Chapter

Europe's Raw Materials Supply Chain: Front-End Considerations

Antje Wittenberg, Daniel de Oliveira, Tom Bide, Julie Hollis, Siim Nirgi, Gorazd Žibret, Håvard Gautneb, Martiya Sadeghi, Rafael Navarro Domínguez and Boris Malyuk

Abstract

Supply chains are linked for specific purpose and by something. Hence, the respective links of the chain must be hooked in the right place, sufficiently strong, and have to start somewhere. This chapter looks at the raw materials supply chain as the first link in a commodity supply, from the European Union (EU) perspective. Aspects of the raw material potential of critical or strategic mineral resources in Europe, its further exploration, and the concept of modifying factors are considered, and reporting systems of resources and reserves are described, underpinned by examples of mineral potentials in different regions of the EU. Thus, targeted exploration of raw materials, especially within the framework of national geological research, serves to support a sustainable and resilience supply chain. EU projects, such as GeoERA and Geological Service for EU, assist in shaping the tailor-made exploration programs fit for providing mineral data publicly available through EuroGeoSurveys' European Geological Data Infrastructure. In the future, raw materials may be seen as global public goods required to address many challenges, from the climate crisis to geopolitical instability; therefore, the society could conceptualize them in a new way, from a dominant investment returns-oriented viewpoint to one linked to delivering global objectives.

Keywords: exploration, raw materials, sourcing, strategic, critical, potential, Europe, resource management, UNFC

1. Introduction

Supply chains may be defined as including all stages involved in producing and delivering a final product, including managing supply and demand, sourcing raw materials and parts, manufacturing and assembly, and warehousing and inventory. They are essential for maintaining and improving the well-being of societies worldwide [1]. Mineral and energy raw materials are of particular importance, for example, [2, 3] in many supply chains, because they provide the basis for products, as well as they are essential for the supply of energy [4, 5]. Mineral raw materials can be divided into primary raw materials, which are extracted from the Earth's crust, and secondary raw materials, which are produced in the process of recycling. This chapter will focus on primary inorganic raw materials of natural origin and in particular on metals and metalliferous minerals (e.g., Fe, Cu, Pb, Zn, Au), and industrial minerals (e.g., salt, clay, barite, fluorite, limestone), while construction minerals (e.g., sand, gravel, marble, granite, basalts) are only touched upon. Primary raw materials are the starting point of the complex supply chains in Europe and beyond [6].

Primary raw materials pass through extraction, beneficiation, and transport processes before being introduced into the manufacturing process of various goods. Different regions and countries are involved in these actions. Numerous players with different interests and objects have to play together, including producers and manufacturers, suppliers, traders, and customers, ensuring the flow of goods and products on the global markets as much as in the local one. Establishing global relationships by upstream and downstream industries, including the primary raw material production, is part of common strategies [7, 8]. The functioning of supply chains is also influenced by the collaboration, innovation, trade relationships, and relationships among various disciplines and stakeholders, up to foreign affairs.

Europe's key industries, including automotive, electronics, and pharmaceuticals, need a steady flow of essential goods made from minerals and metals [9], and the requirement is not limited to them. Moreover, economy is highly dependent on reliable and timely supply of raw materials and semifinished or finished goods [10, 11]. Geographic considerations have been a key component for building up raw materials supply chains for centuries when manufacturing facilities, for example, were established in proximity to raw material sources and related refinement facilities to minimize logistical challenges, including transportation costs. Nowadays, geographic location is of less importance since many supply chains are globalized [12, 13]. The belief in a fair and open market was high, while in Europe raw material prospection, exploration, and mining were often considered as unfavorable [14]. Yet, many downstream industries in Europe have withdrawn their direct engagement in mining since 1990, while new players arrived on the global market. During this time, the demand for commodities has increased significantly and with it the competition for the available resources [15].

The plentiful crises of the last decade have pointed out the importance of undisrupted raw materials supply chains, highlighted also by headlines of daily news [16–20]. Events that are not only difficult to influence, such as natural disasters, political instabilities, or changes in trade policy, but also labordisputes and the like can lead to significant bottlenecks, price fluctuations, or delays that disrupt the entire raw materials supply chain [21–24]. Any market distortion or failure has its consequences, some of which have hit Europe's economy unexpectedly hard [25].

Thus, modern supply chain planning benefits from a good knowledge of primary raw material deposits, the local conditions, where they are mined and processed, and the framework conditions under which the partners in the supply chain perform [26, 27]. Such planning enables companies to anticipate potential supply shortages, assess risks, and develop strategies to secure a stable and reliable supply of raw materials. At the same time, sustainability practices, such as responsible sourcing, ethical labor practices, and minimizing the environmental footprint associated with raw material extraction, are becoming increasingly important [19, 27–29]. This is due to both the need to meet production demands and consumer concerns about the associated environmental and social impacts [30–32].

Hence, it is currently widely recognized that functional supply chains serve our societies through the functioning of our economies by providing jobs and high living standards. This holds at least for developed and industrialized countries. Thus, building up resilient supply chains has become as much of strategic importance by governments [21, 22, 33–38] as by industry [38–40] and is a matter of many supply risk studies in the twenty-first century [41–44].

2. The raw materials supply chain front-end approach

Over the last decades, Asia has become an important player on the global market. China, in particular, has demonstrated strength in all parts of the raw materials value chain. It continues to build its position with strategic activities abroad, for example [42, 45–48]. Supported by strategic exploration programs, China is systematically improving its knowledge of national resources and acquiring competencies in the most preferred technologies [44, 45, 49, 50]. Other countries, such as Saudi Arabia and Indonesia, for example, are gaining more and more market dominance on raw materials such as nickel, cobalt, gold, and their related supply chain. The increasing global competition and the very fragile supply chains call urgently for actions and smart strategies by companies and governments [51, 52]. Strategic thinking starts often only at the extraction stage [1, 22, 53]. Yet, all of the supply chain stepping-stones are more or less obviously related to mining. In contrast, the very first step—the exploration of potential resources—is often overlooked, while the general principles still hold [8]. Thus, a first step toward greater resilience by promoting import independence is knowledge about one's own raw material deposits (potentials), especially their distribution, quantities, and qualities (see 3.2). The regional and National Geological Survey Organizations (NGSOs) and their European umbrella organization "EuroGeoSurveys" act particularly, but not exclusively, in the first segments of the supply chain that sets the raw material value chain in motion (**Figure 1**).

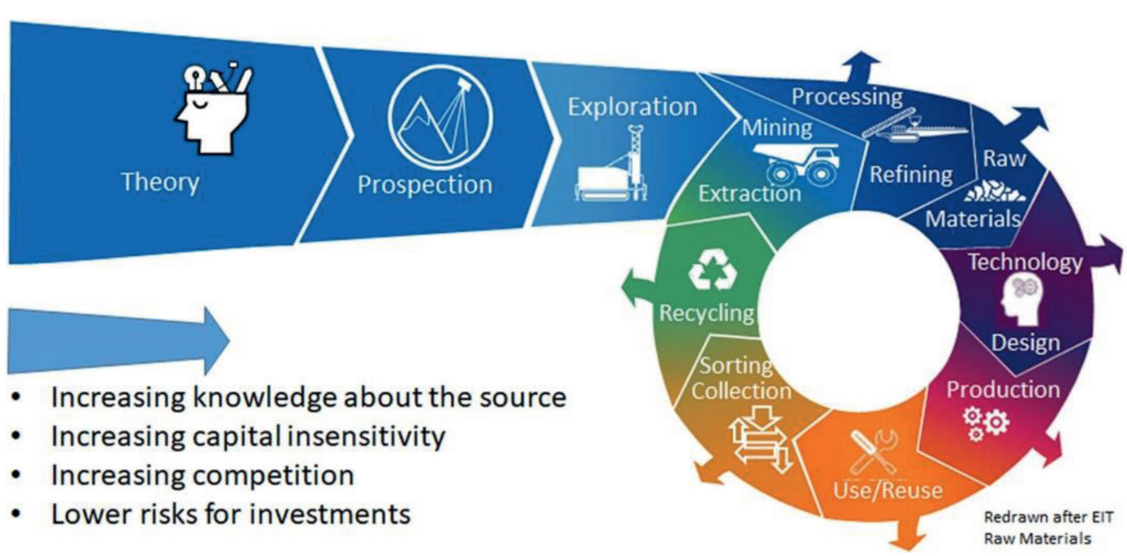

Figure 1.
The supply and value chain of raw materials shows the importance of the first segments of the supply chain—From theory (e.g., geological modeling) to exploration—To turn the wheel of a (circular) economy, redrawn after ref. [54]. The smaller arrows indicate the inevitable loss of resources associated with the respective segment of chain link, making mining indispensable even in the best possible circular economy.

2.1 The political dimension of exploration and mining data in the raw material supply chain

Europe is the only populated continent that has seen a decline in mining production by 31% in the period 2000–2021 [55]. Lack of investment in European exploration, mining, and processing is a key reason for the EU's current raw materials supply chain weakness. For example, the supply chain squeezes on magnesium [56], gallium and germanium [57, 58], illustrates China's dominance on several commodities along the value chain. Europe's weak position is also caused by limited focus on international raw materials strategic partnerships and diversification of sourcing over the same period.

