Draft report supply chain mapping, requirements elicitation, classification

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Summary

This draft report aims to lay the groundwork to map the supply chains of critical raw materials and establish criteria to identify the leverage points for traceability technology. The document starts by proposing a framework that can be used to map the supply chains of cobalt, lithium, natural graphite, and neodymium by focusing on the cobalt supply chain as an example. Preliminary information is also provided for the other materials. This is then followed by the definition of the criteria to identify the leverage points for traceability technology. The state of practices of control methods and tracing solutions, along with the identification of the requirements, elicitation, and classification for digital product passports, create the bridge between the identification of the leverage points and the development of digital tracing technology that can be deployed in these strategic points of the supply chains of the materials. The conclusions highlight key aspects of the report.

Keywords

EV batteries, cobalt, supply chain mapping, requirements elicitation

Abbreviations and acronyms

BGR	German Federal Institute for Geosciences and Natural Resources
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
HHI	Herfindahl-Hirschman Index
IP	Identity preservation
LCA	Life Cycle Assessment
Li-ion	Lithium-ion
MFP	Material fingerprinting

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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 motor vehicles. The responsible sourcing of materials, namely lithium, cobalt, and natural graphite for batteries and neodymium for EV motors, has become a central concern for stakeholders across the supply chain (European Commission, 2023).

The urgency to address responsible sourcing (i.e., the management of social, environmental and/or economic sustainability in the supply chain through production data (van den Brink et al., 2019)) and transparency challenges have sparked the emergence of digital material passports as an innovative and technologically advanced solution (Berger et al., 2022). This cutting-edge system serves as an all-encompassing repository, meticulously documenting the entire lifecycle of specific raw materials or products, which detailed insights into their origin, extraction processes, production methods, trade flows, and involvement of various stakeholders at every stage (Kaikkonen et al., 2022). However, despite the potential of the digital material passport, there exists a crucial gap in the practical implementation and effectiveness of this innovative solution within the supply chain of CRMs.

While the theoretical foundation of digital material passport is well-known, the successful application of requirements elicitation techniques to tailor the system to precise stakeholder needs has not been fully explored (Paramatmuni & Cogswell, 2023). As the development and implementation of such a sophisticated system demand substantial resources and collaboration among diverse stakeholders, it becomes imperative to ensure that the digital material passport is aligned with the unique traceability requirements and compliance criteria of the EV battery materials supply chain stakeholders.

Addressing this gap requires a focused and systematic approach to requirements elicitation. This pivotal step entails the diligent gathering and extraction of detailed and comprehensive information regarding the needs, desires, and expectations of stakeholders within the cobalt supply chain (Andry et al., 2020). For example, the application of diverse techniques such as interviews, surveys, workshops, and observations could enable a better understanding of the specific functionalities and features crucial for fulfilling material traceability and transparency effectively (Blengini et al., 2017). In the context of our technical report focusing on EV battery materials, requirements elicitation we merged expertise from different fields, from industrial ecology to geological surveys and chemical and digital traceability. The knowledge from these different fields has been integrated into the development of the digital material passport, ensuring that it is tailor-made to address the data requirements and compliance criteria precisely while considering the specificities of the supply chains of the materials used in batteries.

Furthermore, identifying leverage points within the EV battery materials supply chain provides critical opportunities for targeted interventions or improvements. By capitalizing on these leverage points, stakeholders can effectively implement traceability technologies, enhance transparency, and foster responsible sourcing practices, ultimately reinforcing supply chain resilience (van den Brink et al., 2019). For instance, focusing on enhancing traceability at the extraction and refining stages may provide valuable insights into the material's origin and production methods, while enhancing traceability along trade flows (e.g., for waste and scrap) can provide transparency into the dynamic of EV battery flows throughout the global market. In addition to identifying leverage points, it is crucial to establish comprehensive criteria that allow the development of a methodology for certifying responsible sourcing. Such a methodology can be established by applying standards such as CERA 4in1, which is a certification scheme that provides multiple criteria to assess the social, environmental, and ethical practices across minerals' supply chains (CERA 4in1, 2021).

Aligned with MaDiTraCe project commitment to advancing responsible sourcing practices and cutting-edge traceability technologies, the D3.1 report examines the cobalt, lithium, natural graphite, and neodymium supply chains by mapping the mine sites and the trade flows and establishing a classification and requirements elicitation. The primary objective of this report is to lay a robust foundation for future initiatives aimed at fostering transparency and accountability in the supply chain of CRMs. Moreover, the D3.1 report lays the ground for the final report of Task 3.1 (i.e., D3.8), which will consider the insights gained from the feedback of selected case studies and the knowledge developed by the MaDiTraCe consortium in the upcoming years.

By employing systematic analysis, we identify leverage points that hold the potential to leverage traceability technologies effectively, thereby enhancing sustainability practices across the supply chain. To do so, we address four key questions:

1) What are the flows/stocks of the EV battery and motor materials supply chains, including extraction, primary production, trade flows, and key stakeholders involved?

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2) Which specific points in the EV battery and motor materials supply chains offer the greatest potential for implementing traceability technologies to enhance transparency and sustainability?
3) What are the current practices used for control and tracing at various checkpoints in the EV battery materials and motor supply chains?
4) What are the key prerequisites, procedures, and methodologies needed to establish a digital material passport within the cobalt supply chain, ensuring compliance with CERA 4in1 standards through data vocabulary, attributes, and accessibility?

By addressing these key questions, the D3.1 report provides a comprehensive supply chain mapping (from extraction and primary production to encompassing trade flows and key stakeholders within the supply chain), leverage points for cobalt traceability, the state of practices of control methods and tracing solutions, as well as requirements, elicitation, and classification for digital material passport.

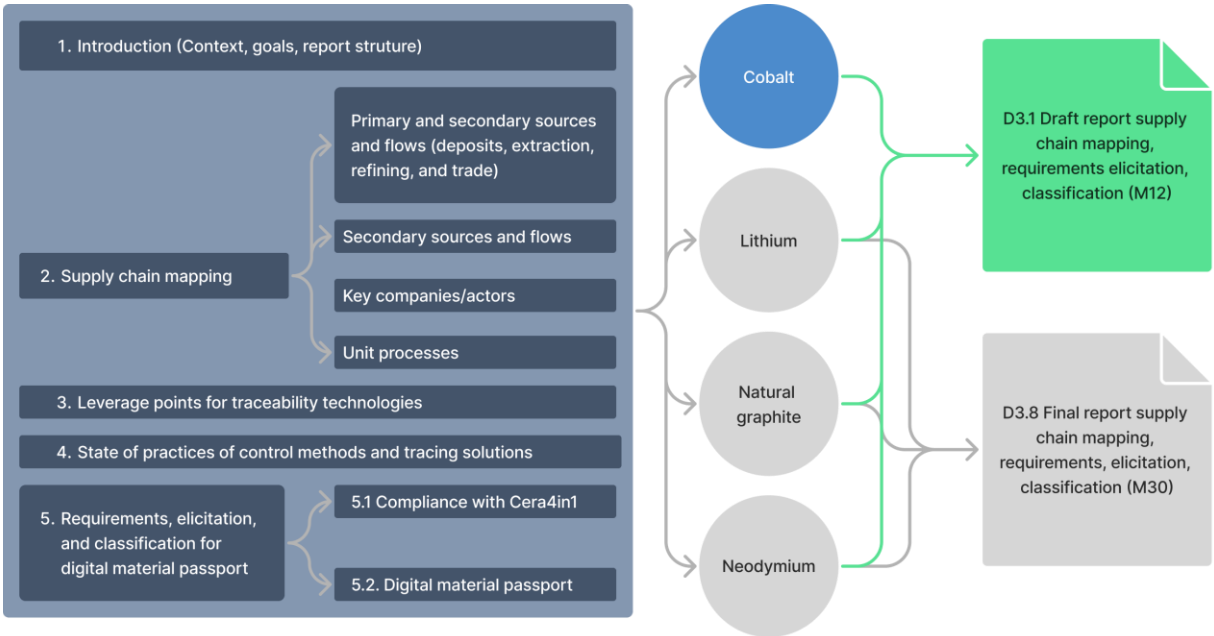

Figure 1: D3.1 report structure within the context of Task 3.1 and its two deliverables.

A fundamental aspect of our analysis concerns the present state of practices governing control methods and tracing solutions. Considering the collective expertise of our partners involved in the MaDiTraCe project, we assess existing practices and offer prudent recommendations for enhancements. Furthermore, this report explores requisites, elicitation procedures, and classification methodologies indispensable for the establishment of a digital material passport within the supply chain of cobalt. With meticulous adherence to compliance with CERA 4in1 standards, we propose data vocabulary, attributes, and accessibility for facilitating the implementation of digital material passports.

In this report, we cover all four key questions for cobalt while only partially detailing the supply chains of lithium, natural graphite, and neodymium. These materials will be further developed as part of the D3.8 report in the upcoming year.

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2 Supply chain mapping

This chapter offers a comprehensive supply chain mapping for the selected CRMs: cobalt, lithium, natural graphite, and neodymium. The mapping includes both primary and secondary sources and flows. Primary flows refer to the direct extraction and production processes of these CRMs, starting from their source in mines or extraction sites and continuing through their initial refinement and manufacturing stages. Secondary flows encompass the recycling, reprocessing, and reuse of these materials, reflecting their contribution to a circular economy and sustainable resource management.

Furthermore, this chapter provides an overview of key players and stakeholders involved in the supply chain. It is important to notice that while the identification of key companies was initially developed for cobalt, comprehensive stakeholder information for lithium, natural graphite, and neodymium will be provided in D3.8 in the upcoming year.

2.1 Cobalt

In recent years, cobalt has gained immense attention due to its role in shaping the future of sustainable technologies and the global energy transition. As we look ahead to a world driven by electric mobility and renewable energy solutions, cobalt emerges as a linchpin in powering these transformative technologies (Bobba et al., 2020). Furthermore, the development of emerging energy-related technologies, such as fuel cells and hydrogen-based energy solutions, relies heavily on cobalt as a CRM (Aguilar-Hernandez et al., 2022).

As mentioned in Chapter 1, the responsible sourcing and traceability of cobalt have emerged as key concerns for stakeholders across the supply chain (European Commission, 2023). Ensuring the ethical extraction and transparent flow of cobalt becomes essential to adhere to sustainability principles and address social and environmental impacts associated with its production. The traceability of the cobalt supply chain is crucial to prevent potential risks, which have been associated with some cobalt mining operations in certain regions (Shafique et al., 2023).

In this chapter, we explore the cobalt supply chain by examining the primary and secondary flows, their international trade, and identifying the key actors along the supply chain. By combining existing knowledge with the most recent data - for example, using the CEPII-BACI database for 2021 (Gaulier & Zignago, 2010) - this chapter aims to lay a robust foundation for our subsequent chapters focusing on requirements elicitation and classification for the digital material passport within the cobalt supply chain. It should be noted that the accuracy of trade data can vary. For example, lithium ore can also be traded as white pigment.

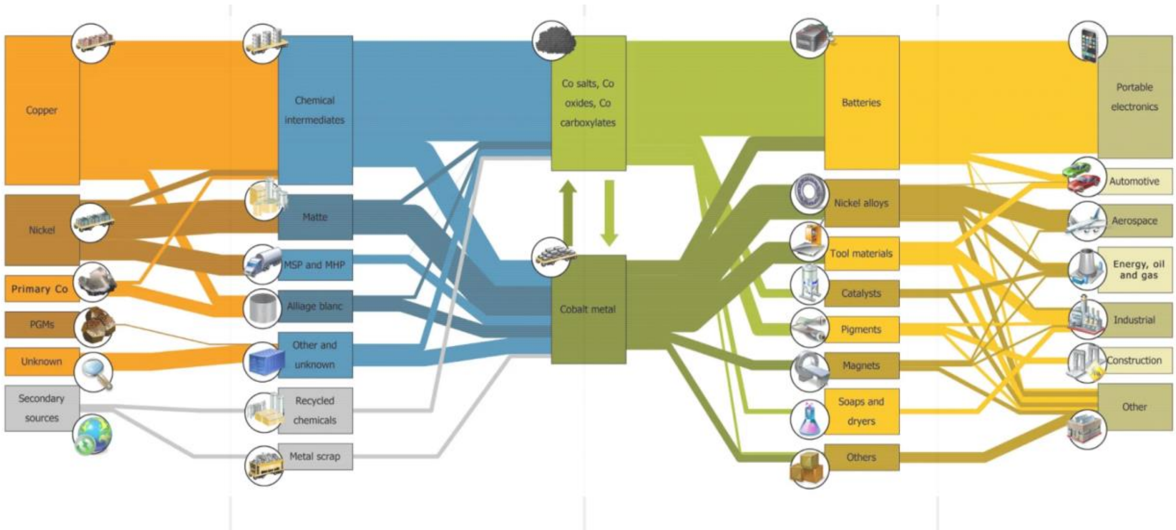

Figure 2: Illustration depicting the flows of the Cobalt supply chain (Cobalt Institute, 2021b).

Several studies have focused on mapping global cobalt flows and identifying the key actors within the cobalt supply chain. For instance, van den Brink et al. (2020a) highlighted the concentration of cobalt mining in the Democratic Republic of the Congo and refining in China, with cobalt mostly mined as a by-product of copper and nickel. Furthermore, Sun et al. (2019) analyzed cobalt flows throughout its life cycle from 1995 to 2015, identifying the major opportunity for secondary cobalt recovery in batteries. More recently, Liu et al. (2022) examined the resource dependence between different phases of the cobalt industrial chain in various countries, establishing a global cobalt flow network system. The Cobalt Market Report 2022 from the Cobalt Institute (2023a) has also contributed with information on the mapping of the cobalt supply chain for 2021.

Considering secondary supply, cobalt from recycling provided less than 5% of the total global supply in 2022. However, it is expected to support 15% in 2030 and more than 40% by 2040 (Cobalt Institute, 2023a). Moreover, Godoy's research (see Figure 3 on the end-of-life cobalt in the EU (European Union) reveals that around 8% of the initial stock of cobalt stays in use, 3% is being hoarded by users, and 89% has been lost due to non-selective collection practices and exports of recycled cobalt (Godoy León et al., 2020).

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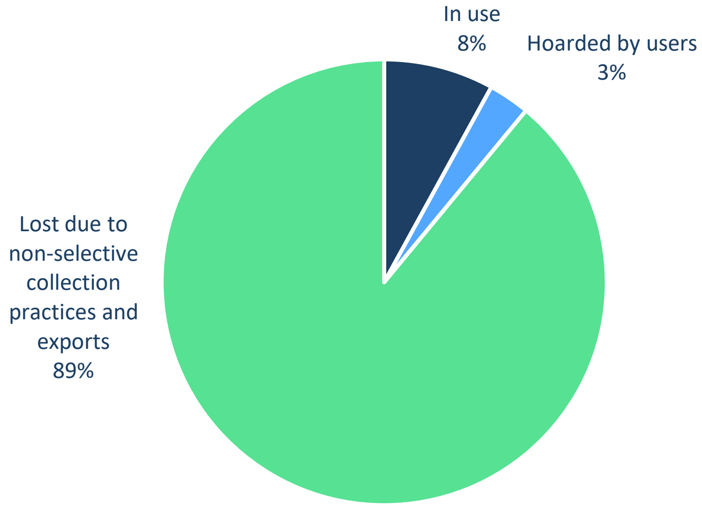

Figure 3: End-of-life cobalt in the EU based on findings from Godoy León (2020).

In the following section (2.1), we explore the cobalt supply chain, focusing on the mapping of extraction and primary production in 2021. We then identify the main cobalt trade flows between countries (Section 2.2) and key stakeholders (Section 2.3), providing an update on cobalt supply chain mapping.

2.1.1 Primary sources and flows

Deposits – current and future sources

Figure 4 illustrates the current cobalt reserves per country, with the countries being referred to in their ISO 3166 Alpha-3 codes[1]. Currently, there are 14 countries with cobalt reserves worldwide, which amounts to around 8300 kilotonnes (kt) (USGS, 2023). The top 5 reserves are allocated in the Democratic Republic of the Congo (48% of total global reserves), Australia (18%), Indonesia (7%), Cuba (6%), and the Philippines (3%).

