd.	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Bikita, Zimbabwe	Bikita Minerals (Private) Limited, Sinomine Resource Group Co. Ltd., Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Cachoeira, Brazil	Companhia Brasileira de Lítio (100%)	Chemical plant unit Divisa Alegre, Brazil		The same owner
Finniss, Australia	Core Lithium (100%)	Sichuan Yahua and Ganfeng Lithium		Offtake deal: Finniss (CORE) secured long term offtakes with two of the world's largest lithium companies – Sichuan Yahua and Ganfeng Lithium (CORE Lithium 2024)
	(Operator), Sinomine Resource Grp Co Ltd (100%)		Resource Grp Co Ltd (Owner*)	
Wodgina, Australia	Albemarle (50%), Mineral Resources Ltd. (50%)	The owner of the mine (Albemarle) owns the following processing	Albemarle	The same owner

Mine	Owners	Plant	Owner	Link
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Alvarrões, Portugal	Sinomine Resource Group Co . Ltd.	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Bikita, Zimbabwe	Bikita Minerals (Private) Limited, Sinomine Resource Group Co. Ltd., Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Cachoeira, Brazil	Companhia Brasileira de Lítio (100%)	Chemical plant unit Divisa Alegre, Brazil		The same owner
Finniss, Australia	Core Lithium (100%)	Sichuan Yahua and Ganfeng Lithium		Offtake deal: Finniss (CORE) secured long term offtakes with two of the world's largest lithium companies – Sichuan Yahua and Ganfeng Lithium (CORE Lithium 2024)
		plants: Guangxi Tianyuan, Kemerton, Kings Mountain, La Negra, Langelsheim, Meishan, New Johnsonville, Silver peak		

Mine	Owners	Plant	Owner	Link
Altura, Australia	Pilbara minerals	Guangxi Tianyuan, China	Albemarle	Link between Altura and Tinyuan has at least existed in the past (ASX 2019)
Alvarrões, Portugal	Sinomine Resource Group Co . Ltd.	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Bikita, Zimbabwe	Bikita Minerals (Private) Limited, Sinomine Resource Group Co. Ltd., Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Cachoeira, Brazil	Companhia Brasileira de Lítio (100%)	Chemical plant unit Divisa Alegre, Brazil		The same owner
Finniss, Australia	Core Lithium (100%)	Sichuan Yahua and Ganfeng Lithium		Offtake deal: Finniss (CORE) secured long term offtakes with two of the world's largest lithium companies – Sichuan Yahua and Ganfeng Lithium (CORE Lithium 2024)
		plant, Taipei and Qinzhou		
Yichun Tantalum Niobium, China	Ningxia Non-Ferrous Metals (Operator), Yichun Tantalum Niobium Mine Co., Ltd. (Jiangxi			Unknown

Mine	Owners	Plant	Owner	Link
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Alvarrões, Portugal	Sinomine Resource Group Co . Ltd.	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Bikita, Zimbabwe	Bikita Minerals (Private) Limited, Sinomine Resource Group Co. Ltd., Tantalum Mining Corporation of Canada Limited	Jiangxi Dongpeng New Material plant, China	Sinomine Resource Group Co. Ltd.	The same owner
Cachoeira, Brazil	Companhia Brasileira de Lítio (100%)	Chemical plant unit Divisa Alegre, Brazil		The same owner
Finniss, Australia	Core Lithium (100%)	Sichuan Yahua and Ganfeng Lithium		Offtake deal: Finniss (CORE) secured long term offtakes with two of the world's largest lithium companies – Sichuan Yahua and Ganfeng Lithium (CORE Lithium 2024)
	Tungsten Industry holding Group Co., Ltd.,) (100%)			

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