This vulnerability has not gone unnoticed in the EU. As far back as 2008, the European Commission established the raw materials initiative, which set the framework for the future EUs raw material supply security. The initiative consists of three pillars: (i) access to raw materials on world markets at undistorted conditions, (ii) foster sustainable supply of raw materials from European sources, and (iii) reduce the EU's consumption of primary raw materials [59, 60], followed by the European Innovation Partnership (EIP) on raw materials, the raw material alliance, strategic partnerships on raw materials and not yet adopted Critical Raw Materials Act (CRMA) [33]. Within the Act European Commission defined a) critical (CRMs) and b) strategic raw materials (SRMs) as a) materials of high importance to the economy, while the supply is associated with a high risk of disruption; b) crucial to technologies important to Europe's green and digital ambitions and for defense and space applications, while being subject to potential supply risks in the future [58, 59]. The European Commission updates periodically its list of CRMs. The list of 2023's contains a total of 34 individual raw materials or groups of raw materials [61].

Unfortunately, such EU actions have been overtaken by subsequent events that heavily impacted European raw materials supply chains, including the COVID-19 pandemic, the Russian war in Ukraine, and the international race for mineral security to meet the ambitions of the required green transition. As a result, the pace of EU strategic and legislative action has increased in the years 2021 to 2023, for example, through initiatives such as the Global Gateway [62] and InvestEU [63], as well as implementation of the European Climate Law [64], REPowerEU Plan [65], the Green Deal Industrial Plan [66], the Chips Act [67, 68], the Corporate Sustainability Reporting Directive [69, 70], as well as the recently proposed Net Zero Industry Act [71] and CRMA [33].

Sustainable sourcing and efficient use of raw materials are key for Europe's long-term resilience and competitiveness in the face of global markets. The upcoming CRMA sets the benchmarks for annual consumption of raw materials in the European Union for domestic sourcing through extraction, processing, and for import dependencies from a single third country. Moreover, these benchmarks are the main objective of Europe's strategy on critical and strategic raw materials [43]. Moreover, the EU is trying to increase its knowledge on raw materials by investing in geoscience data acquisition (see also 3.1). Estonia, for example, focuses its "General principles of Earth's crust policy until 2050" on the collection of geological information and the use of the national resources the most profitable way for the country [72]. At national level, several countries, including Austria, Finland, France, Germany, Sweden, and more recently Norway and Spain, have developed or updated strategic initiatives, such as the "Roadmap for the Sustainable Management of Mineral Raw Materials" [73–75]. Some strategic actions have been devised to stimulate the industrial sectors related to mineral raw materials, thereby ensuring access to essential mineral resources. These initiatives include the implementation of diverse types of instruments: a) regulatory mechanisms that align mining legislation with the European Union's action plans, b) sector-specific tools that secure the principles of the circular economy, knowledge enhancement, and ensure regulatory compliance, c) cross-cutting instruments to foster public-private collaboration and enhance citizen involvement in decision-making, as well as risk finance instruments to stimulate capital investments, and d) an impetus toward research spanning the entire value chain (from cradle-to-gate [76]). The NGSOs play a key role in examining the geological potential of individual countries. This is why the CRMA sets a precedent in identifying the NGSOs, for the first time in EU legislation, as central point to provide required geoscientific data and expert advice to drive domestic exploration investment, which is currently a limiting factor in maintaining the uninterrupted raw materials supply chains (point 1, above). Such strategic approach has been successfully applied in China and led to its economic boom in the 21st century, for example [77].

2.2 Elements of a strong raw materials supply chain

Building strong, reliable supply chains that fulfil the concept of sustainability is the golden rule. Like investments, this requires a good governance structure, reliable political and legal frameworks, fair tax systems, and transport and tariff regulations [78, 79]. It also requires good working conditions, such as high work safety and low risk of labor disputes, as well as low risks for natural disasters (e.g., weather, earthquakes, landsides) that can affect the functioning of a supply chain [10, 80, 81].

Key elements of a robust raw materials supply chain are as follows:

- Access to reliable exploration data and mineral resource databases of primary and secondary raw materials.

- Access to primary production, from mining to processing of the ores and concentrates of the raw material demanded.

- Access to secondary production, from collection to recovery and refining.

- Access to the downstream production of the finished or semifinished products.

Chemical elements are not equally abundant nor equally distributed on the Earth's crust [82]. Mineral resources must be extracted where they occur, and this will affect the environment where they are exploited. What sounds like a truism, however, sets the framework where, how, when, and by whom these resources can be used at all. Ideally, these key elements take place in a setting, free of geopolitical risk and with access to water, (green) energy, infrastructure, and similar.

3. How exploration and extraction fits in the supply chain

The supply chain for minerals is fed by continuous investment into investigations over the location and properties of minerals found in the Earth's subsurface. The importance of exploration to the mineral supply chain is highlighted by several reports [83–85]. This is conducted at a wide variety of scales and levels of details (i.e., from remote sensing surveys and regional airborne geophysics to site-level detailed exploration drilling) by different actors from public research organizations to private companies and investors. While it will always be commercial entities that are responsible for bringing mineral projects into production, state agencies, such as NGSOs provide an important role in creating and providing data and knowledge through exploration on the geological potential for resources. Their unbiased assessment of geological potential helps guide exploration and mining activities by identifying areas that are most likely to yield economically viable deposits. These assessments can be used to target specific regions for more detailed commercial exploration, determine the best drilling locations, and inform decisions related to resource extraction and state aid level as on company level.

3.1 Geological data and information

Geological data and information underpin key elements of a robust raw materials supply chain. Data from NGSO's, on a national and regional scale, provide information on the structure and composition of the Earth's subsurface that influences the likelihood of mineral deposit occurrences. Due to new technologies, changes in demand, and new environmental regulatory requirements there is a constant need to keep geological data up to date. This importance is acknowledged in the CRMA Article 20 [33].

Assessments and forecasts on the national potentials for raw materials and the related industry are done by many NGSOs. These lay down the treasure trove of national raw materials, where in Europe commodities relevant for infrastructure and construction, such as aggregates, sand, and gravel, are the top commodities in terms of quantities, while in terms of value industrial miners (e.g., potash) and metals play an important role, for example [86]. While there is no geological shortage for many raw materials, there might be a shortfall in the availability and access to the treasure deposits. Moreover, resource inventories form the basic data critical for underpinning decision-making relating to resource management for a wide range now widely implemented, or upcoming policies from national government such as security of supply, decarbonization, circular economy, etc. [87].

The NGSOs have developed the European Geological Data Infrastructure (EGDI, www.europe-geology.eu) applying the FAIR (Findable, Accessible, Interoperable, Reusable) data principles that provide open access on maps and aggregated national data on production, trade, resources, reserves, and exploration at commodity level.

Since establishment of the 2008 Raw Materials Initiative, the European Commission has acknowledged the key role of research, development, and innovation in driving investments in and advancement of the European raw material sector and the role of collaborative science. Underpinning funding instruments (e.g., the current Horizon Europe program, EIT-Raw Materials, ERA-MIN) stimulate research and innovation in the field of raw materials and cooperation among and between various research institutions, educational institutions, public bodies, NGSOs, and industry. The projects ProMine, ORAMA, GeoERA, SCRREEN (1-3), FutuRaM, and GSEU are good examples of such cooperations [14].

Notably, many of such projects involve or involved NGSO as coordinators or partners. The importance of NGSOs in collaborative pan-European projects that aim to deliver an European perspective on CRMs stems from their national mandates to collect, archive, and deliver geoscientific data and knowledge. As a collaborative network of NGSOs, linked through the umbrella organization EuroGeoSurveys, this has brought EU-level benefits in the form of a committed approach to data harmonization and delivery of EU-scale products. Such contributions have been progressively built through projects such as EGDI Scope, which developed the framework for a common open subsurface data infrastructure, followed by GeoERA, which delivered multiple pan-European harmonized datasets related to minerals, energy, and groundwater. Currently, the NGSOs and other key partners collaborate through the Geological Service for Europe (GSEU) project, which takes data collection, harmonization, and delivery further, developing the EGDI into a knowledge hub, while preparing and delivering extensive data products, including CRM data. Such data and data products can then inform policy makers, expert and layman and allowing the assessment, evaluation and interpretation of genetic and prospectivity aspects of selected commodities for example [88, 89].

3.2 Reporting codes and standards

To understand raw material supply chains, it is important to use exploration data to conceptualize and quantify, where resources are and of which quality. There are many different types of data and metrics regarding these aspects of mineral exploration and extraction, but the most fundamental commonly used of these is the concept of "resources" and "reserves."

The most widely accepted definition published by the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) is in simple terms and reserves are that part of an identified resource that could be economically extracted at the time of the assessment [90]. The determination of mineral resources and reserves is the means by which deposits that are currently economically extractable (reserves) are distinguished from those where economic extraction of a commodity is potentially feasible (resources).