[1] https://www.iso.org/obp/ui/#search

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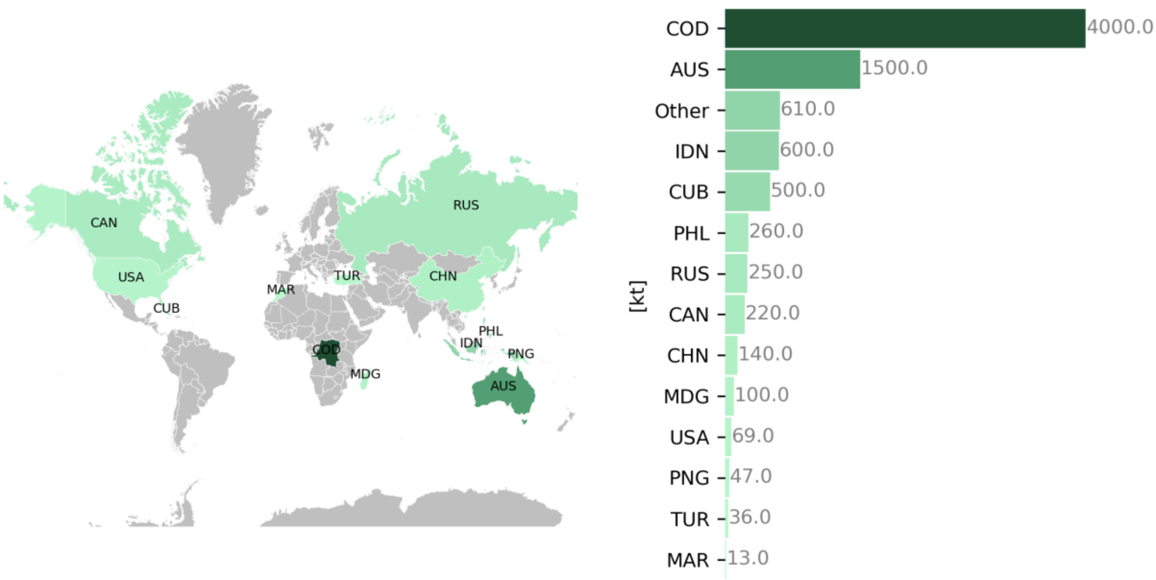

Figure 4: Current cobalt reserves per country.

Regarding cobalt deposits for the future market, cobalt deposits are found in 7 key geological settings, with significant deposits identified globally (SCRREEN2, 2023):

- Stratiform sediment-hosted deposits: These are found in the Central African Copperbelt, spanning Zambia and the Democratic Republic of Congo. These deposits primarily contain Cu-Co sulphides and oxides. Cobalt grades range from 0.1–0.4% Co.
- Magmatic deposits: These deposits are primarily mined for nickel, copper, and platinum group metals and are in Russia (Norilsk), Canada (Sudbury), and Australia (Kambalda). Cobalt content averages 0.1% Co.
- Lateritic Ni deposits: Mainly exploited for nickel, these deposits in New Caledonia and Cuba contain cobalt at levels ranging from 0.05–0.15% Co.
- Hydrothermal and volcanogenic deposits: Cobalt is a by-product of polymetallic mining in various countries, including Finland, Sweden, Norway, the USA, Canada, and Australia. The Bou Azzer deposit in Morocco, for example, is a significant source with a typical ore grade of 0.05–0.1% Co.
- Shale-hosted polymetallic sulphide deposits: These deposits are found in several countries and often contain cobalt as a potential by-product. For instance, the Terrafame Sotkamo mine in Finland is one such source.
- Seafloor deposits: Cobalt-rich polymetallic nodules occur mainly in the Pacific Ocean's Clarion-Clipperton Zone (CCZ), estimated at 21.1 billion tonnes with cobalt content at 0.2%. Furthermore, cobalt-rich ferromanganese crusts, estimated at 7.5

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billion tonnes, are found at depths of 800–3,000 m. While legal and economic barriers hinder exploitation, advancing technology might make this resource economically viable after 2050.

- European deposits: Most cobalt-bearing deposits are concentrated in Nordic countries such as Finland, Sweden, and Norway. Spain and Portugal have significant cobalt occurrences in ferromanganese crusts and polymetallic nodules on the seabed.

Extraction and refining

The deposit types that include cobalt in concentrations that are economically relevant are stratiform sediment-hosted copper-cobalt deposits, nickel-cobalt laterite deposits, and magmatic nickel-copper sulfide deposits, which is why most mined cobalt (98%) is a by-product of the mining activities for copper or nickel (BGS, 2021; Cobalt Institute, 2023c). In 2021, the global cobalt extraction amounted to 131 kilotonnes (kt) of cobalt mined (see Figure 5). The main supplier of cobalt mined was the Democratic Republic of Congo, where 71% of the total global extraction occurs. Other key suppliers of cobalt mined were Russia (6% of total global extraction), Australia (4%), Cuba (3%), Canada (3%), Papua New Guinea (2%), and Madagascar (2%). The share of main suppliers has been stable in the past decade (SCRREEN2, 2022). However, in 2022, Indonesia has become a key supplier of cobalt mined, representing the second largest producer with 5% of global extraction in this period (Cobalt Institute, 2023b).

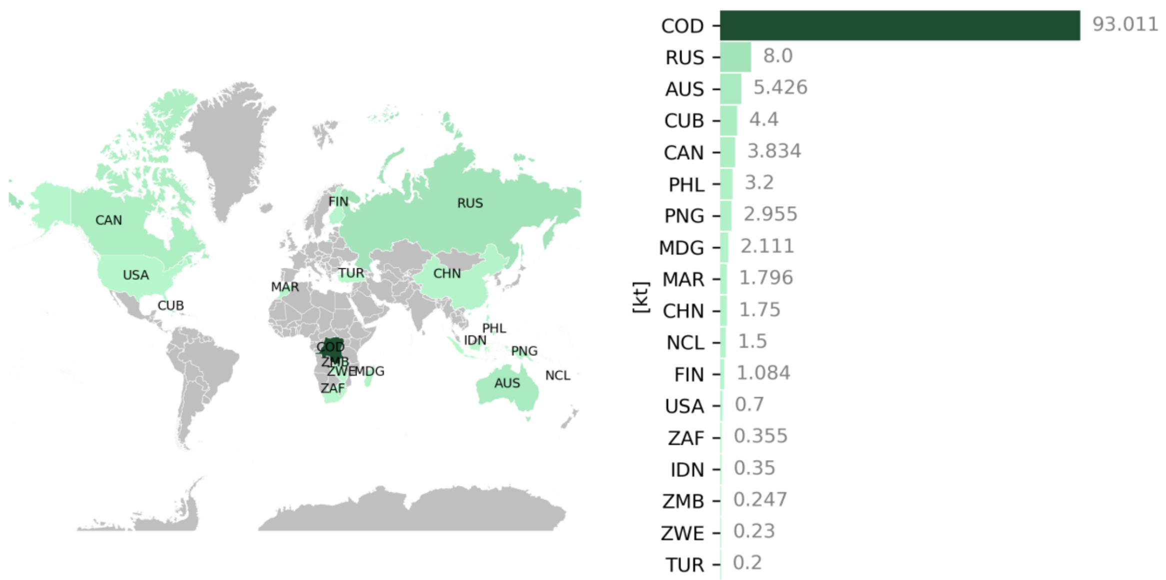

Figure 5: Cobalt mined per country for 2021, in kilotonnes (kt). Based on: BGS database (2023).

For refined cobalt, the global production was around 166 kt of processed cobalt in 2021 (see Figure 6). The main supplier of refined cobalt was China, with 77% of total production, followed by Finland (9%), Canada (4%), Norway (2%), Japan (2%), Australia (2%), Madagascar (1%), Russia (1%), Morocco (1%), and Belgium (1%). Furthermore, refined cobalt in 2021 was used in 3 main applications: Electric vehicles (EVs) batteries (approx. 40% of total cobalt used), portable electronics (30%), and super alloys (10%) (Cobalt Institute, 2023a). Other applications (20%) were related to tool materials, pigments, catalytic, and others (SCRREEN2, 2023).

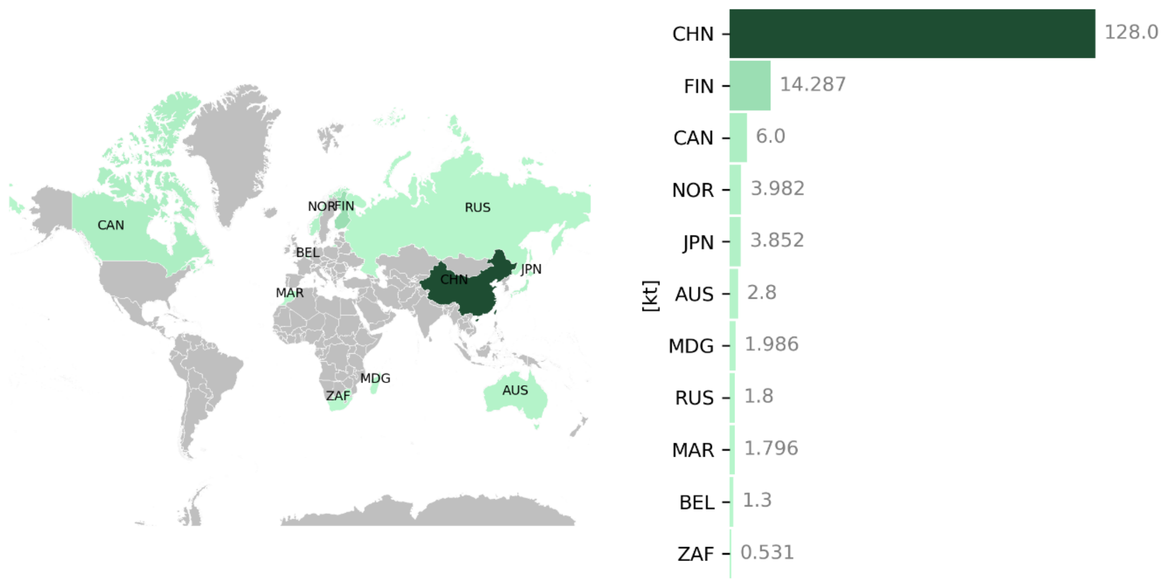

Figure 6: Cobalt refined per country for 2021, in kilotonnes (kt). Based on: BGS database (2023).

Trade

The global trade of cobalt ores and concentrates (HS code 260500) amounted to 21.3 kt in 2021. The largest exporter of cobalt ores and concentrates was the Democratic Republic of Congo, with 91% of total exports, while the largest importer was China, with 92% of total imports (see Figure 7 & Figure 9). The share of cobalt ores and concentrates trades was relatively constant during the past five years (see, for example, SCRREEN2, 2022; van den Brink et al., 2020b). The cobalt content of the traded cobalt ore has been estimated to vary between 0.1% and 2.5%, depending on the deposit.

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Mines 2016	Refineries 2016	Intermediate Cobalt Product Trade Flows
Nickel (17) Copper (12) Nickel and/or Copper (10) Cobalt (1)	All items (23)	Cobalt ores and concentrates (tonnes): Cobalt mattes and other intermediate products of cobalt metallurgy, cobalt and articles thereof (tonnes):

Figure 7: Geographic cobalt supply chain, including intermediate cobalt product flows, in 2016. From Van den Brink et. al (2020).

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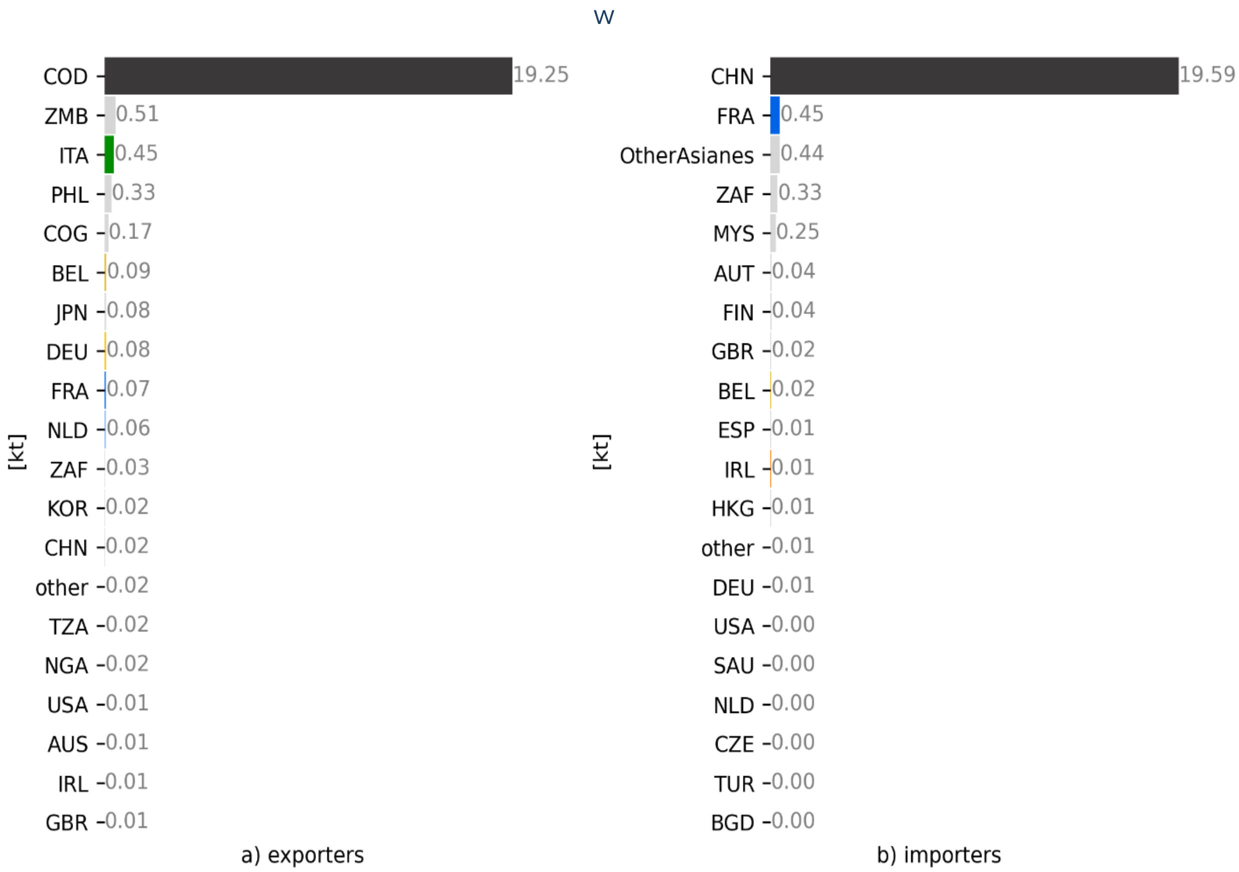

Figure 8: Top-20 (a) exporters and (b) importers of cobalt ores and concentrates total exports in 2021. Total cobalt ores and concentrates traded = 21.3 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

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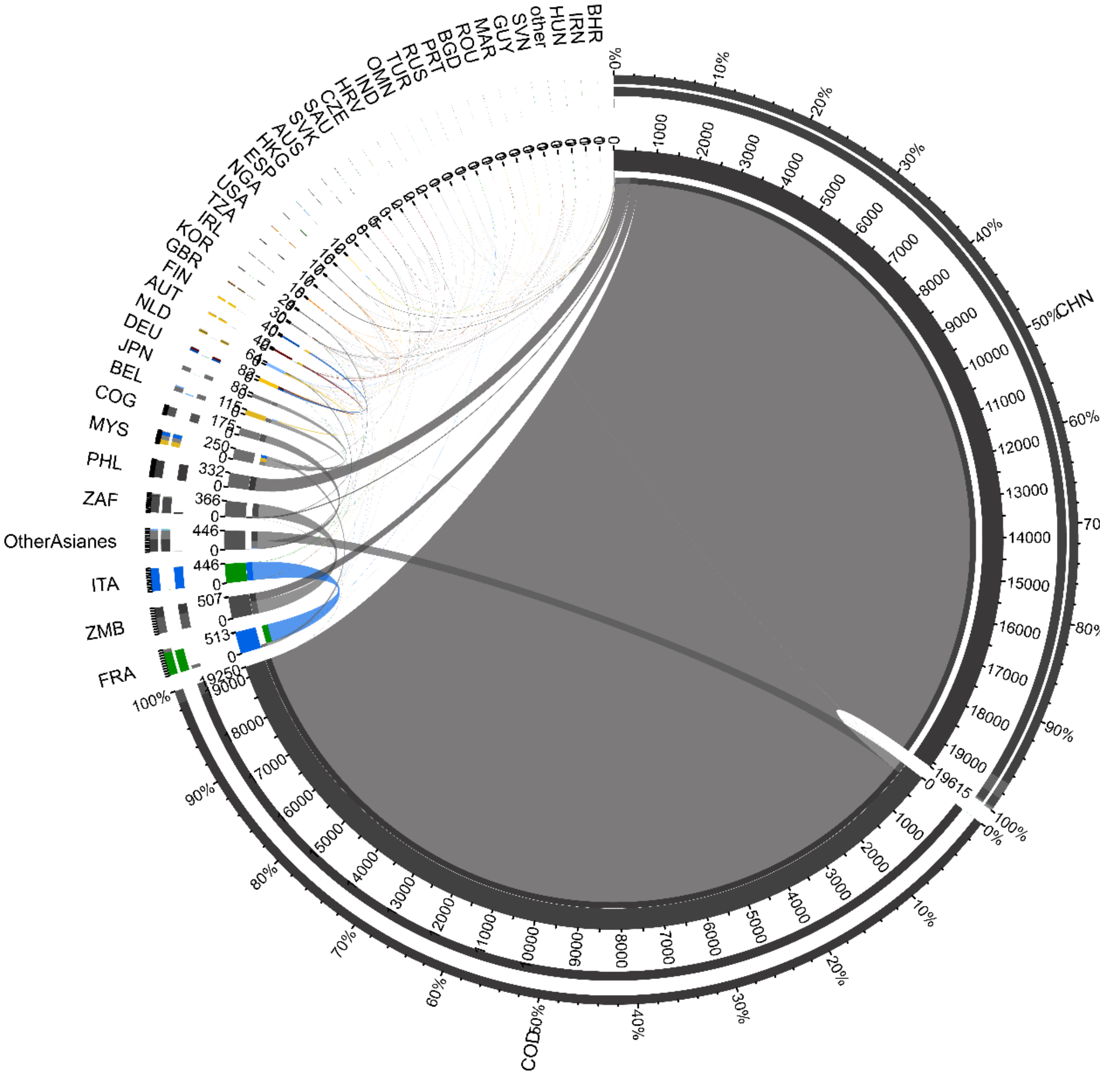

Figure 9: Trade of cobalt ores and concentrates in 2021 represented in a chord diagram in kilotonnes (kt). Total cobalt ores and concentrates traded = 21.3 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

Figure 9 presents a chord diagram that illustrates and quantifies the trade of cobalt ores and concentrates in 2021, according to data published in CEPII-BACI, which in turn is based on UN Comtrade (Gaulier & Zignago, 2010). The diagram presents three outer rims, one inner rim, and chords linking the different countries in the center:

- The outer most rim of the three outer rims presents the relative distribution of the total trade with all countries (imports and exports);
- The middle outer rim is for the relative distribution of the imports;
- The third outer rim, which is the closest to the center of the three, stands for the relative distribution of the exports;

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- The thicker inner rim, which has absolute values, represents the color of the country;
- The chords are colored with the color that stands for the importing country (destination of the flow) and have a set transparency.