This estimation comes along with uncertainties. Stepwise, these uncertainties are minimized to increase the likelihood of success. Those steps are verifying the basic conceptual idea of the location of a mineral occurrence in the field. That includes a) converting exploration results from a prospective area into a quantitative estimate of the amount, quality, and distribution of the target mineral (e.g., by drilling, assaying, and preliminary laboratory testing to determine if the mineral can be effectively separated from its host rock) and b) detailed evaluation of all aspects of geological confidence, technical feasibility, environmental, social factors, etc., and may take several years to complete. The vast majority of reconnaissance exploration projects are abandoned without ever verifying the presence of a discovered resource because one or more of these factors limit the financial viability of the project in the market. The next step is the determination of the technological setup that makes mining and process feasible and includes a) comprehensive technical investigations to confirm the size and grade of the deposit, b) determination of geological and physical constraints that may affect how a mine needs to be designed and constructed, how the extraction can take place technicality and how the extracted material need to be treated to liberate the target materials. In conjunction with further modifying factors (MF), a mineral reserve is then defined with a full financial analysis to confirm economic viability, usually associated with a bankable feasibility study. However, this reserve is valid only at a particular point in time (as market, regulatory, political, and social conditions can vary significantly over sometimes even short time scales) and is best regarded as a working inventory of the amount of minerals available to extract at the time the assessment was made. The work required to calculate resources and

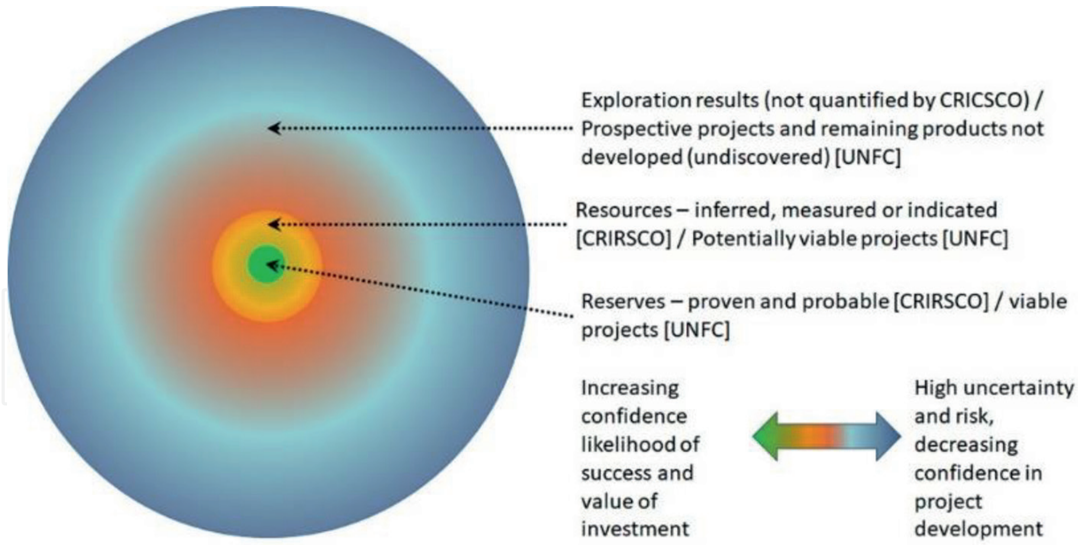

Figure 2.
Schematic representation of the relative size of the quantities represented by the terms resources and reserves (not to scale) and how the most commonly used definitions fit within this.

reserves is very costly and, as such, project operators typically only define resources and reserves to the level that it will be possible to obtain further investment. Thus, the quantity of undiscovered resources is almost always very much larger than that of discovered resources, which, in turn, is much larger than that of reserves, often by many orders of magnitude [91]. Each successive class is associated with an increasing level of confidence, corresponding to the increasing amount of data required for its classification (**Figure 2**). Forecasting with the assumption that "all we known is all there is" (e.g., [92]) has been shown to be incorrect by, for example [93].

At the very early stage of exploration, the quality and accessibility of data and information sets the course for future resource availability. This pre-production part of the supply chain must continue to provide data on regional prospectivity through to actual resources. This will allow the necessary exploration investment to flow and sustain the activity required for a small percentage of exploration projects to be successful.

3.3 Modifying factors

The application of the modifying factors (MF) constitutes an integral part of the mineral reserve estimation process (mineral reserves are mineral resources that are economically exploitable under current technological and market conditions). Such adequate consideration during the estimation and reporting of mineral reserves is crucial [94]. Hence, the MF are acknowledged by all international standard codes for reporting (see 3.2). Commonly, the following key MF are considered in alphabetic order [94–96]:

- Beneficiation (e.g., metallurgical recoveries).
- Economic (e.g., raw materials quality, royalties, exchange rates, transport costs, final product, and its market conditions).
- Environmental (i.e., Environmental Impact Assessment (EIA), by mining, mining residuals, and after mines lifetime).

- Infrastructural (e.g., physical access, energy, water supply, labor, and facilities).
- Legal (e.g., permitting procedures—duration, reliability for exploration, and mining rights).
- Marketing and market developments (e.g., price and demand forecasts).
- Mining (technical and geological aspects, e.g., mining losses and dilution).
- Social and governmental (establishing trust and getting acceptance and the license to operate).

Ideally, these key MF are considered adequately and reported in a transparent and understandable format to allow a comprehensive risk assessment on all aspects. All of these MF will probably also be considered in reserve estimations for secondary raw materials in the future.

3.4 Comparability of reporting codes and standards

Development of potential exploration projects requires risk estimation, including expectations on volumes, cost, and other associated risks. The mineral industry typically needs these estimates to communicate with stock exchanges and investors. The majority of industry data adheres to the International Reporting (ITR) template in CRIRSCO style, an internationally accepted standard designed specifically for the reporting of results to stock exchanges and investors to ensure a consistent standard is applied [90]. As a result, any reported "reserves" should not be considered as physical stocks, but as economic entities that have a realistic chance of being extracted in the foreseeable future (typically within 3–5 years). While these international reporting standards are a mandatory requirement by international stock exchanges, there is a lack of requirement to use them in Europe outside the financial sector.

National governments and regional bodies conversely require data that may be more focused on long-term strategic planning and less on short- to medium-term investment decisions. As a result, many countries have their own specific way of recording such information. The wide variety of definitions can lead to incompatible data being aggregated and misunderstandings about what data points represent, which can lead to poor policy decisions [93, 97].

To establish interoperability of data from different reporting standards, the United Nations Economic Commission for Europe (UNECE) has developed a code, namely the United Nations Framework Classification (UNFC), bridging differences between different standards; thus, the UNFC allows a comparable representation of data, **Figure 3** [98].

The importance of clear, reliable, and comparable data is noted in the CRMA, which calls for an obligatory use of an international standard the United Nations Framework Classification (UNFC) for reporting resource data of projects considered strategic in the EU. New research, development, and innovation projects under EIT Raw Materials are already evaluated according to the UNFC on the basis of their economic, technical, social, and environmental feasibility for resource production [98–100]. The various classification criteria are set up in three categories based on a) *environmental-socioeconomic viability* (E-category), b) *project status and feasibility* (F-category), and c) *degree of confidence in the estimates* (G-category), **Figure 3** [98].

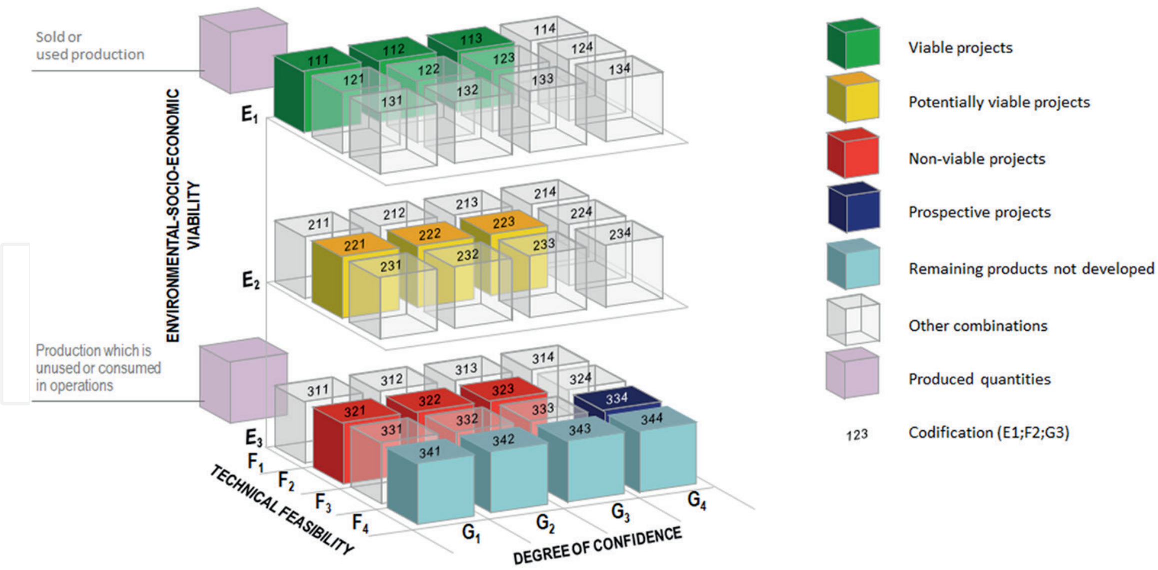

Figure 3.
The UNFC classification system. From United Nations framework classification for resources updated 2019, UNECE, © (2022) United Nations. Reprinted with the permission of the United Nations [98].

3.5 The use of raw material reporting data in understanding supply chains

Exploration activity and subsequent data reported by industry will be focused on maximizing economic value for investors. This may cause issues with knowledge gaps around commodities where they may be a mismatch between economic returns to the extractive industry and the strategic needs of a country or region. For instance, with regard critical raw materials, these are often produced as by- or co-products of other primary mineral production (cobalt as by-product of nickel production or rhenium, tellurium, gold, and selenium as by-products of copper extraction, as examples) [101–103]. These may not be of primary interest to investors as they may have a small contribution to economic feasibility of a mining project. Similarly, critical minerals, which may occur in minor amounts in deposits or those that might occur in mining residuals (heaps and tailings), are often even not analyzed or reported.

This can be at odds with the intense focus on CRMs by national governments. However, it can also counteract opportunities for transdisciplinary—or niche – solutions, as well as new business models. The UNFC may provide an advantage here by providing easy understandable and comparable information for different projects and/or commodities, including those that are currently not economically extract, meeting the wider [104]. According to UNFC, details on MF like ecological, social, technical, and financial aspects can be outlined in a comparable way and allows comparison of projects of different nature for decision-making. Significant barriers in terms of technical, environmental, or societal constraints can be identified and monitored assisting governments and companies to develop suitable measurements to overcome such barriers for projects of general interest (e.g., projects required for the energy transition). Countries, such as Finland, Sweden, Norway, Hungary, and Ukraine, for example, provide or plan to provide standardized and harmonized, UNFC and INSPIRE-compliant mineral data to the pan-European digital platforms on the whole range of minerals with a special emphasis on strategic minerals [105].

Moreover, the UNFC reporting is flexible enough to include data on quantities of material that are considered currently noneconomic. This data, often collated in national inventories by NGSs and mining authorities, is critical for understanding the pipeline of available minerals over decadal times or longer, as well as minerals that may currently be uneconomic to extract now but may be in the future. Currently, there are a couple of projects for mining critical and strategic raw materials in the pipeline that build on such data treasures that form the bulk of mineral potential on national and regional scales. In the cases of Zinnwald Lithium Project at the Czech-German border, for example, adding new data using modern technologies will provide answers to questions on what may currently be in production and what may be produced over the next five or so years. Yet, at the moment, it is impossible to answer many questions currently asked by those with concerns over supply chains, such as, where indigenous production of certain minerals is possible over longer timescales or what the geological availability may be if certain policy decisions were implemented or economic barriers significantly changed. Regardless of the shortfalls, the UNFC system is still best suited to resource reporting and aggregation of resource quantities at national and regional scales, thereby facilitating decision-making on large-scale, long-term, and resource management.

4. Europe's geological potential

The European territory contains some areas, which are favorable for finding the occurrences of mineralization. Geological studies of such areas facilitate genetic studies of ore deposits, putting emphasis on their metallogenetic relationships in space and time, which are fundamental for determining new mineral exploration targets. The geological evolution of the European terrains identified several favorable conditions for the formation of a variety of mineral deposits. These deposits are unevenly distributed geographically because they formed in a various epoch of the Earth history and can form regional clusters. These clusters or areas are called metallogenic provinces or districts [106]. An active interface with all types of subsoil resources, their location, mining or oil-gas status, related reserves, possibilities of use, needs of each industrial sector, and also risks impact that their exploitation would have on the environment and is a starting point for drawing up viable and long-term strategies by lowering the uncertainties and assisting in fostering the raw material resilience [107].

As the geological potential is an expert estimate or interpretation based on available data and knowledge at a given time, it rather provides an indication of where exploration efforts may be more promising [108]. However, it can also be impacted by additional MF, including company strategies, data maturity and reliability, commodity prices, geopolitical issues, and future market outlooks.

The mineral potential of Europe has been investigated at all levels from small exploration companies to government. It can be seen as an indicator of various parameters, such as a) known deposits occurrences, b) share on public revenue, c) share on gross domestic product (GDP), d) public acceptance, e) competing commercial sectors interested to use the same space, or f) technical readiness, for example.

Potential is, therefore, a function of the geological setting, the physical accessibility, and the level of detail of geological information. In the case of Europe, seven mineral-hosting metallogenic belts/areas/provinces are recognized, **Figure 4**.

Each mineral commodity is distributed in specific geographical locations that contain similar geological structures, including host rocks, state of rock alteration, and similar structural domains, as detected by the GeoERA project on Forecasting

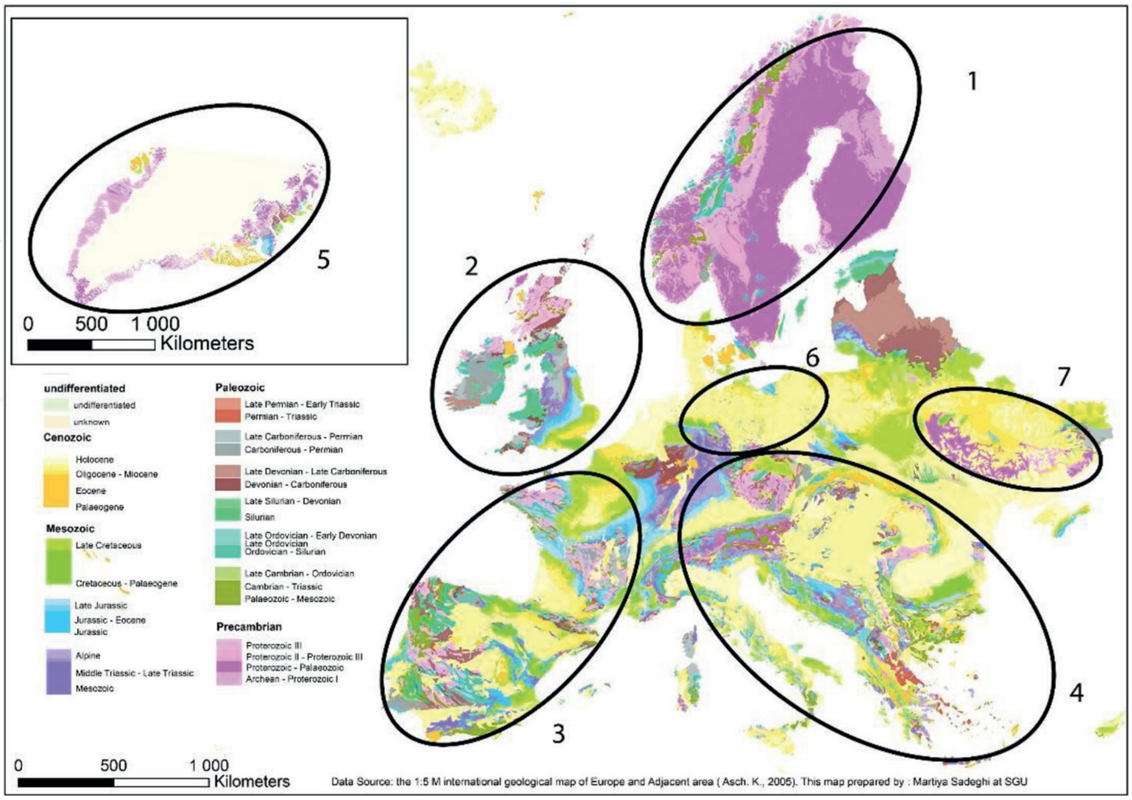

Figure 4.
An overview of major metallogenic belts and endowment of Europe and Greenland modified after refs. [105, 106, 109] And the main metallogenetic areas in Europe listed according to their most common abundance. 1: Fennoscandian shield with potential for Fe, Cu, Zn, Pb, Ni, Cr, Ti, Au, Ag, Te, Se, Mo, Co, Li, graphite, Be, REE, Sc, Si, V, Sb, Bi, Nb, Ta, In, Ge, PGM; 2: Britain and Ireland with potential for Zn, Pb, Ag, Sn, Cu, Ni, Mo, Au, barite, fluorspar, Li, Co, Be, Sb, W, PGM; 3: Iberian-Variscan belt with potential for Cu, Zn, Pb, Ni, Au, Ag, Al, Se, Mn, Li, Co, Si, W, In, Ta, Nb, Be, Bi, Ga, fluorspar, barite; 4: Tethyan/Carpathian-Balkan with potential for Cu, Zn, Pb, Ni, Al, Cr, Mo, Au, Ag, Re, Se, Li, Co, Mn, Sb, W, Bi, REE, PGM, Sc, Ge, V, Nb, Ta, Mg, graphite, magnesite, fluorspar, barite, borate; 5: North Atlantic/Greenland with potential for Fe, Cu, Zn, Ni, Cr, Ti, Zr, Sn, Ag, Au, REE, Nb, Ta, W, Co, PGM; 6: Fore-Sudetic with potential for Cu, Zn, Ni, Sn, In, Ag, Co, Li, W, Mo, Au, Se, Re, PGM; 7: Ukrainian shield with potential for Fe, Mn, Ni, Co, Ti, Au, Li, U, Be, REE, Sc, V, Nb, Ta, Zr, graphite.

and Assessing Europe's Strategic Raw Materials Need (FRAME) for example [106, 110, 111]. These differences are expressed in **Figure 5** that shows (A) the lithium metallogenic belts that differ significantly to those of (B) cobalt metallogenic belts. For further details, see https://data.geus.dk/egdi/?mapname=egdi_geoera_frame#baslay=baseMapGEUS&extent=1139240,1,345,340,7,499,790,4,120,660&layers = frame_li_occurrences_deposits,frame_lithium_metallogenic_areas [88].