The outer rims may be excluded for countries that only import or export. Because it is relevant to identify flows with European countries, the non-European countries have been attributed a shade of grey while European countries have been attributed a shade of a color. Additionally, it is possible to observe that the chords are detached (white space between the chord and the rim that represents the color of the country) on one side and attached on the other.

It is possible to observe that the main exporter of cobalt ores and concentrates is the Democratic Republic of the Congo, and the main importer is China. China also has imports from other Asian countries not elsewhere specified (OtherAsianes in Figure 9) but no exports, which either means that the material is fully consumed in the Chinese market or that it is transformed into another product before it is exported, which is the case, as presented in this document.

The flows with European countries are all significantly smaller compared to the trade between China and the Democratic Republic of the Congo. A European flow that is easy to observe is a flow of cobalt ores and concentrates from Italy to France. However, this is a flow that requires further explanation, as Italy has no domestic extraction of cobalt (see Figure 5 and Figure 6) and no imports of cobalt ore. It is possible that this is either an error in the data or a flow from a stock acquired in a different year or accumulated in a span of several years. Figure 28 to Figure 31 in appendix 8.2 present plots with time series of the imports and exports for Italy and France. These values suggest that the exports from Italy may be the result of an accumulated stock imported in 2003.

Cobalt mattes and other intermediate products of cobalt metallurgy, unwrought cobalt, waste, and scrap, powders (HS code 810510) are also traded as unrefined cobalt. The global trade of these products amounted to 395 kt in 2021. The largest exporter was the Democratic Republic of Congo, with 88% of total exports, while the largest importer was China with 97% of total imports (see Figure 10 and Figure 11).The cobalt content of cobalt mattes is around 1.5% to 2%, of unwrought cobalt, it can be 60% to 68% depending on the form in which the unwrought cobalt is presented, and of powders is about 99%.

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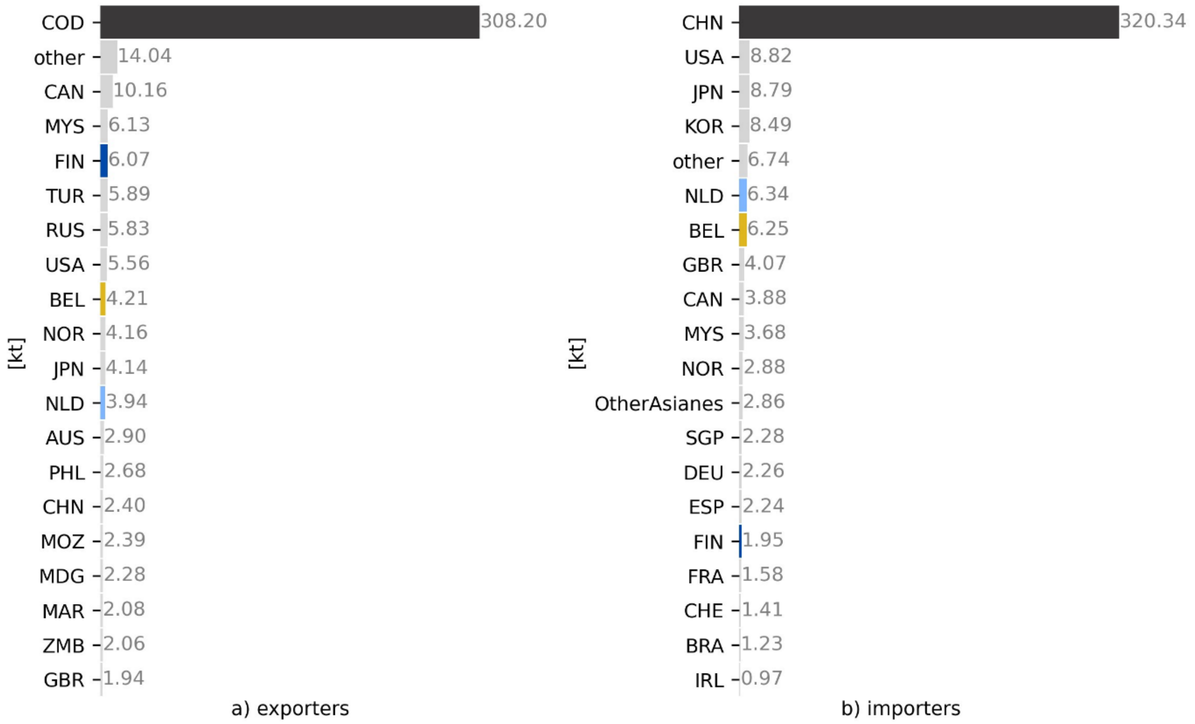

Figure 10: Top-20 (a) exporters and (b) importers of cobalt mattes and other intermediate products of cobalt metallurgy, unwrought cobalt, waste, and scrap, powders in kilotonnes (kt). Total traded = 394 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

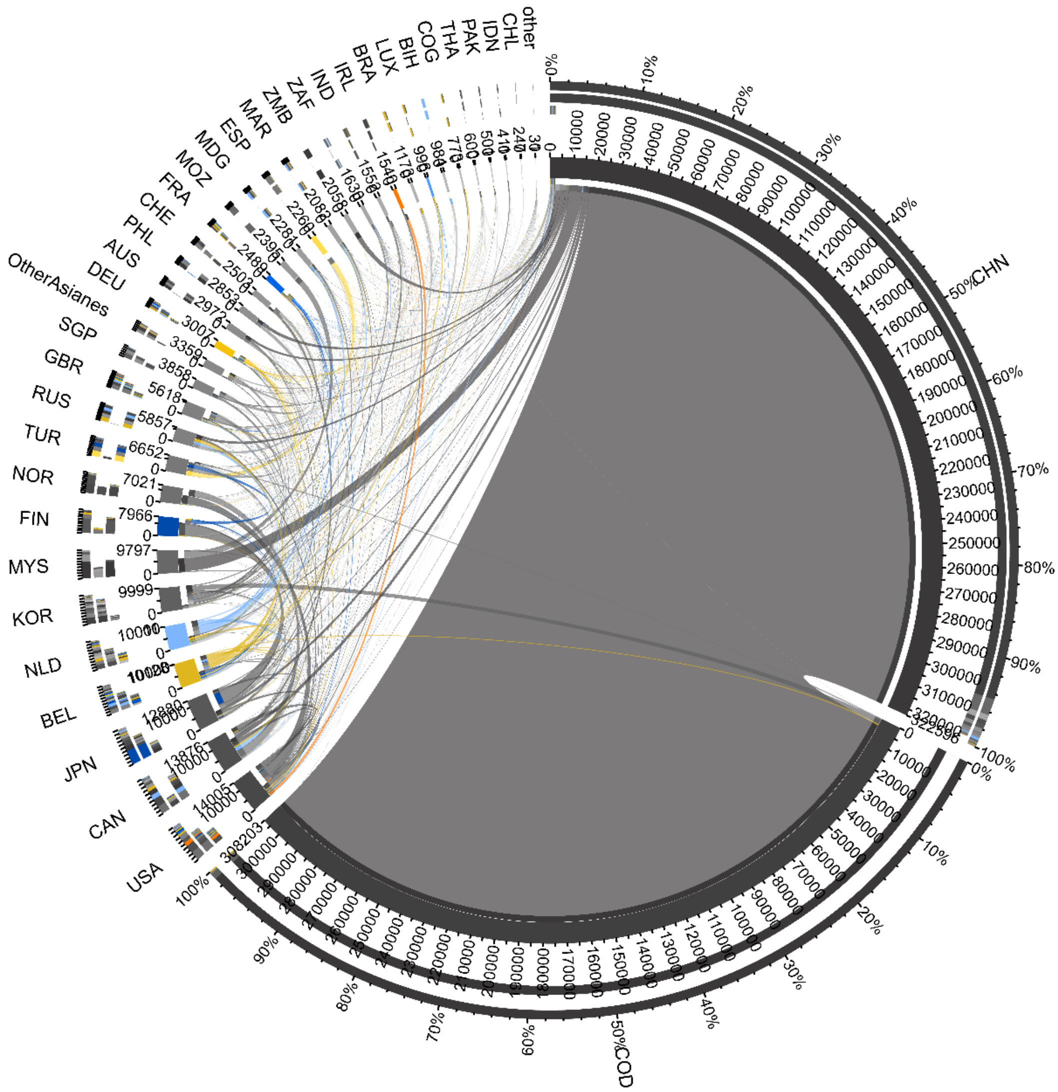

Figure 11: Trade of cobalt mattes and other intermediate products of cobalt metallurgy, unwrought cobalt, waste and scrap, powders, in tonnes (t). Total cobalt products traded = 395 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

For cobalt refined products, international trade amounted to 43 kt in 2021 (see Figure 12 and Figure 13). In this report, cobalt products consist of cobalt oxides and hydroxides (HS code 282200), and cobalt articles not elsewhere specified (HS code 810590). Similar to cobalt ores and concentrates, the main exporter of cobalt products was the Democratic Republic of Congo with 73% of total exports, followed by Finland (3%), China (2%), Canada (2%), and Belgium (2%). For cobalt product imports, China was the largest importer, with 74% of total imports, followed by South Korea (4%), the US (3%), Belgium (2%), and Japan (2%).

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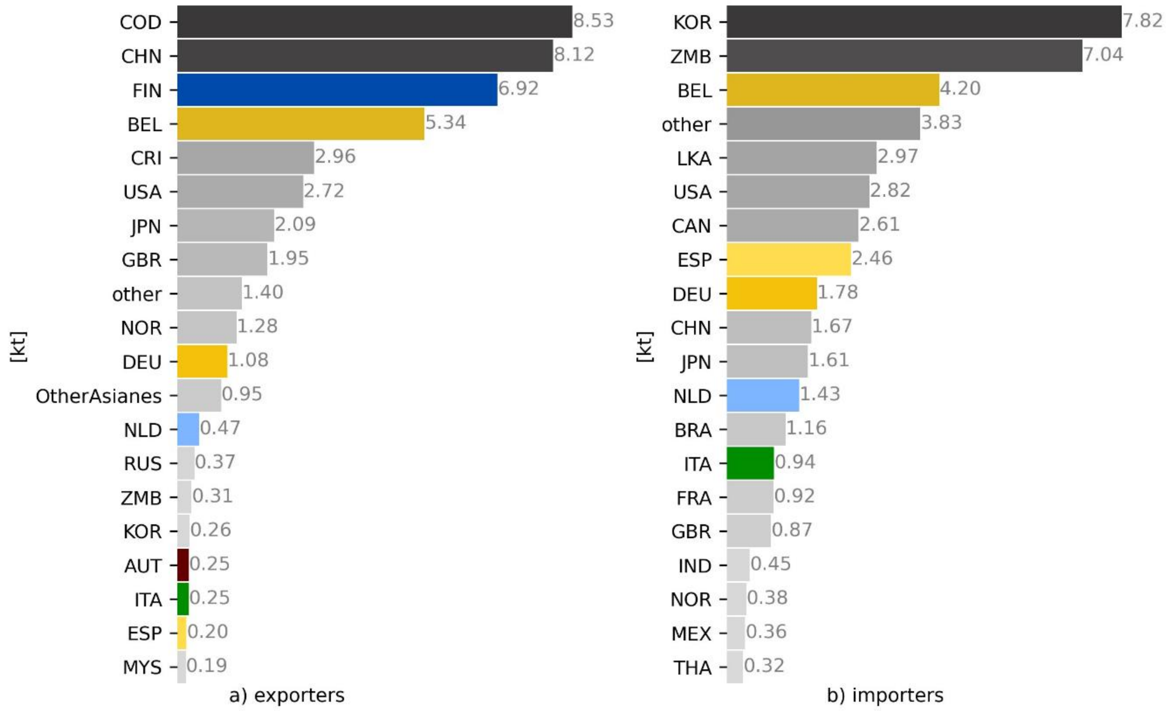

Figure 12: Top-20 (a) exporters and (b) importers of cobalt products (Cobalt oxides and hydroxides: commercial cobalt oxides; and other excluding waste and scrap), in kilotonnes (kt). Total cobalt products traded = 43 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

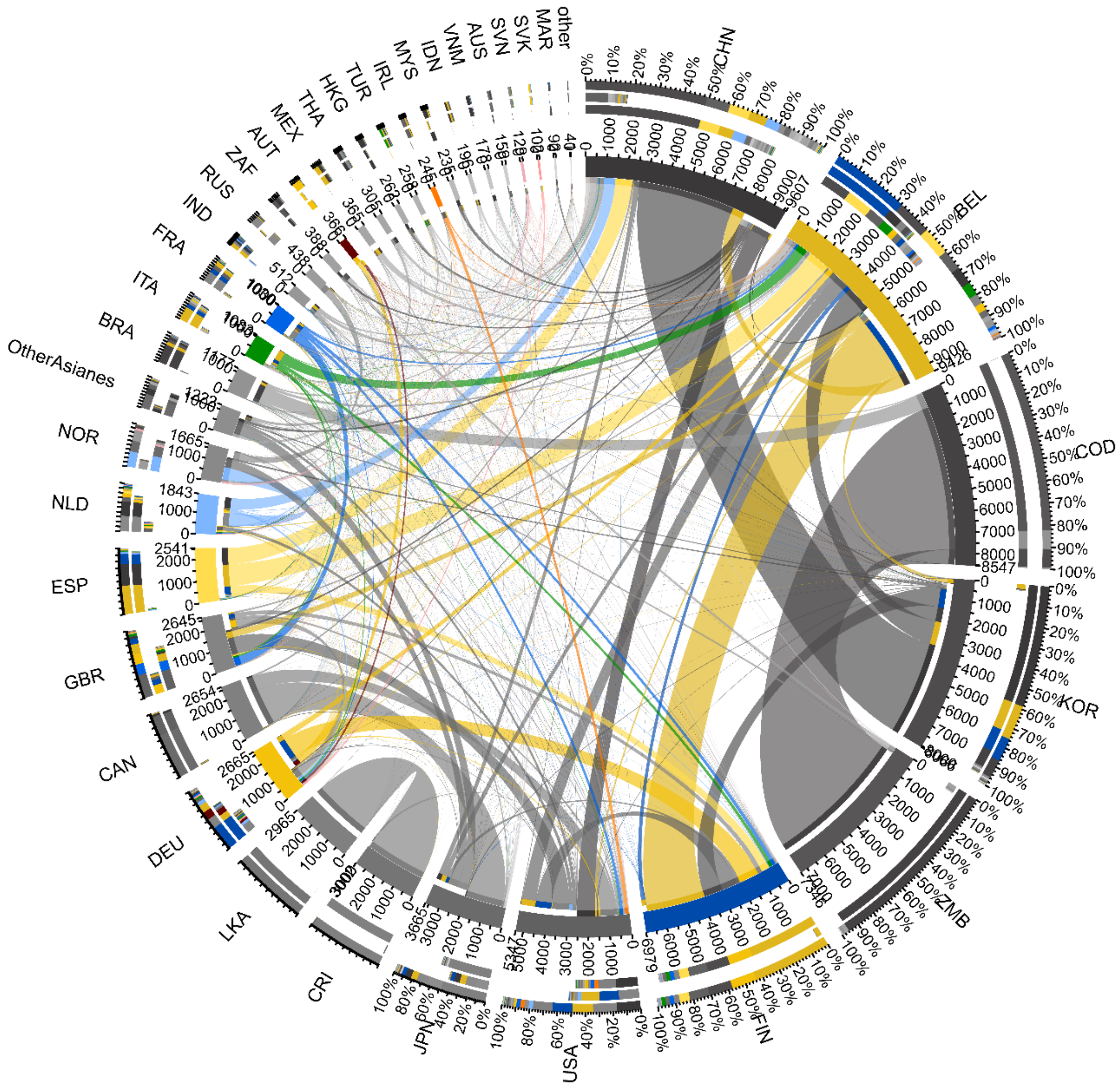

Figure 13: Trade of cobalt oxides and hydroxides: commercial cobalt oxides; and other excluding waste and scrap in 2021 represented in a chord diagram, in tonnes (t). Total cobalt products traded = 43 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

2.1.2 Secondary sources and flows

There is high uncertainty in the data related to secondary production/recycling rates of cobalt, and the values can vary with the sources (BRGM, 2021). Roskill has estimated the supply of recycled cobalt in the market to be between 10 and 15 kt in 2020, of which 65% is from battery recycling, 24% from tungsten carbide recycling, and 11% from the recycling of alloy scraps and catalysts (Cobalt Institute, 2021a). UNEP, on the other hand, estimates that the secondary production of cobalt is 25 kt, with most coming from "new scrap" (manufacturing offcuts).