4.1 Paving the way for exploration activities in Europe

Exploration is a constant task for all actors given the fact that needs by industry is developing as well as technologies used to discover and to mine unknown deposits and to process ores. Chemical elements, which are now important to our economies, have been of low interest for centuries, and hence rather a target of academic interest only. Systematic exploration for these elements and for deep-seated deposits has started rather recently. Thus, in Europe, many mineral/metal potential maps are based on data that has been collected within the last century. Further progress depends on: the improvements in exploration methods and technologies (from geophysics to drilling technologies), more efficient and environmentally sustain mining

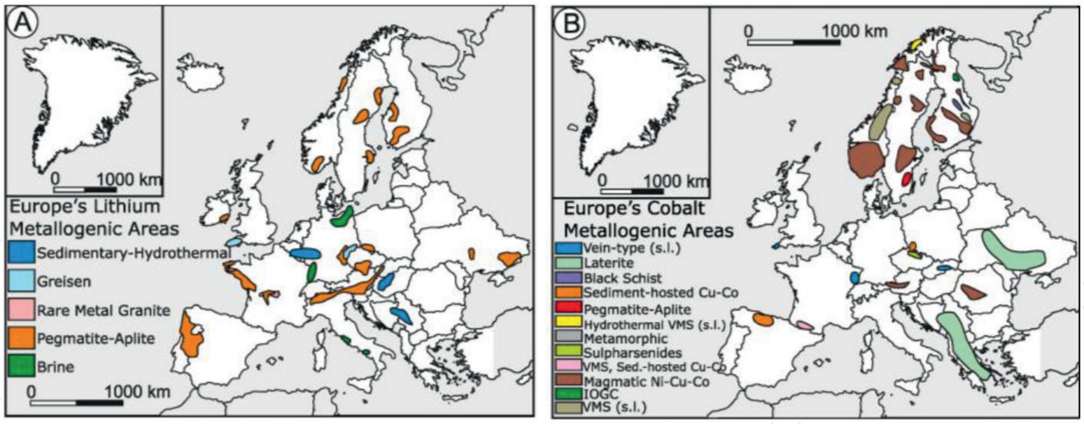

Figure 5.
Metallogenic belt maps for lithium (A) and cobalt (B). Modified after refs. [106, 112].

process and minerals processing technologies, on the global price market of the target raw materials (see Section 3.3), and on the ability of geologists to identify new potential areas for greenfield exploration, which means the exploration in the areas of no known historical mining or exploration activities.

The incoming CRMA calls on members states to set up National Exploration Programmes, which will become a mandatory task as stated in CRMA Article 18 [33]. The exploration potential of Europe can be demonstrated in various forms: be they from recent success stories of new mineral finds in both brownfield and greenfield areas, by innovation regarding new sources of minerals, or by advanced mathematical means. One example combining many forms in advances is the discovery of the Kiruna rare earth elements (REE) deposit owned by the state company LKAB in Sweden, which is said to contain one million metric tons of rare earth oxides. This discovery could pave the way for REE to start being mined in Europe is such a successful example of brownfield exploration. Yet, REEs deposits are not scarce but requires smart technological solutions to be further processed and separated. Hence, the REE-bearing ores (and tailings) of Kiruna will be separated by a new chromatography-based technology developed by REEtec (https://ree-map.com/). This has the potential to be a game changer. The separated individual REE in oxide form, which will, in turn, be converted to metal by the British Less Common Metals Ltd. (LCM). In addition, the rare earth processing factory in nearby Estonia (https://www.silmet.ee/) that produces a variety of high-purity rare earth materials from mixed REE feedstock. Products include neodymium-praseodymium (NdPr) oxide as one of its kind in the European Union being currently the only industrial-scale rare earth separation plant in full-scale operation in Europe. Moreover, a sintered rare earth permanent magnet factory is being built in the same location that will certainly contribute to the global supply chain. Further down the supply chain companies as the German Vacuumschmeltze GmbH (VAC) will use these materials to produce permanent magnets and magnetocaloric alloys, all needed for the energy transformation of the society. With these links connected and all placed in Europe a step toward resilient supply chains in a cradle-to-gate scenario similar to the battery challenges is made [113].

A huge driver for innovative research is the efforts to meet the UN sustainable development goals, which also pushes the development of innovative ways to extract lithium from European geothermal fluids sourced from geothermal and hydrocarbon drill holes [112], which is a potential nontraditional source of this metal. Similar leached-type lithium deposits (salars) are exploited in the Li-triangle at the borders of Argentina, Bolivia, and Chile [114–117]. In recent years, there has been considerable interest for the potential of lithium extraction from southwest England, France, Spain, and Germany, for example, to feed the battery raw material supply chain from both hard rock and brine sources. Although occurrences of lithium-bearing minerals and brines have been noted previously, no detailed exploration had been undertaken due to the previous low value in lithium and a lack of historical interest, a situation, which has dramatically changed in recent years. This has resulted in considerable investment in new drilling and geological evaluation and qualification of resources in two projects as well as new technology for the processing of geothermal brines to be developed [118, 119]. This activity is being undertaken against a backdrop of increased interest in metal mining in southwest England for a variety of other metals due to the current focus on critical raw materials. Southwest England has a long mining history and was once a global mining hub. To ensure that any future development makes this renaissance of metals mining a success for everyone in Cornwall, researchers have been collaborating with policymakers and the industry using the UNFC to help regional stakeholders consider the whole range of sustainable development actions, which are needed for well-being of all. This is done by first using the UNFC to classify projects in the area with the intention to understand the development stage they are in and the barriers they may face. Furthermore, these are integrated with the United Nations Resource Management System (UNRMS) to give a strategic view of environmental impacts and how they can be linked with regional initiatives, to ensure that a social licence to operate is maintained and incorporated geoscience data into the decision making process [120]. Contrary, the discovery of the one of the largest lithium deposits in the world in western Serbia attracted interests from the global mining companies to extract this commodity, in particular the Rio Tinto Group, which planned to start mining operations in 2023. However, the project faced severe public opposition and has many environmental concerns, so the project has been canceled so far. In a similar situation is the Valdefores project in Cáceres (Spain), operated by the company Infinity Lithium, which has encountered strong opposition from the public opinion and local politicians. This opposition primarily stems from the proximity to the city and the potential environmental impact on the territory. These examples point out that the socioeconomic factors can be of equal, if not of greater importance than geological or technological ones.

EU projects, such as exploration and information systems (EIS, https://eis-he.eu/tool/), develop innovative exploration tools that push the limits in earth observation further while using artificial intelligence (AI) for curation of huge datasets. Using digitalized information for statistical approaches and different GIS techniques to deliver maps showing favorable areas referring to a specific commodity is becoming a common praxis described elsewhere [121, 122]. Such methods allow prospectivity mapping of the favorability of occurrences of a nonrandom phenomenon and quantitative evaluation to highlight areas of known mineralization and delineate targets for further investigation.

Mineral exploration presents a set of unique challenges, which vary from place to place, including working in remote and inaccessible locations, cost and capital requirements, geological complexity, technological limitations, legal and regulatory hurdles, market volatility, depth of exploration, limited success rates, environmental and social considerations (the so-called "social license to operate"), health and security, and political instability. These are all part of MF considerations [123].

The latter two are the most difficult to overcome and predict and they affect almost all exploration activities. Whereas the public acceptance of mining is usually negative in Europe, there is a great need for completely transparent population-engaging mechanisms in place from the very beginning. One such example can be found in Estonia, where a deposit of the critical raw material phosphorite that had been thoroughly investigated and already mined during the twentieth century was disapproved due to the public outcry because of several reasons, that is. demographic, environmental, and political issues. Hence, new exploration activities by the local NGSO are being carried out openly and include environmental and groundwater research in the initial phases, which result in having at the outset, the public's acceptance. One example of the political instability issue is the current Russian war in Ukraine. Despite Ukraine's significant mineral potential [105], the outcome of this war is still not known, while the first steps to link Ukraine's raw materials potential to the European supply chain have already been made before the invasion started [124, 125].

5. Outlook/uptake

Europe has been among the leading regions in the raw materials supply sector for thousands of years, with the introduction of copper, bronze, and iron products, and later on, with the mining of many other various elements, such as silver, gold, lead, tin, and mercury. The largest renaissance in mining dates back to medieval ages when Georgius Agricola completed his cutting-edge opus magna "De Re Metallica" that paved the way for modern science-based fieldwork, exploration, mining technology, metallurgical work, and many more [126]. Europe's long tradition in mining has added significantly to the raw material stock in the value chain. Still, there is a potential even for critical and strategic minerals from primary and secondary resources. Based on existing knowledge and data, target areas can be identified, while modern and more detailed exploration campaigns using the most advanced technologies will assist in discovering yet hidden resources. Additional information on a possible exploration target will help reduce the risk of failure, whether being of economic, environmental, or social aspects. These risks associated with the development of any kind of a project can be expressed in a comparable format proposed by UNECE. Hence, the UNFC can support reliable supply chain decision-making as options can be compared on an equal basis [16, 120, 127]. The NGSOs will be required to play a key role regarding the required national programs for the general exploration of critical raw materials if the CRMA comes alive (Art 18 CRMA). The recent networking project GSEU - A Geological Service for Europe might serve as a stepping-stone and the Nordic Countries as a model to unlock Europe's raw material potential.