Waste and scrap trade flows

For cobalt waste and scrap (HS code 810530), international trade amounted to 0.16 kt in 2021. There were only 15 trade partners (see Figure 14 and Figure 15). The largest exporter of cobalt waste and scrap was Belgium, with 48% of total exports, followed by Austria (26%), Australia (12.5%), Bosnia and Herzegovina (7%), Bulgaria (5%), Bangladesh (1%), and Brazil 0.5%). Main importers were US (26%), Germany (22%), Sweden (17%), United Kingdom (16%), India (12%), Singapore (6%), Russia (1%), and the Netherlands (1%). Considering the exports-imports connection, exports from Belgium to the US constituted 26% of total cobalt waste and scrap traded. Together with exports from Austria to Sweden (17%) and from Belgium to India and the United Kingdom (20%), those trade flows represented more than 60% of total cobalt waste and scrap.

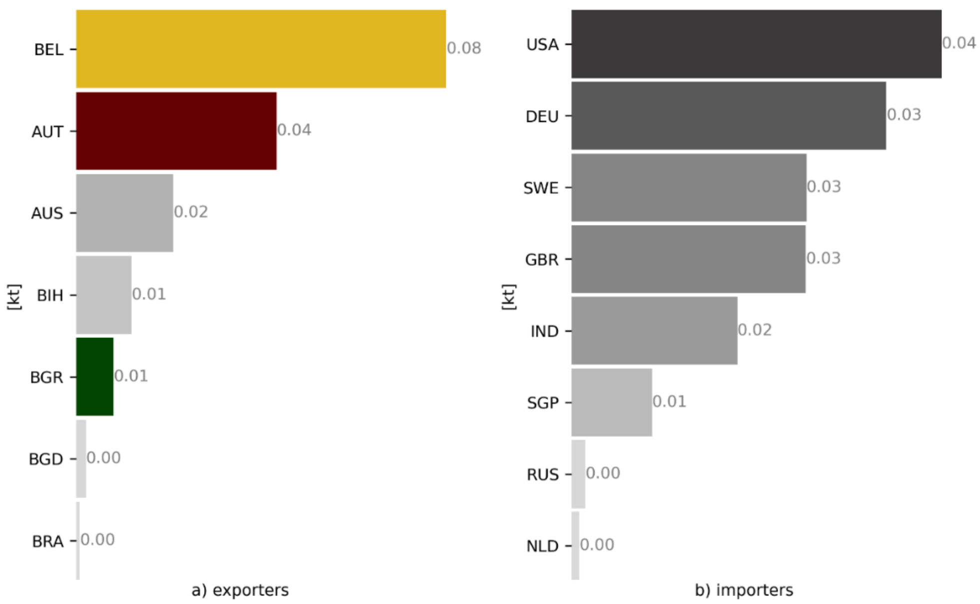

Figure 14: Total exports (a) and imports (a) of cobalt, waste, scrap (t) by country in 2021 for the countries with the largest trade flows, in kilotonnes (kt). Total cobalt waste and scrap traded: 0.16 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

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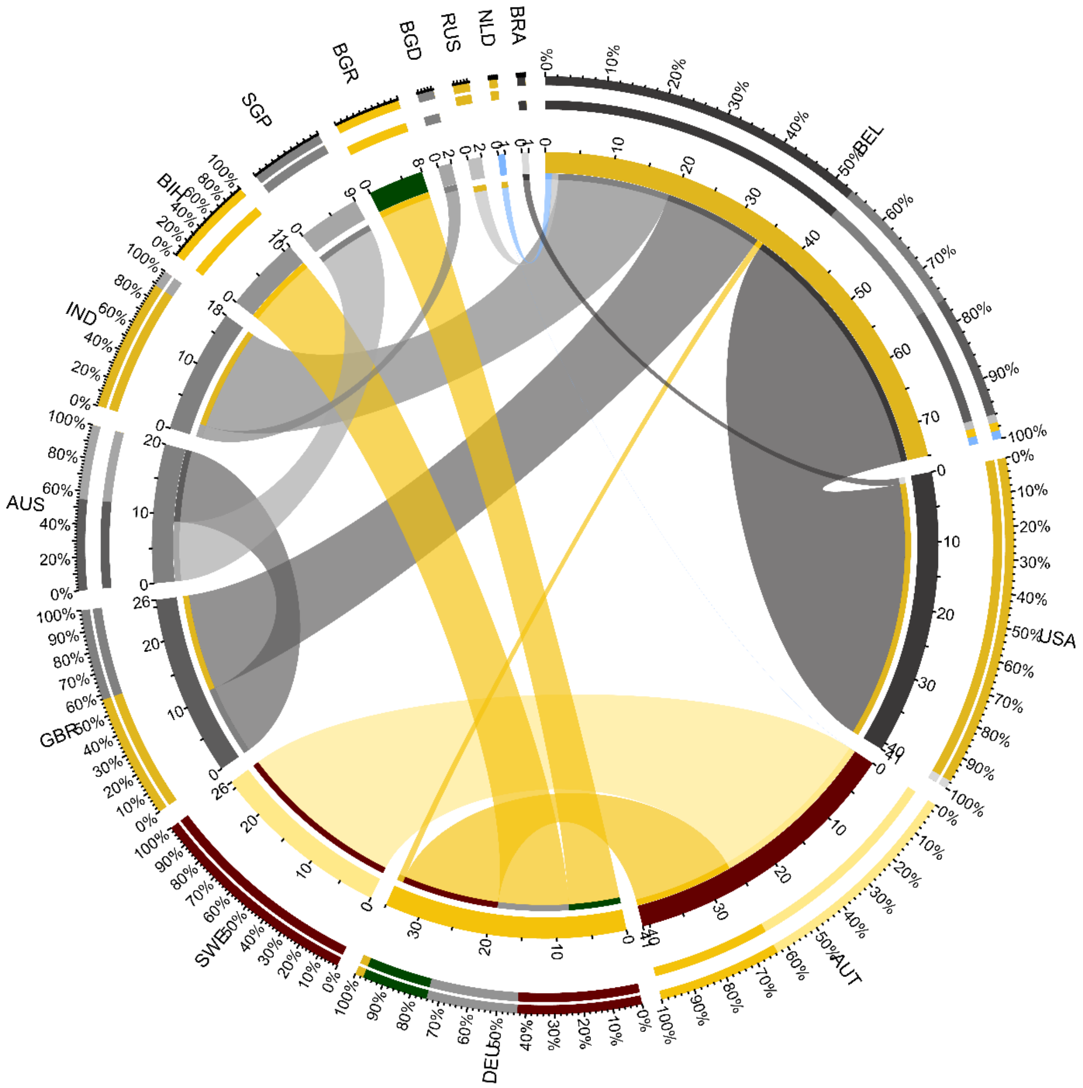

Figure 15: Chord diagram representing cobalt waste and scrap trade flows between countries for 2021, in kilotonnes (kt). Total cobalt waste and scrap traded = 0.16 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

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2.1.3 Key companies/actors or focus on Europe and cobalt

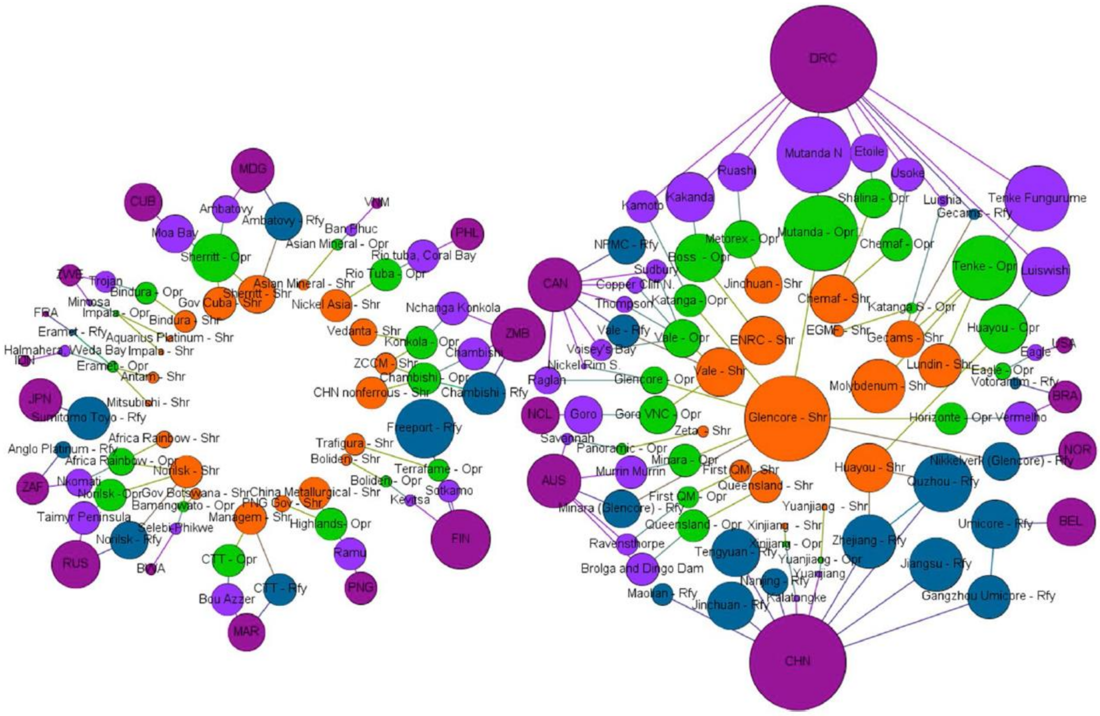

Figure 16: Cobalt supply chain network in 2016. From van den Brink et al. (2020a). Nodes represent countries and companies, with sizes corresponding to cobalt production levels (mined and refined). Orange links denote connections between companies, green links between operators and mines (refineries as operators), and purple links between companies and locations. Colors represent countries (dark purple), mines (light purple) mine operators (green), mine shareholders (orange) and refineries (blue). Refer to van den Brink et al. (2020) for company name abbreviations.

The key players in the cobalt supply chain have been identified by van Brink et al. (2020a). The researchers develop a visualization of the company network (see Figure 16). Their results reveal that global cobalt mining is largely dominated by a limited number of mine operators, primarily situated in the Democratic Republic of the Congo. In contrast, cobalt refining is concentrated in China but involves a more evenly distributed number of companies. Notable entities in the cobalt supply chain include:

- Glencore: The largest shareholder, Glencore, holds shares in multiple mine operator companies in the Democratic Republic of the Congo, Australia, Canada, and Norway (Glencore, 2023), making it a pivotal player in the cobalt supply chain.
- Mutanda ya Mukonkota Mining and Tenke Fungurume Mining, both operating in DRC: These operators are among the largest, contributing significantly to global cobalt production.

- Jervois (2023) -including the former Freeport Cobalt Oy - in Finland and Huayou Cobalt (2023) in China: These refineries play a crucial role in the cobalt refining process, underscoring their importance.

While these companies are major players, the cobalt production landscape is relatively diversified, as indicated by the Herfindahl-Hirschman Index (HHI) scores, which are 990 for operators, 1360 for shareholders, and 730 for refineries.

Most shareholders have a single link to one operator company, but a few, such as Glencore, hold shares in multiple mine operator companies. Companies with many linkages may pose a higher risk to the global cobalt supply chain if they experience disruptions. Glencore acts as a critical bridge between other companies or countries, enhancing supply chain resilience. The removal of these nodes can significantly impact the overall supply chain.

Multinational companies such as Glencore, Vale, Norilsk Nickel, and Chambishi Metals are prominent for their vertical integration, owning both cobalt mines and refineries, further solidifying their influence in the cobalt supply chain. Although the key players were identified in 2016, the current supply chain remains with a similar structure (SCRREEN2, 2023). For example, the largest cobalt producer in 2021 was Glencore, followed by Eurasian Group LLP, CMOC Group Ltd., Gécamines SA, and CN Nonferrous Mining Corp. Ltd (S&P Global, 2023).

Within the EU, a few key players contribute significantly to the cobalt supply chain. Mining companies include Terrafame in Finland, known for its contributions to cobalt production (Terrafame, 2023). In Spain, Aguablanca plays a significant role in sourcing cobalt within the EU (Aguablanca, 2023). Moreover, in the refinement of cobalt products, Eramet is becoming a significant player within the European landscape for battery recycling (Eramet, 2023).

2.1.4 Unit processes

Figure 17 summarizes cobalt transformation throughout the supply chain, including the unit process in each stage. As mentioned in Section 2.1.1, there are multiple types of cobalt deposits at the beginning of exploration and extraction, such as stratiform sediment-hosted copper-cobalt, nickel-cobalt laterite, and magmatic nickel-copper-cobalt sulfide. These forms are transformed into cobalt sulfide (CoS) and cobalt hydroxide (CoOH), as well as sulfide cobalt matte (from magmatic Ni sulfide). Then, the refining stage is used to transform CoOH into cobalt chemicals (i.e., carbonates and sulfates) and/or CoOH, CoS, and matte into cobalt metal and cobalt powders. In the downstream supply chain, these cobalt forms

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are used to produce tricobalt tetraoxide (Co_3O_4), nickel cobalt manganese hydroxide, and nickel cobalt aluminum oxides, which are applied in catalysis, batteries, pigments, and magnetic materials (SCRREEN2, 2023). Furthermore, refined cobalt compounds are transformed into lithium cobalt oxide and cathode materials – such as Li $(NiMnCo)O_2$ and $Li(NiCoAl)O_2$- that have direct applications in Li-ion battery manufacturing.

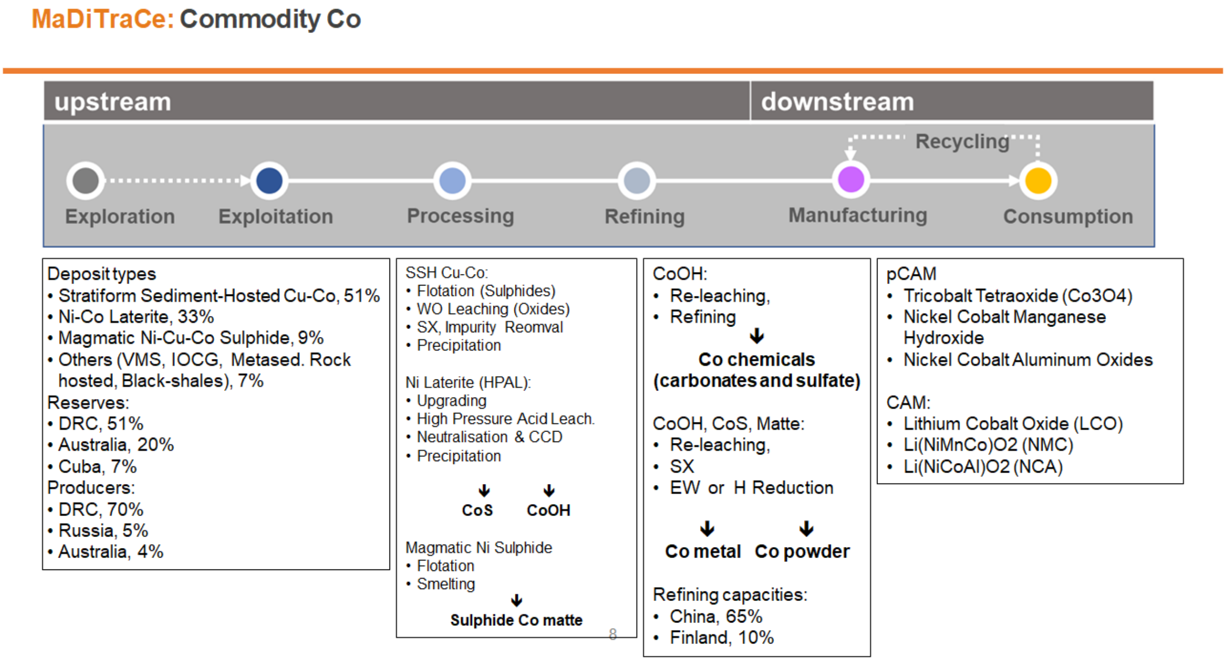

Figure 17: Upstream and downstream cobalt supply chain and unit processes.

2.2 Lithium

2.2.1 Primary sources and flows

Deposits – current and future sources

This section will be updated in the final deliverable D3.8.

Extraction and refining

In 2021, the global lithium extraction amounted to 115 kilotonnes (kt) of lithium mined in Li content (see Figure 18). The main supplier of lithium mined was Australia, with 48% of the total global extraction, followed by Chile (26%), China (12%), Argentina (9%), and the US (4%). Other suppliers of lithium mined were Zimbabwe, Portugal, Bolivia, Brazil, and Nigeria, which represented around 0.7% of global lithium extraction.

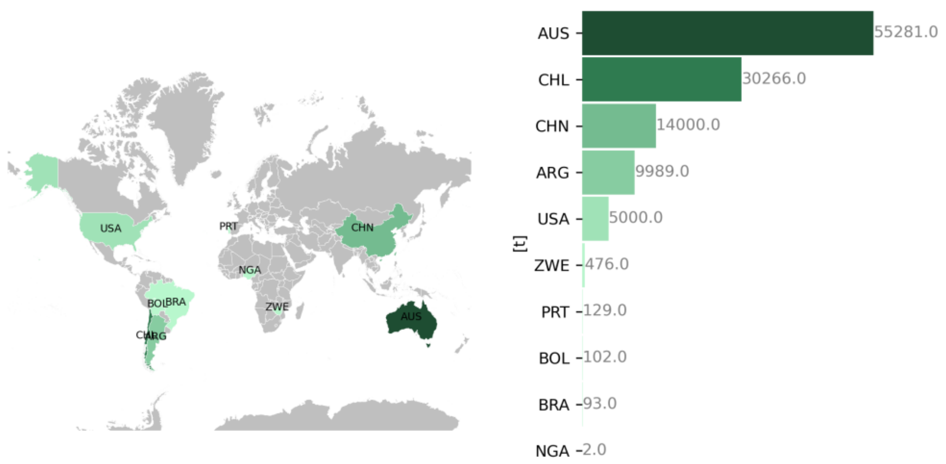

Figure 18: Lithium mined (in Li content) per country for 2021. Based on: BGS database (2023).

Trade

The global trade of lithium products amounted to 275 kt in 2021 (see Figure 19 and Figure 20). In this report, lithium products include lithium oxides and hydroxides (HS code 282520) and lithium carbonate (HS code 283691). The largest exporter of lithium products was Chile, with 53% of total exports, followed by China (30%) and Argentina (11%) (see Figure 19). Regarding imports, the largest importer was South Korea, with 35% of total imports, followed by China (30%) and Japan (20%). Within the EU, the Netherlands was the largest exporter of lithium products, representing around 5% of global exports. Furthermore, the Dutch exports consisted of lithium carbonates, lithium oxides, and hydroxide.

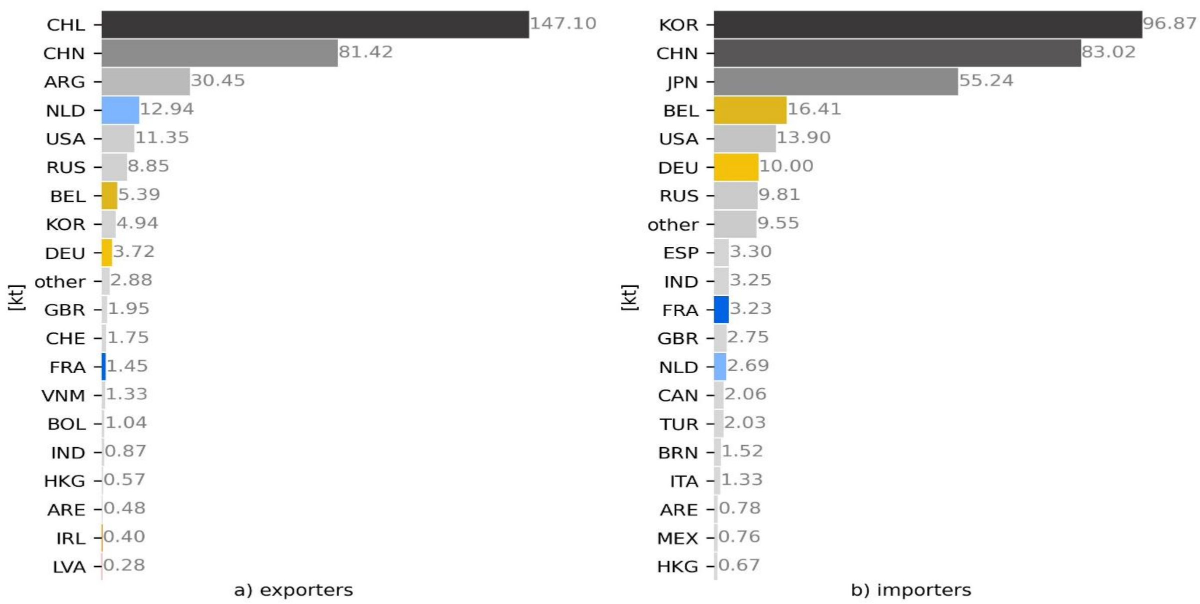

Figure 19: Top-20 (a) exporters and (b) importers of lithium products (lithium carbonate, and lithium oxide and hydroxide) in kilotonnes (kt). Total lithium products traded = 275 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

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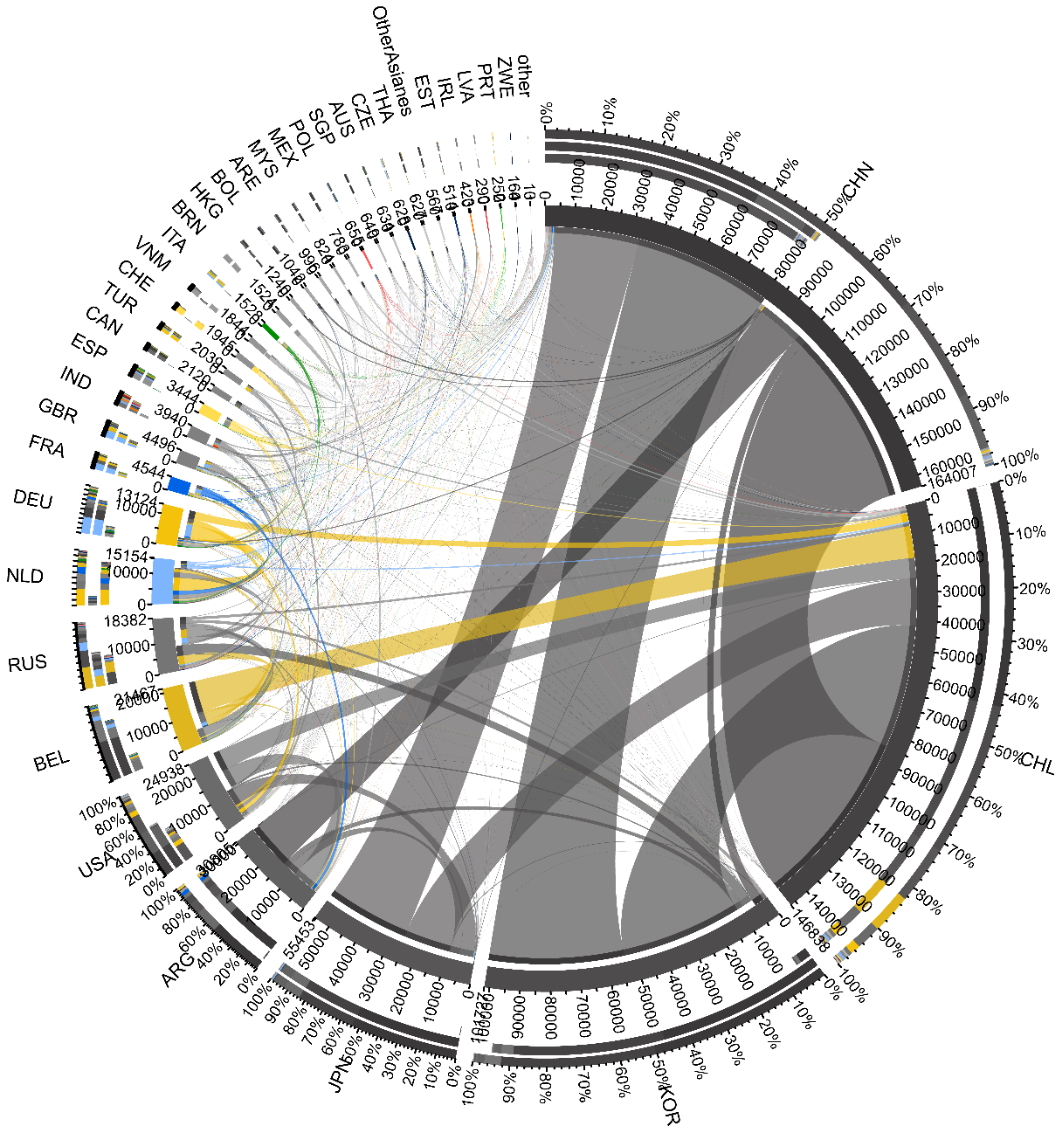

Figure 20: Chord diagram representing lithium products trade flows between countries for 2021, in kilotonnes (kt). Total lithium traded = 275 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

2.2.2 Secondary sources and flows

This section will be updated in the final deliverable D3.8.

2.3 Natural graphite

2.3.1 Primary sources and flows

Deposits – current and future sources

This section will be updated in the final deliverable D3.8.

Extraction and refining

Global natural graphite extraction amounted to 1270 kt (see Figure 21). The main producer of natural graphite was China, with 65% of the total global extraction, followed by Madagascar (8%), Brazil (7%), Mozambique (6%), and South Korea (3%). Other suppliers of natural graphite were Turkey, India, Russia, Austria, Ukraine, Norway, and Canada, which represented 11% of global natural graphite extraction.

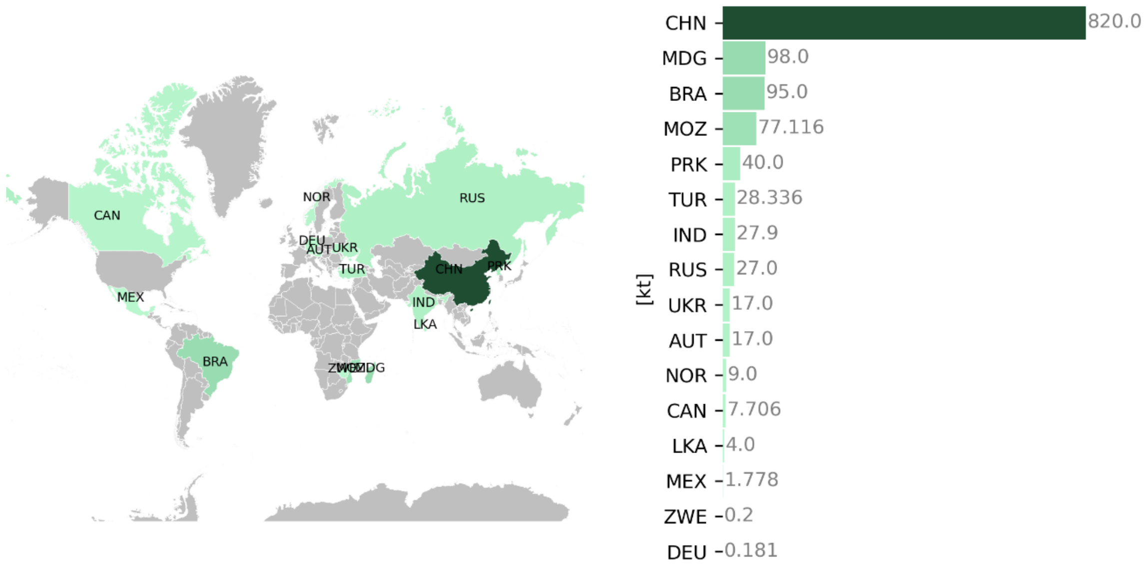

Figure 21: Natura graphite mined per country for 2021, in kilotonnes (kt). Based on: BGS database (2023).

Trade

The trade of natural graphite amounted to 1077 kt in 2021 (see Figure 22 and Figure 23). In this report, natural graphite includes both powder or flakes (HS code 250410) and in other forms, excluding powder or flakes (HS code 250490). The largest exporter of natural graphite was the US, with 47% of total exports, followed by China (25%), Madagascar (8%), and Mozambique (6%). Furthermore, the largest importer was the Dominican Republic, with 46% of total imports, followed by Japan (9%) and China (6%). However, Figure 32 to Figure

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35 show how atypical the flow is for the Dominican Republic. The detailed data shows that this is a flow from the HS code 250490 and that it was imported from the USA. It seems that this flow between the USA and the Dominican Republic can represent a particular situation of one year or an inexplicable reason. Other databases and documents do not indicate a major role of this Caribbean country in the natural graphite supply chain (see, for example, BRGM, 2024). Besides the US-Dominican Republic trade, other key importers were Germany, South Korea, the US, and India, whose combined share was almost 20% of total imports.

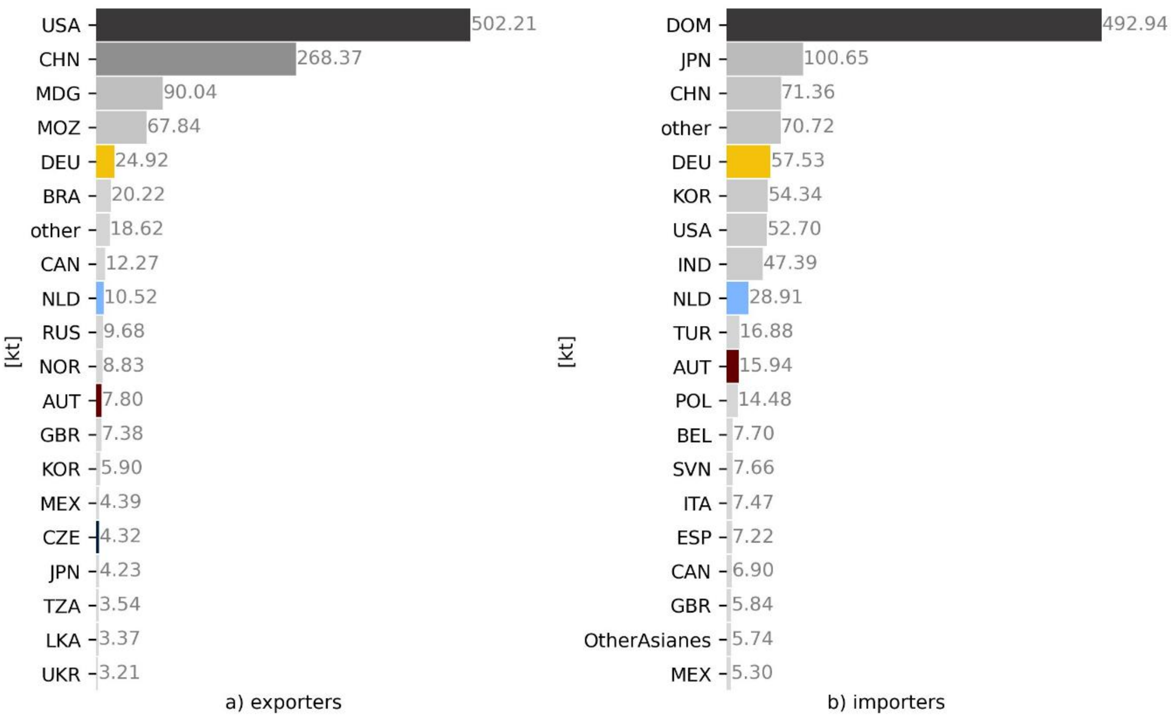

Figure 22: Top-20 (a) exporters and (b) importers of natural graphite in kilotonnes (kt). Total traded = 1077 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

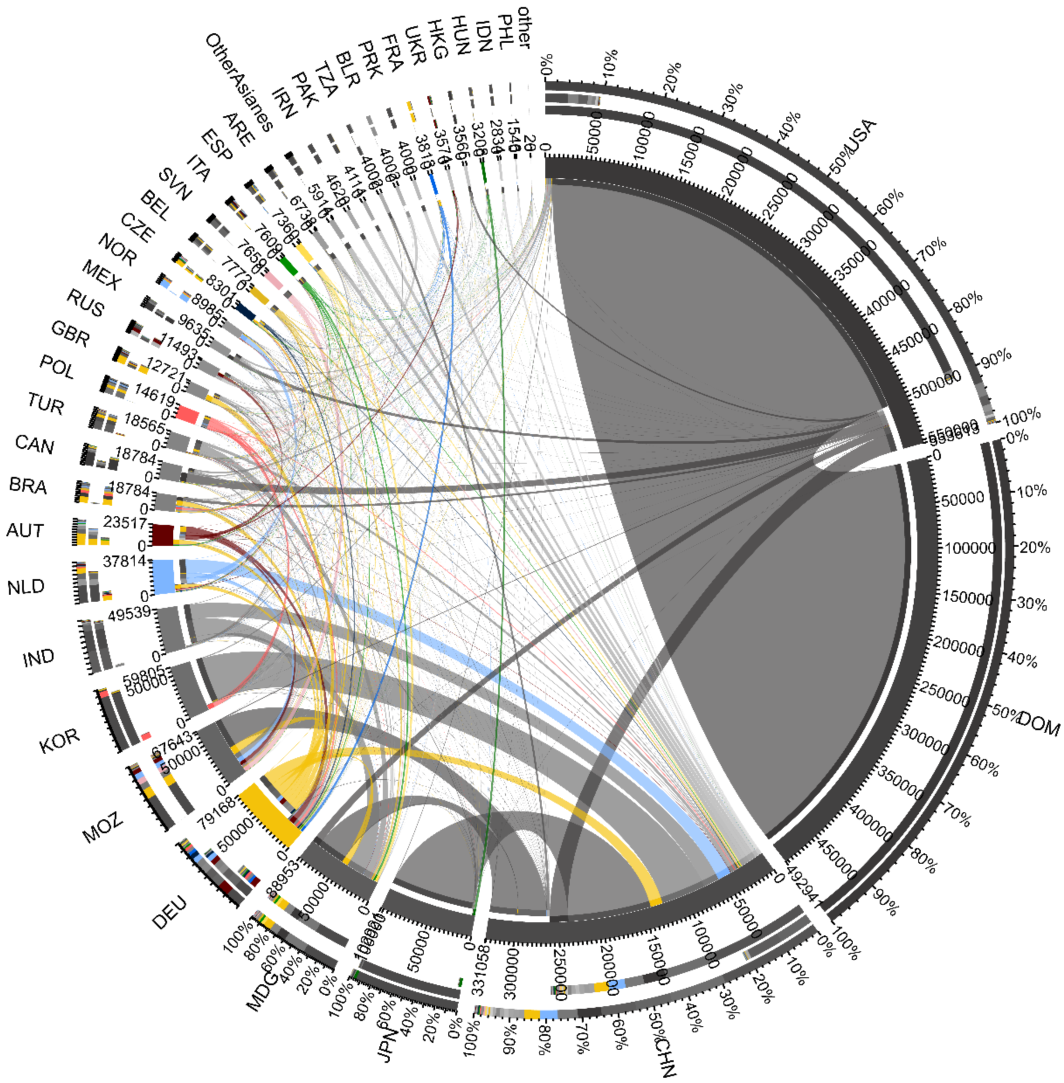

Figure 23: Chord diagram representing natural graphite trade flows between countries for 2021, in kilotonnes (kt). Total natural graphite traded = 1077 kt. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

2.3.2 Secondary sources and flows

This section will be updated in the final deliverable D3.8.