6. Conclusions

Europe is not a resource-poor region albeit access to known resources is limited and the knowledge on its raw material deposits is still a matter for improvement. Most of the potential sites for mining are small in size compared to the frontrunners on the global market. However, to improve Europe's raw material resilience, all sites that can be developed in line with the sustainable development goals count. To classify a potential raw material deposit as an exploitable mineral reserve, which can be put on the market, modifying factors, including geological, technical, economic, environmental, and societal ones, must be considered. Setting up the right network between National Geological Survey Organizations for the general mineral potential assessment and exploration companies, miners, processing units, final customers, local population, environmental organizations, decision makers, and other important players down the value chain is a stepping-stone for success. The European Union recognized the importance of uninterrupted mineral raw material supply for the economy already in 2008 when establishing the Raw Materials Initiative, stimulating raw material supply from global markets, supply from European sources, and reducing the EU's consumption of primary raw materials. This initiative was followed by various actions, including EU's strategic partnerships, various collaborations, and research projects on raw materials. The foreseen adoption (as in September 2023) of the European Critical Raw Materials Act sets the frame to decrease the European dependency for raw materials imports. European national geological surveys will play a key role in doing that. They will be crucial for preparing national exploration plans, new geological, geochemical and geophysical data acquisition, data storage, and service to enable the diverse and sustainable supply chains that are required. First steps have already been made by setting up the European Geological Data Infrastructure, and by successful implementation of the Geological Service for Europe project funded by the Horizon Europe financial mechanism. This would not be possible without the umbrella organization, EuroGeoSurveys, which is connecting the national geological surveys of Europe.

Acknowledgements

This chapter is based on research by GeoERA Raw Materials project that has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 731166. Any information published in this paper reflects only the authors' view.

The authors thank the GeoERA Raw Materials Team, the EuroGeoSurveys Mineral Resources Expert Group Members (MREG), and the NGSOs. We are grateful for the constant support, valid sharing of information and data on resources and reserves occurring in the very country, and the ongoing cooperation possible.

Conflict of interest

The authors declare no conflict of interest.

Appendices

See **Table A1**.

DOI: http://dx.doi.org/10.5772/intechopen.113793

Raw Material	Global production, 2021 [t]	EU27, UK, NO mining production, 2021 [t]	EU27, UK, NO global share [%]	countries potential hosting primary deposits [country code]
Antimony	9724	n.d.	n.d.	AT, CZ, FR, IT, RO, PT, SI, SP
Barite	6,795,998	127,921	1.88	AT, BG, CZ, DE, GR, IE, IT, PL, PT, RO, SE, SI, SK, SP, UK, UA
Bauxite	380,131,540	157,490	0.04	AT, FR, GR, IT, HU, HR, RO, SI
Beryllium	6805	n.d.	n.d.	FI, FR, NO, PT, SE, UA
Borate	6,897,867	n.d.	n.d.	DE, IT
Cobalt*	131,766	1084	0.82	DE, FI, IT, PL, SE, SP, UA
Fluorspar	8,417,382	215,155	2.56	BE, BG, DE, FR, GR, IT, NO, PL, RO, SE, SP
Natural Graphite	1,159,618	6574	0.57	AT, CZ, DE, FI, IT, NO, SE, SP, UA
Phosphate†	74,316,730	363,720	0.49	EE, FI, FR, PL, SE, SP, UA
Strontium	583,586	281,535	48.24	CY, IT, SP, UK
Tantalum*	1319	n.d.	n.d.	FI, NO, SE, SP, PT, UA

*Note: * given in tonnage of yield; † as P_2O_5; n.d. no data available or not significant; source of data [128].*

Table A1.
Critical elements for which the high supply risk already exists in the mining phase are shown with the global annual production for 2021 compared to the production in the EU27, the UK, and Norway (NO). Apart from strontium, where Spain plays an important role globally, Europe contributes only a very small part to global production from primary deposits. The geology and knowledge of former mining of these raw materials are further indications of a possible raw material potential in these countries.

Author details

Antje Wittenberg[1]*, Daniel de Oliveira[2], Tom Bide[3], Julie Hollis[4], Siim Nirgi[5], Gorazd Žibret[6], Håvard Gautneb[7], Martiya Sadeghi[8], Rafael Navarro Domínguez[9] and Boris Malyuk[10]

1 BGR - Federal Institute for Geosciences and Natural Resources, Hannover, Germany

2 LNEG - The National Laboratory of Energy and Geology, Amadora, Portugal

3 BGS - British Geological Survey, Nottingham, UK

4 EGS - EuroGeoSurveys, Brussels, Belgium

5 EGT - Geological Survey of Estonia, Rakvere, Estonia

6 GeoZS - Geological Survey of Slovenia, Ljubljana, Slovenia

7 NGU - Geological Survey of Norway, Trondheim, Norway

8 SGU - Geological Survey of Sweden, Uppsala, Sweden

9 IGME-CSIC - Geological and Mining Institute of Spain, Granada, Spain

10 BRGM - The French Geological Survey, Orleans, France
(formerly at SRDE "Geoinform of Ukraine")

*Address all correspondence to: antje.wittenberg@bgr.de

References

[1] Beamon BM. Supply chain design and analysis: Models and methods. International journal of production economics. 1998;**55**(3):281-294

[2] European Commission. Europe's Future Well-Being-Proposal for a European Innovation Partnership on Raw Materials. Brussels: Publications Office of the European Union; 2012

[3] Pavel C, Tzimas E. Raw Materials in the European Defence Industry. JRC Science for Policy Report. Luxembourg: Publications Office of the European Union; 2016. 126 p. DOI: 10.2790/509931

[4] Nuss P, Graedel TE, Alonso E, Carroll A. Mapping supply chain risk by network analysis of product platforms. Sustainable Materials and Technologies. 2016;**10**:14-22. DOI: 10.1016/j.susmat.2016.10.002

[5] Magagna D, Shortall R, Telsnig T, Uihlein A, Vázquez HC. Supply Chain of Renewable Energy Technologies in Europe: An Analysis for Wind, Geothermal and Ocean Energy. Luxembourg: Publications Office of the European Union; 2017. DOI: 10.2760/271949

[6] Cook J, DeBree K, Feroleto A. From raw materials to customers: Supply chain management in the service industry. SAM Advanced Management Journal. 2001;**66**:14-21 https://scholarworks.rit.edu/article/508

[7] Hendriksen C. Artificial intelligence for supply chain management: Disruptive innovation or innovative disruption? Journal of Supply Chain Management. 2023;**59**(3):65-76. DOI: 10.1111/jscm.12304

[8] Stadtler H, Kilger C, Herbert M. Supply Chain Management and Advanced Planning. Berlin, Heidelberg: Springer; 2014. 557 p. DOI: 10.1007/978-3-642-55309-7

[9] Alicke K, Bayazit C, Beckhoff T, Foster T, Mysore M. Supply Chains: To Build Resilience, Manage Proactively. McKinsey and Company. McKinsey Global Publishing; 2022. Available from: https://www.mckinsey.com/capabilities/operations/our-insights/supply-chains-to-build-resilience-manage-proactively

[10] Kolotzek C, Helbig C, Thorenz A, Reller A, Tuma A. A company-oriented model for the assessment of raw material supply risks, environmental impact and social implications. Journal of Cleaner Production. 2018;**176**:566-580. DOI: 10.1016/j.jclepro.2017.12.162

[11] Watzel R. Minerals for future technologies: How Germany copes with challenges. In: Smelror M, Hanghøj K, Schiellerup H, editors. The Green Stone Age: Exploration and Exploitation of Minerals for Green Technologies. London: Geological Society, Special Publications; 2023. pp. 13-24. DOI: 10.1144/SP526-2022-12

[12] Kotabe M, Murray JY. Global sourcing strategy and sustainable competitive advantage. Industrial Marketing Management. 2004;**33**(1):7-14. DOI: 10.1016/j.indmarman.2003.08.004

[13] Sauer PC, Seuring S. Sustainable supply chain management for minerals. Journal of Cleaner Production. 2017;**151**:235-249. DOI: 10.1016/j.jclepro.2017.03.049

[14] Wittenberg A, de Oliveira DPS, Flindt Jørgensen L, González J, Heldal T, Aasly KA, et al. GeoERA Raw Materials

Monograph: The Past and the Future. Hannover, Germany: GeoERA Project; 2022. 141 p. DOI: 10.25928/geoera_rawmat22_1

[15] Mateus A, Martins L. Building a mineral-based value chain in Europe: The balance between social acceptance and secure supply. Mineral Economics. 2020;**34**:239-261. DOI: 10.1007/s13563-020-00242-3

[16] Haschke M, Gielisch H, Berse R. The Impact of COVID-19 on Critical Raw Material Supplies needed for the Healthcare and Possible Mitigation Actions. Geneva, Switzerland: UNECE; 2022. 84 p. DOI: 10.13140/RG.2.2.26024.44806