2.4 Neodymium

This section will be updated in the final deliverable D3.8.

2.4.1 Secondary sources and flows

This section will be updated in the final deliverable D3.8.

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3 Leverage points for traceability technologies

Leverage points are specific junctures in the supply chain where even minor adjustments can lead to significant positive changes, corresponding to strategic intervention spots (Bolton, 2022; Fischer & Riechers, 2019). Moreover, levers represent the practical tools and methods that are implemented at these leverage points to facilitate changes in a system (Chan et al., 2020). 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.

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. A set of three criteria to identify these strategic points of the supply chain was selected:

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

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.

The ports of entry in the EU can be identified by mapping the supply chain of the material in question, as presented in chapter 2. By tracking the import and export flows, not only can the ports of entry in the EU be identified, but also the origin of each flow, for the case of cobalt. For example, Figure 11 shows that the Netherlands and Belgium import significant amounts of cobalt mattes and other products with origins in countries like Canada, Russia, Madagascar, Morocco, and China. As circular economy policies evolve and the market for secondary materials becomes larger, it is also important to track these flows. Figure 14 shows that European countries like Belgium, Austria, and Bulgaria export significant amounts of cobalt waste that is bought by a variety of EU and non-EU countries. This analysis suggests that ports in Belgium and the Netherlands are then key leverage points to deploy traceability verification measures, ensuring that the materials entering Europe have their true provenance documented. This example shows how supply chain mapping can provide relevant information to identify leverage points.

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 24 illustrates the processes that the selected materials explored in this project are subject to. The choice of leverage points will require an analysis of these processes to identify key leverage points that should be monitored by sophisticated tools, such as chemical traceability through material fingerprinting.

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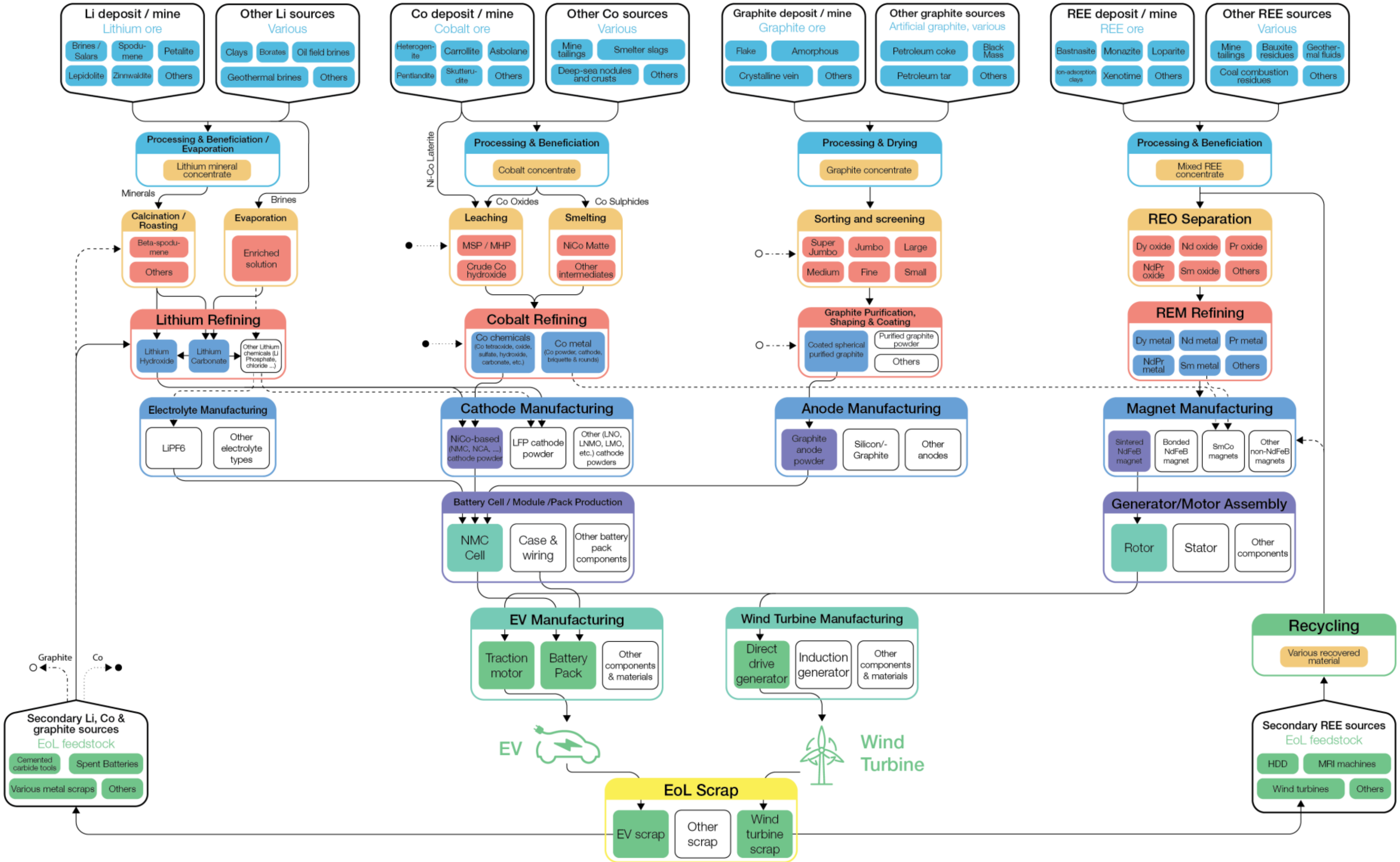

Figure 24: Process-level mapping of lithium, cobalt, natural graphite, and REEs for EVs and wind turbine manufacturing. Retrieved from: D2.1, MaDiTraCe project (Donnelly et al., 2023).

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 protocols (see Chapter 4 for detailed information). 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, one potential source of information is the S&P Global database (S&P Global, 2023), which offers pertinent data on company ownership, serving as a reliable indicator for changes in ownership events.

Identifying leverage points for traceability technologies requires a comprehensive methodology. This involves a hotspot analysis of the supply chains associated with the respective materials. Moreover, other considerations, such as where it is strategically most beneficial to deploy traceability technologies, should be defined as part of the criteria for a leverage point. This methodology will be proposed in D3.8. In the next chapter, the example of the lithium supply chain is described.

3.1 Lithium supply chain and material fingerprint case study

The lithium supply chain case is well suited to highlight and identify the leverage points to be covered by the material fingerprinting protocol developed in the MADITRACE project. Processes, transportation, and changes in ownership vary widely for a commodity depending on the country of origin and policies, deposit type, capacity of production and processing, costs, and global market, as well as the chemical form of the final product and its uses. To cover the leverage points for the traceability of these products following the three criteria mentioned earlier (processing, transportation, and ownership changes) is a complex task because of the multiple steps of chemical processes and transports from the mine to the final product. Figure 25 is an example of the pathways of four different lithium hydroxides used in the battery sector imported in Europe (Desaulty et al., 2020; Grant et al., 2020; Kesler et al., 2012; Swain, 2012).

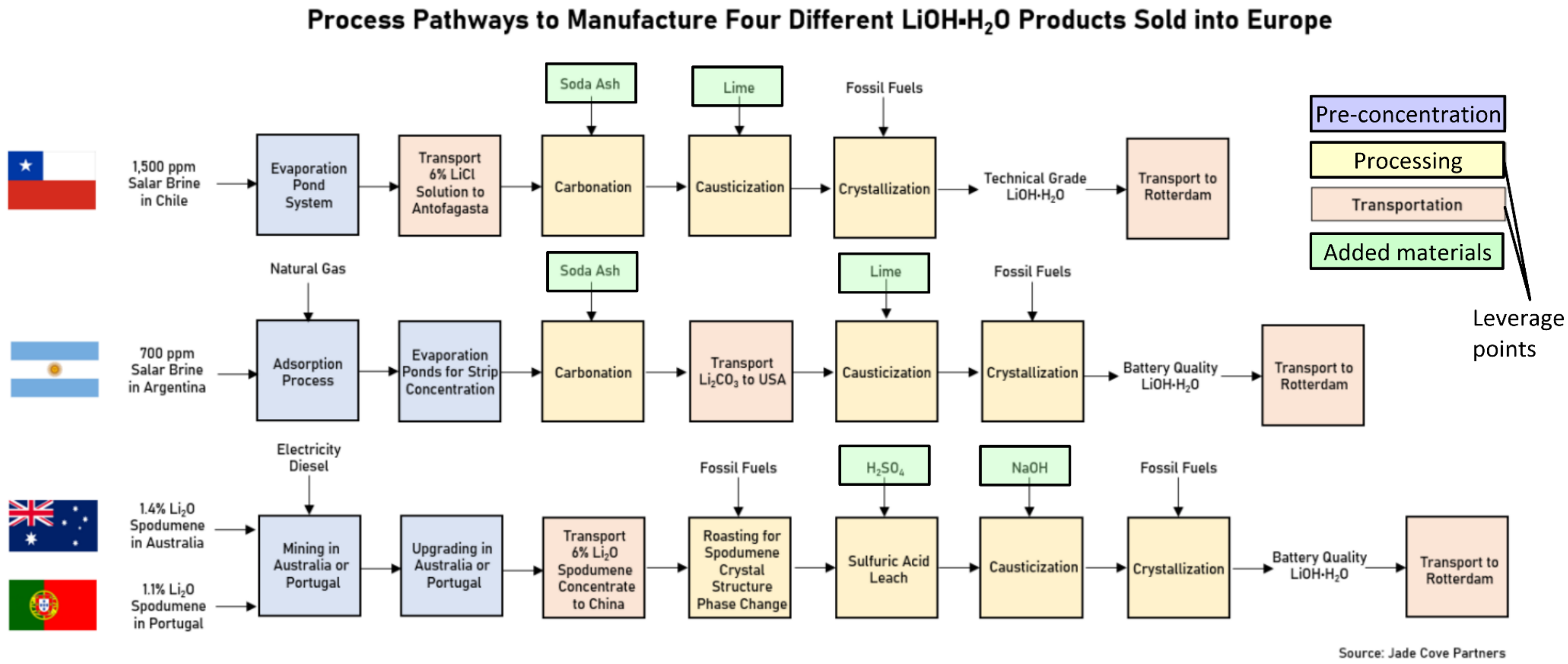

Figure 25: Process pathways to manufacture four different LiOH.H2O products sold in Europe modified from Grant et al. (2020). The transportation, extraction, and purification stages represent leverage points to be covered by the material fingerprinting protocol developed in the MADITRACE project

In this example, lithium from salar deposits of Chile and Argentina, despite coming from the same region of the world and the same deposit type, follows different pathways: lithium from Chile is concentrated in evaporation ponds and sent directly after to the port city of Antofagasta as a 6% Li liquid solution (LiCl). In Argentina, it is first subject to an adsorption process before going into evaporation ponds and then being transformed by carbonation and transported as lithium carbonate to the USA in order to undergo purification steps. This is partly due to the different natural concentration of lithium and constraining elements between these two deposits that drive the downstream processes (Kesler et al., 2012). Otherwise, lithium from "hard rock" deposits (coming from Australia and Portugal in this example) is pre-concentrated into spodumene concentrates (the lithium-bearing mineral in the deposits) and shipped to China.

The products coming from salar and spodumene mines are subject to extraction and purification processes after these pre-concentration steps in order to form high-purity, battery-grade lithium hydroxides (~≥99.5%). The extraction and purification processes induce major changes in the product chemistry and require the addition of numerous additives. Spodumene concentrates from Australia and Portugal are first roasted and then leached with sulfuric acid to dissolve lithium in an aqueous state. Finally, the products coming from the two types of deposits are mixed with additives (such as soda ash, lime, or sodium hydroxides) to remove undesirable elements, change their chemical form, and prepare them for the high-purification crystallization process. This last step produces battery-grade mono-hydrated lithium hydroxides for products from Argentina, Australia, and Portugal. The hydroxide originating from Chile does not fit the purity requirements and will need further transformation to reach the battery grade. For a situation of Li-ion batteries in Europe, all these products are then sent to the port of Rotterdam (The Netherlands).

These differences in processes and the chemical forms of the transported products are making the harmonization of traceability tools (mostly physicochemical fingerprinting methods) difficult. Traceability systems would require a custom technical development for each of them. Nevertheless, each process affects the chemical composition of the product differently, which could allow for downstream verifications of the fingerprinting of each specific process or pathway instead of the origin.

The mixing with additives, as well as the last purification steps, are likely to have drastic impacts on the chemical signature of the products. This makes it much more difficult to trace back the origin of these lithium hydroxides with physicochemical fingerprinting tools, despite them now being in the same chemical form and all passing through the port of Rotterdam.

This example shows how difficult it will be to develop the material fingerprinting protocol for the lithium supply chain. In particular, it will be necessary to implement intervention spots that consider both practical and technical aspects.

Another challenge is that typically, the processing plants use products from multiple mines, and lithium companies can own different lithium mines around the world, resulting in a mix that cannot be easily assessed in proportion and over time. Not all traceability tools are resilient to these mixes: adaptation, knowledge, and understanding are keys to addressing this problematic for intervention spots.

Thus, fingerprinting methods must be adapted to the nature and the processes undergone by the product at a certain point. Numerous different processes for each CMR commodity exist, and each of them can affect the physicochemical tracers differently. In the case of lithium, processes are different based on the deposit type and other parameters (Swain, 2017), and a study highlighted that the isotopy of lithium, which can be used for traceability, is modified by some processes (Desaulty et al., 2022). This reinforces the need to use a combination of different traceability methods (such as trace elements composition, isotopy, and artificial fingerprinting) to crosscheck the results.

In addition, future changes in the supply chain (new mines, processing plant constructions, and new technologies) may affect traceability tools and material flows. Intervention spots and technical methods must be resilient and/or adaptive to these changes, and a good understanding of the evolution of the supply chain will be necessary. Moreover, as regulations are country- and region-specific, any implementation of fingerprint methods should consider the existing and future regulations in the country of application in order to comply with legal requirements.

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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 5 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 a raw material. At this stage of the MaDiTraCe project, we have a preliminary understanding of the attributes that will be included in DPPs. It is important to note that this list is expected to evolve and expand throughout the course of the MaDiTraCe project, and more details will be provided in D3.8.

Data Attributes

The attributes listed below are mainly common to the CRM supply chain stages:

- 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.
    - Environmental impact of the process: Information regarding the environmental consequences of the processing stages, such as energy consumption, emissions, and waste generation.
    - Location of the process: The physical location where the processing occurs, including specific facilities or plants.

  - 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., n.d.).
- 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.
- 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 1). This helps ensure consistency and clarity in data representation and makes it easier for different stakeholders to understand and use the information.

Table 1. Data vocabulary for DPP methodology.

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.