[17] Alblowi R, Brydges T, Henninger CE, Heinze L, Retamal M, Parker-Strak R, et al. Exploring supply chain sustainability drivers during COVID-19- tale of 2 cities. Journal of Cleaner Production. 2022;**373**:133956. DOI: 10.1016/j.jclepro.2022.133956

[18] PWC. Impact of COVID-19 on the Supply Chain Industry. PricewaterhouseCoopers International Limited [Internet]; 2020. Available from: https://www.pwc.com/ng/en/assets/pdf/impact-of-covid19-the-supply-chain-industry.pdf [Accessed: September 7, 2023]

[19] Lèbre É, Owen JR, Corder GD, Kemp D, Stringer M, Valenta RK. Source risks As constraints to future metal supply. Environmental Science & Technology. 2019;**53**(18):10571-10579. DOI: 10.1021/acs.est.9b02808

[20] Yousaf I. Risk transmission from the COVID-19 to metals and energy markets. Resources Policy. 2021;**73**:102156. DOI: 10.1016/j.resourpol.2021.102156

[21] The White House. Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth - 100-Day Reviews under Executive Order 14017 [Internet]. 2021. Available from: https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf [Accessed: August 31, 2023]

[22] Carrara S, Bobba S, Blagoeva D, Alves Dias P, Cavalli A, Georgitzikis K, et al. Supply Chain Analysis and Material Demand Forecast in Strategic Technologies and Sectors in the EU – A Foresight Study. Luxembourg: Publications Office of the European Union; 2023. 261 p. DOI: 10.2760/386650

[23] Lang O. The Dangers of Mining Around the World. BBC News [Internet]. 2010. Available from: https://www.bbc.com/news/world-latin-america-11533349 [Accessed: August 31, 2023]

[24] Sun X, Hao H, Hartmann P, Liu Z, Zhao F. Supply risks of lithium-ion battery materials: An entire supply chain estimation. Materialstoday Energy. 2019;**14**:100347. DOI: 10.1016/j.mtener.2019.100347

[25] Rabe W, Kostka G, Smith SK. China's supply of critical raw materials: Risks for Europe's solar and wind industries? Energy Policy. 2017;**101**:692-699. DOI: 10.1016/j.enpol.2016.09.019

[26] Northey SA, Klose S, Pauliuk S, Yellishetty M, Giurco D. Primary exploration, mining and metal supply scenario (PEMMSS) model: Towards a stochastic understanding of the mineral discovery, mine development and co-product recovery requirements to meet demand in a low-carbon future. Resources, Conservation & Recycling Advances. 2023;**17**:200137. DOI: 10.1016/j.rcradv.2023.200137

[27] Mancini L, Eynard U, Eisfeldt F, Ciroth A, Blengini G, Pennington D.

Social Assessment of Raw Materials Supply Chains. A Life-Cycle-Based Analysis. Luxembourg: Publications Office of the European Union; 2018. p. 94. DOI: 10.2760/470881

[28] Guarnieri P, Trojan F. Decision making on supplier selection based on social, ethical, and environmental criteria: A study in the textile industry. Resources, Conservation and Recycling. 2019;**141**:347-361. DOI: 10.1016/j.resconrec.2018.10.023

[29] Ghadimi P, Wang C, Lim MK. Sustainable supply chain modeling and analysis: Past debate, present problems and future challenges. Resources, Conservation and Recycling. 2019;**140**:72-84. DOI: 10.1016/j.resconrec.2018.09.005

[30] Azimifard A, Moosavirad SH, Ariafar S. Selecting sustainable supplier countries for Iran's steel industry at three levels by using AHP and TOPSIS methods. Resources Policy. 2018;**57**:30-44. DOI: 10.1016/j.resourpol.2018.01.002

[31] Rashidi K, Noorizadeh A, Kannan D, Cullinane K. Applying the triple bottom line in sustainable supplier selection: A meta-review of the state-of-the-art. Journal of Cleaner Production. 2020;**269**:122001. DOI: 10.1016/j.jclepro.2020.122001

[32] Luthra S, Govindan K, Kannan D, Mangla SK, Garg CP. An integrated framework for sustainable supplier selection and evaluation in supply chains. Journal of Cleaner Production. 2017;**140**:1686-1698. DOI: 10.1016/j.jclepro.2016.09.078

[33] European Commission. Proposal for a Regulation of the European Parliament and of the Council Establishing a Framework for Ensuring a Secure and Sustainable Supply of Critical Raw Materials and Amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020 (COM(2023)160 Final) [Internet]. 2023. Available from: https://single-market-economy.ec.europa.eu/publications/european-critical-raw-materials-act_en [Accessed: August 31, 2023]

[34] UNECE. Future-Proofing the Supply of Critical Minerals for Net-Zero Emissions Summary Report, January 2022. Geneve: UNECE and UK Mission Geneva [Internet]; 2022. 5p. Available from: https://unece.org/sites/default/files/2022-01/UNECE%20UK%20Critical%20Minerals%20Report%20Jan%202022.pdf [Accessed: August 31, 2023]

[35] UK Government. Resilience for the Future: The UK's critical minerals strategy. Department for Business, E.I.S. [Internet]. 2022. Available from: https://www.gov.uk/government/publications/uk-critical-mineral-strategy/resilience-for-the-future-the-uks-critical-minerals-strategy [Accessed: August 31, 2023]

[36] Pasimeni P. Supply, or Demand, That Is the Question : Decomposing Euro Area Inflation. Luxembourg: Publications Office of the European Union; 2022. 20 p. DOI: 10.2873/301426

[37] European Commission. Communication from the Commission to the European Parliament and the Council 2022 Strategic Foresight Report Twinning the Green and Digital Transitions in the New Geopolitical Context (COM/2022/289 Final) [Internet]. 2022. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0289 [Accessed: August 31, 2023]

[38] IEA.Critical Minerals Market Review 2023 [Internet]. 2023. Available from:

https://www.iea.org/reports/critical-minerals-market-review-2023 [Accessed: August 31, 2023]

[39] Zanbak C. Hammaddelerin Kritikliği/Stratejikliği ve Türkiye (in Turkish, Engl. Criticality/Strategic Nature of Raw Materials and Türkiye) [Internet]. 2023. Available from: https://www.ituvakif.org.tr/hammaddelerin-kritikligi-stratejikligi-ve-turkiye [Accessed: August 31, 2023]

[40] Langley J. Third-Party Logistics Study - Back to Basics - Results and Findings of the 27th Annual Study. USA: NTT DATA; 2023. 86 p

[41] Zhou X, Zhang H, Zheng S, Xing W, Yang H, Zhao Y. A study on the transmission of trade behavior of global nickel products from the perspective of the industrial chain. Resources Policy. 2023;**81**:103376. DOI: 10.1016/j.resourpol.2023.103376

[42] Wang X, Wang A, Zhong W, Zhu D, Wang C. Analysis of international nickel flow based on the industrial chain. Resources Policy. 2022;**77**:102729. DOI: 10.1016/j.resourpol.2022.102729

[43] Månberger A. Critical raw material supply matters and the potential of the circular economy to contribute to security. Intereconomics. 2023;**58**:74-78. DOI: 10.2478/ie-2023-0016

[44] Liu W, Li X, Liu C, Wang M, Liu L. Resilience assessment of the cobalt supply chain in China under the impact of electric vehicles and geopolitical supply risks. Resources Policy. 2023;**80**:103183. DOI: 10.1016/j.resourpol.2022.103183

[45] Zuo Z, Cheng J, Guo H, McLellan BC. Catastrophe progression method - PATH (CPM-PATH) early warning analysis of Chinese rare earths industry security. Resources Policy. 2021;**73**:102161. DOI: 10.1016/j.resourpol.2021.102161

[46] Yu S, Duan H, Cheng J. An evaluation of the supply risk for China's strategic metallic mineral resources. Resources Policy. 2021;**70**:101891. DOI: 10.1016/j.resourpol.2020.101891

[47] Shuai J, Peng X, Zhao Y, Wang Y, Xu W, Cheng J, et al. A dynamic evaluation on the international competitiveness of China's rare earth products: An industrial chain and tech-innovation perspective. Resources Policy. 2022;**75**:102444. DOI: 10.1016/j.resourpol.2021.102444

[48] Ren B, Li H, Wang X, Shi J, Ma N, Qi Y. The flow of embodied minerals between China's provinces and the world: A nested supply chain network perspective. Resources Policy. 2022;**78**:102853. DOI: 10.1016/j.resourpol.2022.102853

[49] Ramahandry T, Bonneau V, Bani E, Vlasov N, Flickenschild M, Batura O, et al. Key Enabling Technologies for Europe's Technological Sovereignty. Brussels: European Parliamentary Research Service; 2021. 97 p. DOI: 10.2861/24482

[50] Zuo Z, Cheng J, Guo H, Li Y. Knowledge mapping of research on strategic mineral resource security: A visual analysis using CiteSpace. Resources Policy. 2021;**74**:102372. DOI: 10.1016/j.resourpol.2021.102372

[51] van Wieringen K. EU-China 2030: European Expert Consultation on Future Relations with China. Brussels: European Parliamentary Research Service; 2022. 46 p. DOI: 10.2861/729211

[52] Kalantzakos S. The geopolitics of critical minerals. 2019. IAI Papers.