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Digital Material Passport	A digital record or certificate that provides comprehensive information about the origin, processing, and characteristics of a specific raw material.
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.
Quality Control Checkpoint	A specific point in the supply chain where quality checks are conducted.
Traceability	The ability to track and trace the movement of raw materials throughout the supply chain, from mining to production.

Table 1 will be updated with more relevant terms in D3.8.

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. Further information about the role of LCA on DPP will be explored in D3.3 and D4.7 from the MaDiTraCe project (MaDiTraCe, 2024).

4.3 Compliance with CERA 4in1

As explained in section 4.1, a key requirement for DPP is to comply with the CERA 4in1 standard. In general, the standard will verify the capabilities of the companies to generate the data required for the EU Battery Regulation. This means the standard will not verify the correctness of the resultant value.

Detailed information about compliance with CERA 4in1 will be provided in D3.8.

4.4 Methodology for developing the Digital Product Passport

Considering the data vocabulary, attributes, and parameters (including compliance with CERA 4in1 standard) from sections 5.1 -5.3, 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 4in standards through data vocabulary, attributes, and accessibility?*

In this section, we 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.

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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.

5 State of practices of control methods and tracing solutions

Our focus in this chapter shifts to the state of practice of control methods. In particular, this chapter provides an overview of CoC models, with a spotlight on a gold case study. Drawing on the expertise of MaDiTraCe partners involved in WP1 and WP2, this chapter examines the diverse control methods and tracing solutions deployed at different checkpoints across supply chains. More details about the state-of-the-art interventions for traceability technologies (i.e., frameworks, standards, laws/regulations, and initiatives) can be found in the technical report D1.2 from MaDiTraCe project (Fernández et al., n.d.). The rest of the chapter will explore the state of practice of control methods in the context of CoC.

CoC models enhance traceability through the control and analysis of the movement of materials from one supply chain actor (e.g., mining companies, refineries, product manufacturers, retailers) to another, supported by physical or electronic evidence. Besides improving the traceability of raw materials, these models aid in validating claims related to sustainability aspects or that the products or processes have met certain required specifications. The four frequently used CoC models are identity preservation (IP), segregation, mass balance, and book and claim (ISEAL, 2016; Schöneich, S., Saulich, C. and Müller, 2023; van den Brink et al., 2019).

In the case of IP and segregation models (see Figure 26), the products originating from an entity that has fulfilled the standard requirements and policies, termed certified products, are kept separate from non-certified products from entities that do not have the required standard certifications. The IP model holds a slightly higher degree of stringency in handling materials when compared to a segregation model, as it does not allow the products coming from two different certified mines to be mixed, while in the segregation model, this is possible. Nevertheless, IP provides the possibility to make the strongest claim regarding the origin of the material (ISEAL, 2016). Such separation models are preferred by sustainability schemes when dealing with minerals from conflict-affected and high-risk areas, so there is no mixing between certified and non-certified products and the origin of the product can be verified (van den Brink et al., 2019).

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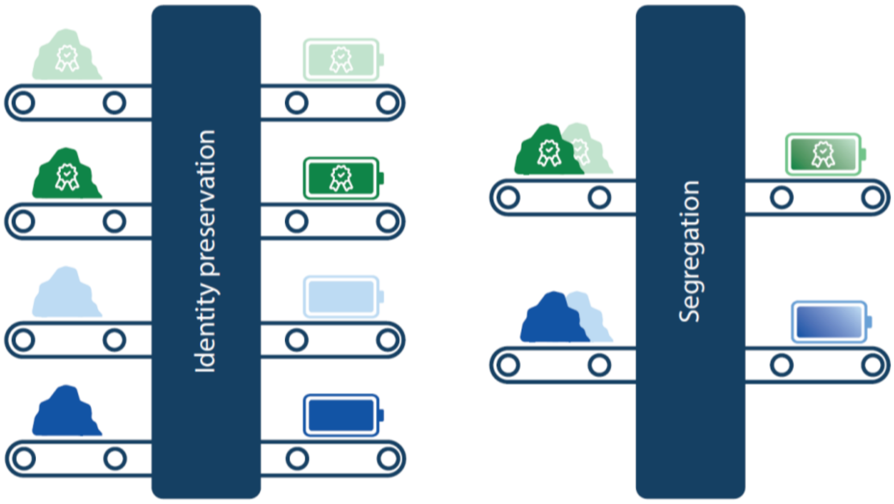

Figure 26: Illustration of the identity preservation and segregation CoC methods.

A mass balance model (see Figure 27) allows the mixing of certified and non-certified products, and the amount of raw materials can be balanced at the batch, site, or group level (ISEAL, 2016). Compared to the separation models, mass balance is a simpler approach that can be handled with a less demanding infrastructure and accounting methods depending upon the nature of claims sought by the entity or the requirements of the standard. For instance, to meet the regulatory requirements, a smelter could adopt a mass balance approach to determine the share of responsibly sourced and conflict-free materials in their product (STRADE, 2018).

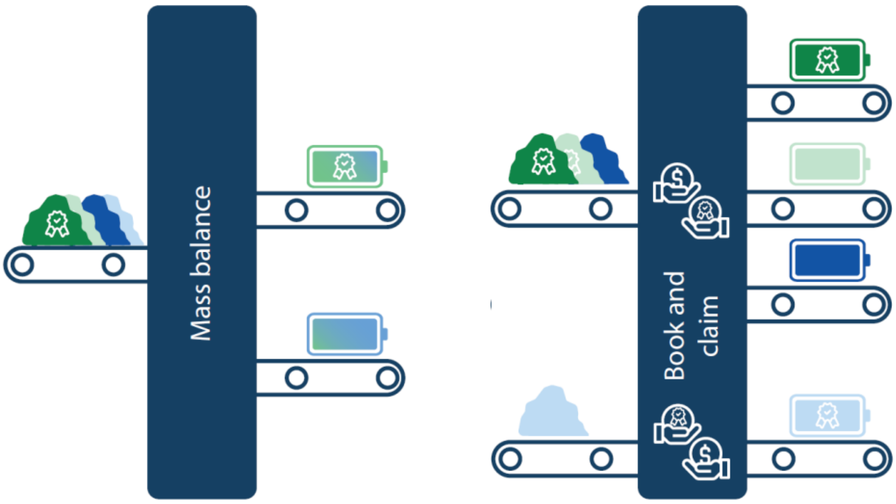

Figure 27: Illustration of the mass balance and book and claim CoC methods.

Unlike the previous models, book and claim models (see Figure 27) do not provide sufficient information about the origin of a product and do not comply with the CoC requirements. This is because the certificates are traded on an online platform, regardless of whether the manufacturer has sourced the raw materials from a responsible source (ISEAL, 2016).

The CoC standard will consider the different CoC models under the management prerequisites, and the allocation will depend upon the environmental, social, and governance (ESG) impacts to help organizations align with stakeholders' expectations and make corresponding claims regarding the procurement and sourcing of their materials.

Gold traceability applications

Even if it is not a commodity covered by the MaDiTraCe project, it is proposed to consider the example of gold as an example of CoC applications, based on the gold case study brought by Pochon et al. (2021). While major gold mining companies focus on primary deposits, artisanal and small-scale operations in secondary eluvial and alluvial sites remain significant. Responding to civil society pressure, importing countries have imposed certified supply chain restrictions, notably through the Dodd-Frank Act in the USA (CFTC, 2023) and the EU Regulation 2017/821 (European Commission, 2020), requiring due diligence to curb funding to armed groups.

There are two primary methods that have been developed to ensure traceability of minerals, such as gold. The first method involves the implementation of CoC systems, relying on shipping documentation and online databases. This approach is called "bagging and tagging" and allows for real-time tracking of materials. However, this method is susceptible to fraudulent activities, raising concerns about its reliability and security. For instance, both the American Dodd-Frank Act and the EU Regulation 2017/821 emphasize the importance of due diligence reviews within these CoC frameworks, which aim to ensure that gold purchases do not fund armed groups in conflict-affected regions. While these regulations provide a foundation, their effectiveness relies on the integrity of the implemented CoC models, which highlight the need for rigorous oversight and verification protocols.

The second method is analytical fingerprinting, which provides details about the intrinsic signatures of raw or treated minerals, offering a more comprehensive yet challenging approach. For example, the German Federal Institute for Geosciences and Natural Resources (BGR) has pioneered this technique, employing a multi-method approach to develop analytical fingerprints for minerals. Similarly, studies focusing on gold have utilized techniques such as laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to quantify trace-level components within gold matrices. By assessing minor element compositions and micro-inclusions in gold crystals, researchers have made strides in distinguishing legal from illegal gold. However, these methods present challenges,

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particularly concerning the heterogeneous composition of gold at the sub-micrometer level, demanding sophisticated multivariate data analysis techniques.

Moreover, the traditional marker of mercury content in recovered gold faces challenges due to evolving regulations. While its presence was indicative of illegal gold due to its usage in small-scale mining, the global shift towards mercury elimination requires the industry to adapt and find alternative markers for distinguishing legal and illegal gold effectively. These challenges underscore the pressing need for innovative traceability technologies that ensure the sustainability and ethical integrity of the gold supply chain.

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6 Conclusions

This report brings a starting point to establish robust traceability and transparency mechanisms within the EV battery and motor vehicle supply chains, particularly focused on the development of an innovative DPP methodology. There are several key aspects that have been highlighted throughout the report:

- Responsible sourcing and traceability challenges: There is a clear necessity for responsible sourcing and transparency, particularly for the selected materials (i.e., cobalt, lithium, natural graphite, and neodymium). These materials are critical for EV battery and motor vehicle advancements and require ethical extraction and transparent supply chains to address social and environmental impacts.
- Supply chain mapping: Comprehensive mapping of primary and secondary flows of CRMs shows the complexity and global dynamics of these supply chains. Insights into trade flows, key stakeholders, and unit processes highlight areas for targeted interventions and traceability technology implementation.
- Leverage points for traceability technologies: Identifying strategic leverage points within the supply chain – which includes changes in location, chemistry, and ownership - offers significant opportunities for deploying traceability technologies but also represents several scientific, technical, logistical, and economic challenges:
    - Material fingerprinting (MFP) work in WP2 of the project needs to demonstrate the feasibility of MFP and material traceability for different substances
    - MFP techniques require a set of chemical and physical analyses that ideally should be made close to leverage points (port of Rotterdam, for example) or close to mines, with results in a short time if possible
    - The cost of different MFP solutions and analysis must be considered in future work of the MaDiTraCe project.
- State of control methods and tracing solutions: The CoC models vary in effectiveness and application for ensuring the legitimacy of materials sourced. Each model is adapted to the specific intrinsic characteristics of different metals but also to different supply contexts. This is particularly evident in the gold case study. Thus, there is a need for rigorous oversight and verification protocols to maintain the reliability of traceability frameworks.

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- Requirements, elicitation, and classification for DPP: The development of a DPP methodology requires attention to data attributes, requirements, accessibility, data vocabulary, metadata, and compliance with standards such as CERA 4in1. In this report, we proposed key aspects for the DPP methodology, including impact analysis, value chain assessment, and stakeholder engagement, as well as ensuring a comprehensive and standardized approach across different product segments.

Overall, the comprehensive insights gained through the supply chain mapping, identifying leverage points, exploring CoC models, and defining DPP requirements establish a solid foundation for advancing traceability, transparency, and ethical sourcing within CRM supply chains. The proposed DPP methodology and insights presented in this report provide key aspects to be considered for future initiatives within the MaDiTraCe project, ensuring sustainability, compliance, and accountability across these critical industries. This work will be extended in other MaDiTraCe deliverables, especially in D3.8.

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8 Appendices

8.1 Cobalt content by HS code

HS code	Description
2605	Cobalt ores and concentrates
2822	Cobalt Oxides and hydroxides: commercial cobalt oxides
8105	Cobalt: mattes and other intermediate products of cobalt metallurgy, cobalt and articles thereof, including waste and scrap
2827 34	Chlorides: of cobalt
2915 23	Acids: saturated acyclic monocarboxylic acids: cobalt acetates: no results import of export data

Cobalt' product'	HS code	Estimated percentage cobalt	Source
Cobalt ores	2605	**0.1% to 2.5%** depending on the deposit	British Geological Survey (2009). Cobalt. https://www.bgs.ac.uk/downloads/start.cfm?id=1400 (accessed 16 April 2019)
Cobalt concentrates	2605	**Up to 15%**	Young, R.S., Campbell Taylor, J. (2017) Cobalt processing. https://www.britannica.com/technology/cobalt-processing (accessed 16 April 2019)
Cobalt oxides	2822	**Around 79%** (depending on form)	Wikipedia (2019). Cobalt (II) oxide. https://en.wikipedia.org/wiki/Cobalt(II)_oxide (accessed 16 April 2019)
Cobalt hydroxide	2822	**Around 54%**	Wikipedia (2019). Cobalt (II) hydroxide. https://en.wikipedia.org/wiki/Cobalt(II)_hydroxide

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		(depending on form)	
Unwrought cobalt	8105	For example an ingot of unwrought cobalt alloy is made up of **68%** cobalt. Bare hard facing welding rots typically contain **60%** cobalt. Electric induction melted **64%.**	Tariff Nomenclature (2016). Other cobalt, unwrought, powders. https://tariff.cc/en/other-cobalt-unwrought-powders (accessed 16 April 2019)
Powders	8105	Commercial cobalt-metal powders are available in purities ranging from **99% to ≥ 99.999%** in many grades, particle size ranges and forms.	International Agency for Research on Cancer. (2018). Metallic cobalt particles (with or without tungsten carbide). https://monographs.iarc.fr/wp-content/uploads/2018/06/mono86-6.pdf (accessed 16 April 2019)

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Cobalt matte	8105	Cobalt content in matte is around **1.5% to 2%.**	British Geological Survey (2009). Cobalt. https://www.bgs.ac.uk/downloads/start.cfm?id=1400 (accessed 16 April 2019)

8.2 Time series plots of specific flows

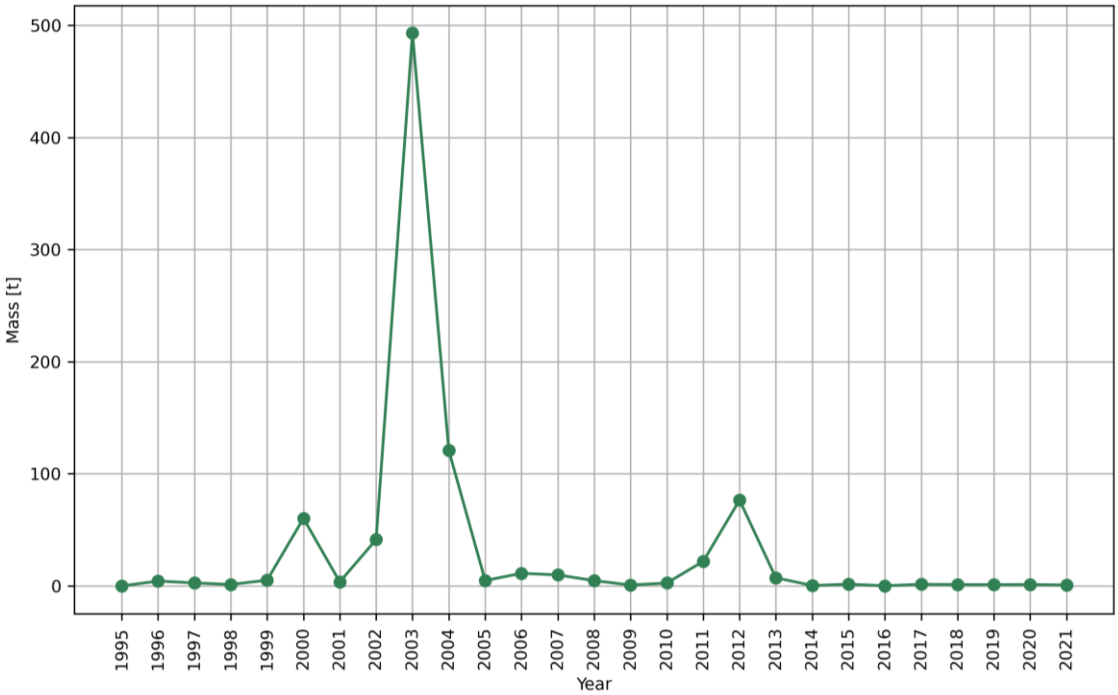

Figure 28: Italian imports of cobalt ores and concentrates between 1995 and 2021. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

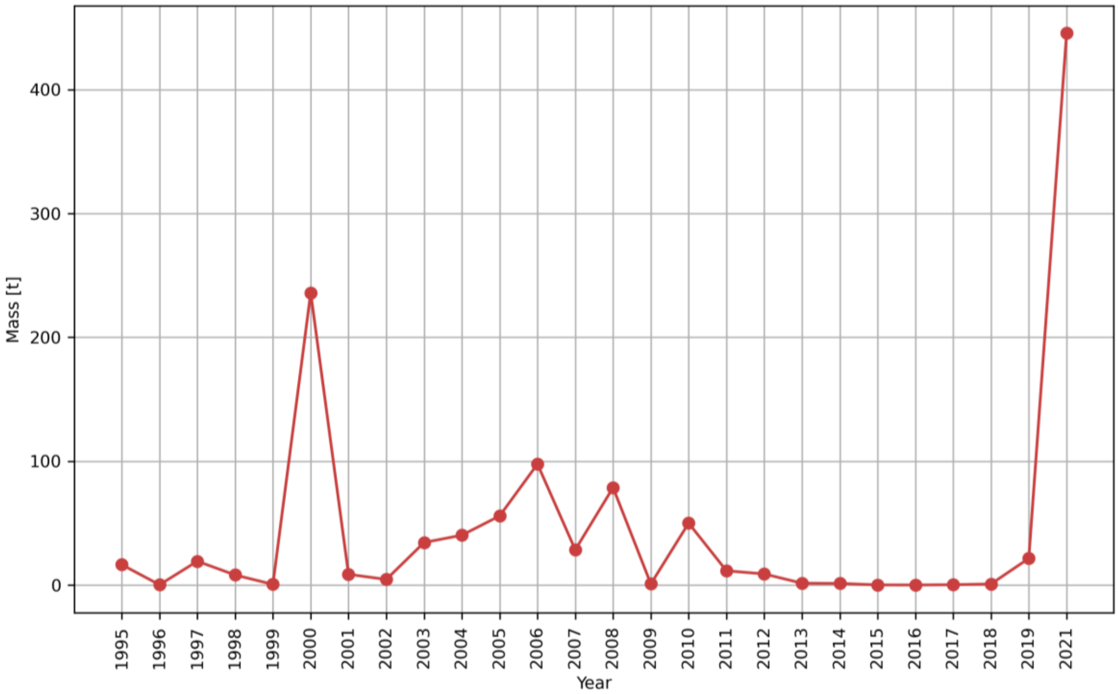

Figure 29: Italian exports of cobalt ores and concentrates between 1995 and 2021. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

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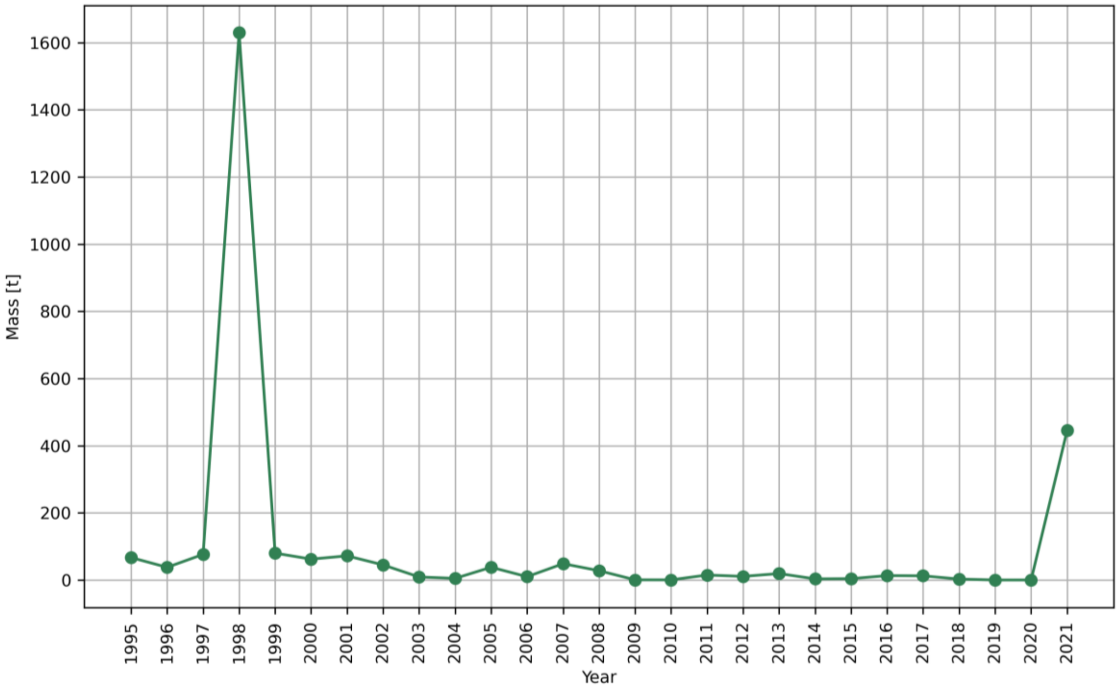

Figure 30: French imports of cobalt ores and concentrates between 1995 and 2021. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

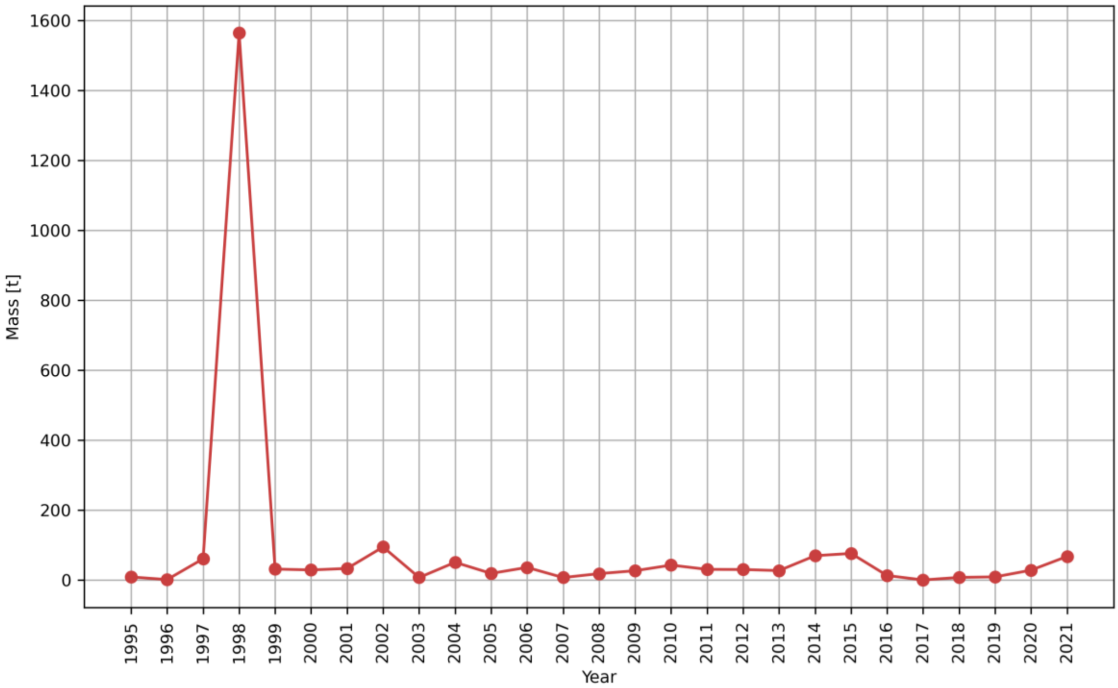

Figure 31: French exports of cobalt ores and concentrates between 1995 and 2021. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

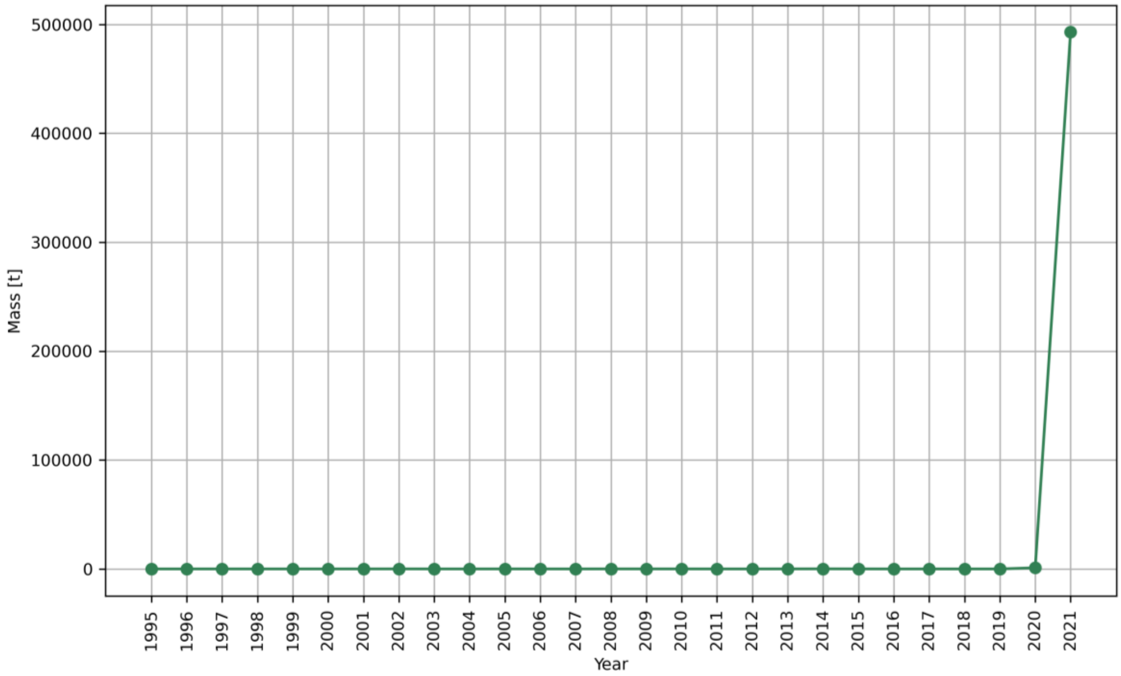

Figure 32: Imports of natural graphite in powder, flakes, and other forms by the Dominican Republic between 1995 and 2021. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

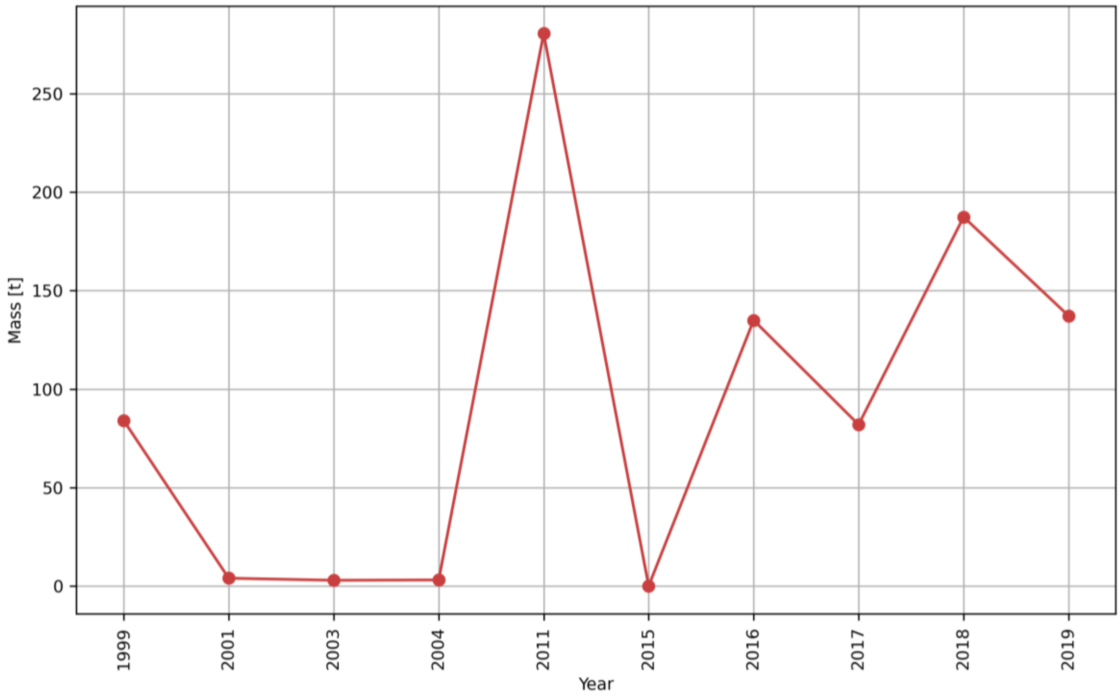

Figure 33: Exports of natural graphite in powder, flakes, and other forms by the Dominican Republic between 1995 and 2021. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

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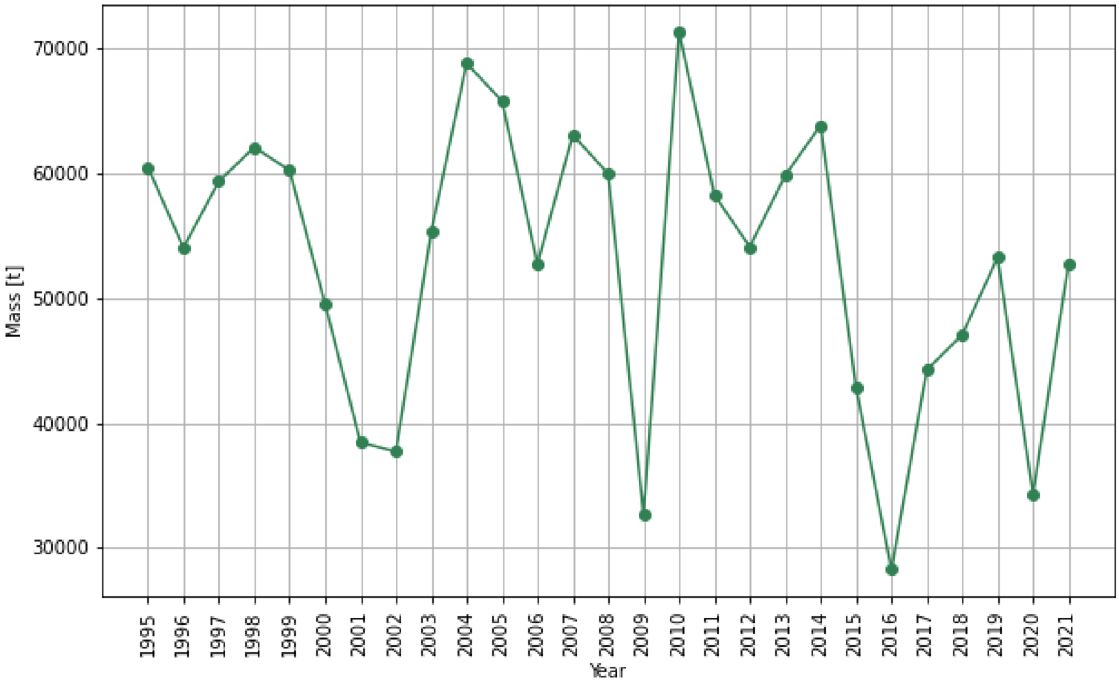

Figure 34: Imports of natural graphite in powder, flakes, and other forms by the USA between 1995 and 2021. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).

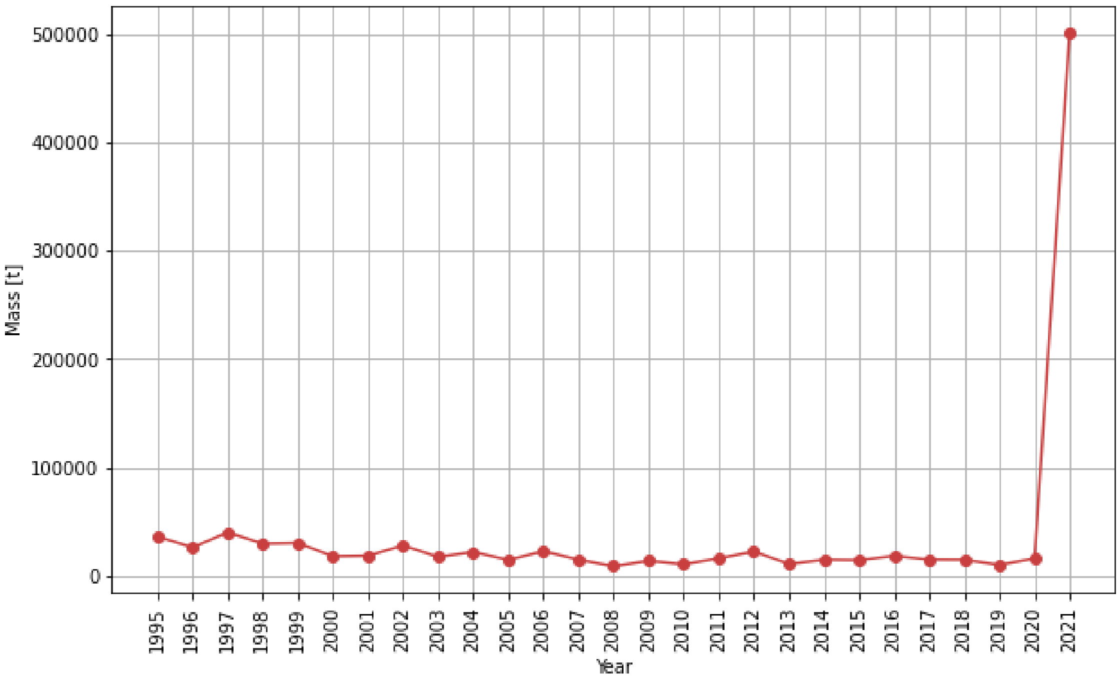

Figure 35: Exports of natural graphite in powder, flakes, and other forms by the USA between 1995 and 2021. Based on: CEPII-BACI database, version 202301 updated in February 2023 (Gaulier & Zignago, 2010).