2019;**19**:27 https://www.jstor.org/stable/pdf/resrep23660.pdf

[53] European Commission. Tackling the Challenges in Commodity Markets and on Raw Materials (COM(2011)0025 Final) [Internet]. 2011. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52011DC0025 [Accessed: August 31, 2023]

[54] EIT Raw Materals. Circular Economy (image) [Internet]. 2018. Available from: https://eitrawmaterials.eu/wp-content/uploads/2018/06/Circular-Economy-5.jpg [Accessed: August 20, 2023]

[55] Reichl C, Schatz M. World Mining Data 2023. Vienna: Federal Ministry of Finance; 2023. 265 p

[56] Imahashi, R. Manufacturers rue Dependence on China for Supplies of Magnesium. Market Spotlight [Internet]. 2021. Available from: https://asia.nikkei.com/Spotlight/Market-Spotlight/Manufacturers-rue-dependence-on-China-for-supplies-of-magnesium [Accessed: August 20, 2023]

[57] Liang A, Marsh N. Gallium and Germanium: What China's New Move in Microchip War Means for World. London: BBC News [Internet]; 2023. Available from: https://www.bbc.com/news/business-66118831 [Accessed: August 20, 2023]

[58] Harper GDJ. China's Gallium and Germanium Controls: What they Mean and What Could Happen Next [Internet]. 2023. Available from: https://theconversation.com/chinas-gallium-and-germanium-controls-what-they-mean-and-what-could-happen-next-209156 [Accessed: August 20, 2023]

[59] European Commission. Communication from the Commission to the European Parliament and the Council - the Raw Materials Initiative: Meeting our Critical Needs for Growth and Jobs in Europe {SEC(2008) 2741} (COM(2008)0699 Final) [Internet]. 2008. Available from: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A52008DC0699 [Accessed: August 31, 2023]

[60] European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Review of the List of Critical Raw Materials for the eu and the Implementation of the Raw Materials Initiative (COM(2014)0297 Final) [Internet]. 2014. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52014DC0297 [Accessed: August 31, 2023]

[61] European Commission. Study on the Critical Raw Materials for the EU 2023: Final Report. Luxembourg: Publications Office of the European Union; 2023. 154 p. DOI: 10.2873/725585

[62] European Commission. Global Gateway [Internet]. 2023. Availible from: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/stronger-europe-world/global-gateway_en [Accessed: August 02, 2023]

[63] European Union. InvestEU [Internet]. 2023. Available from: https://investeu.europa.eu/index_en [Accessed: August 02, 2023]

[64] European Parliament and Council of the European Union. Regulation (EU) 2021/1119 of the European Parliament and of the council of 30 June 2021 establishing the framework for achieving climate neutrality and amending regulations (EC) No 401/2009 and (EU) 2018/1999 ('European climate

law') (PE/27/2021/rev/1). Brussels: Official Journal of the European Union. 2021;**243**:1-17

[65] European Commission. REPowerEU Plan. COM(2022) 230 final [Internet]. 2022. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:230:FIN [Accessed: September 7, 2023]

[66] European Commission. A Green Deal Industrial Plan for the Net-Zero Age. COM(2023) 62 final [Internet] 2023. Available from: https://commission.europa.eu/document/41514677-9598-4d89-a572-abe21cb037f4_en [Accessed: September 7, 2023]

[67] European Commission. A Chips Act for Europe - Staff Working Document PART 1/4 [Internet]. 2022. Available from: https://ec.europa.eu/newsroom/dae/redirection/document/86690 [Accessed: September 7, 2023]

[68] European Commission. A Chips Act for Europe. COM(2022) 45 final [Internet]. 2022. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0045 [Accessed: September 7, 2023]

[69] European Commission. Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on Corporate Sustainability Due Diligence and amending Directive (EU) 2019/1937. COM(2022) 71 final [Internet]. 2022. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0071 [Accessed: September 7, 2023]

[70] European Parliament and Council of the European Union. Regulation (EU) 2017/821 of the European Parliament and of the council of 17 may 2017 laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas. Brussels: Official Journal of the European Union. 2017;**130**:1-20

[71] European Commission. Proposal for a Regulation of the European Parliament and of the Council on Establishing a Framework of Measures for Strengthening Europe's Net-Zero Technology Products Manufacturing Ecosystem (Net Zero Industry Act). COM(2023) 161 final [Internet]. 2023. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52023PC0161 [Accessed: September 7, 2023]

[72] Ministry of the Environment, Republic of Estonia. General Principles of Earth's Crust Policy until 2050. Tallinn: Ministry of Enivronment; 2017; 11 p. https://kliimaministeerium.ee/media/907/download

[73] Ministerio para la Transición Ecológica y el Reto Demográfico. Hoja de Ruta para la gestión sostenible de las Materias Primas Minerales. Madrid: Ministerio para la Transición Ecológica y el Reto Demográfico; 2022; 72 p https://energia.gob.es/_layouts/15/HttpHandlerParticipacionPublicaAnexos.ashx?k=41163

[74] Bundesregierung. Rohstoffstrategie der Bundesregierung - Sicherung einer nachhaltigen Rohstoffversorgung Deutschlands mit nichtenergetischen mineralischen Rohstoffen. Berlin: Bundesministerium für Wirtschaft und Energie; 2020; 37 p. https://www.bmwi.de/Redaktion/DE/Publikationen/Industrie/rohstoffstrategie-der-bundesregierung.pdf?__blob=publicationFile&v=4

[75] Norwegian Ministry of Trade, I.a.F., Norwegian Mineral Strategy.

Norwegian Ministry of Trade, Industry and Fisheries. 2023. 66 p. https://www.regjeringen.no/contentassets/1614eb7b10cd4a7cb58fa6245159a547/norges-mineralstrategi_engelsk_uu.pdf

[76] European Commission. Commission recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. Brussels: Official Journal of the European Union. 2013;**56**:1-210

[77] Zhang Z, Elshkaki A. An analysis of the supply-side factors of geological exploration in China based on provincial panel data between 1999 and 2017. Resources Policy. 2022;**76**:102589. DOI: 10.1016/j.resourpol.2022.102589

[78] Ali SH, Giurco D, Arndt N, Nickless E, Brown G, Demetriades A, et al. Mineral supply for sustainable development requires resource governance. Nature. 2017;**543**:367-372. DOI: 10.1038/nature21359

[79] Jowitt SM, Mudd GM, Thompson JFH. Future availability of non-renewable metal resources and the influence of environmental, social, and governance conflicts on metal production. Communications Earth & Environment. 2020;**1-13**:1-7. DOI: 10.1038/s43247-020-0011-0

[80] van den Brink S, Kleijn R, Sprecher B, Tukker A. Identifying supply risks by mapping the cobalt supply chain. Resources, Conservation and Recycling. 2020;**156**:104743. DOI: 10.1016/j.resconrec.2020.104743

[81] Manhart A, Vogt R, Priester M, Dehoust G, Auberger A, Blepp M, et al. The environmental criticality of primary raw materials – A new methodology to assess global environmental hazard potentials of minerals and metals from mining. Mineral Economics. 2018;**32**:91-107. DOI: 10.1007/s13563-018-0160-0

[82] Girtan M, Wittenberg A, Grilli ML, de Oliveira DPS, Giosuè C, Ruello ML. The critical raw materials issue between scarcity, supply risk, and unique properties. Materials. 2021;**14**(8):1826. DOI: 10.3390/ma14081826

[83] Fogarty JJ, Sagerer S. Exploration externalities and government subsidies: The return to government. Resources Policy. 2016;**47**:78-86. DOI: 10.1016/j.resourpol.2016.01.002

[84] Duke JM. Government geoscience to support mineral exploration: Public policy, rational and impact. PDAC. 2010:1-64. Available from: www.academia.edu/5085907/Government_Geoscience_to_Support_Mineral_Exploration_public_policy_rationale_and_impact

[85] Fogarty JJ. An Economic Assessment of the Exploration Incentive Scheme: 10 Years from 2009 to 2020, Prepared for the Department of Mines, Industry Regulation and Safety. Perth: Geological Survey of Western Australia; 2021. 48 p. https://www.dmp.wa.gov.au/Documents/Geological-Survey/EIS_Economic_Impact_report_10_years.pdf

[86] BGR - Bundesanstalt für Geowissenschaften und Rohstoffe. Deutschland – Rohstoffsituation 2021. Hannover: Bundesanstalt für Geowissenschaften und Rohstoffe; 2022; 162 p. https://www.bgr.bund.de/DE/Themen/Min_rohstoffe/Downloads/rohsit-2021.pdf;jsessionid=2BCA1AC3E15D8C9E0D8D12F4E1CF9267.internet002?__blob=publicationFile&v=4

[87] Simoni MU, Aasly KA, Eilu P, Schjøth F, Lead W. Mintell4EU Deliverable D4.1: Case Study Review with

Guidance and Examples for Applying the UNFC to European Mineral Resources. Report on Harmonization Issues, Data Gaps and Challenges, Reviewing Also the Quality of PanEuropean Aggregated Inventories for Selected Commodities. 2021. 24 p. https://repository.europe-geology.eu/egdidocs/mintell4eu/d41-mintell4eu-case-study-overview-final.pdf

[88] European Geological Data Infrastructure (EGDI) [Internet]. Available from: https://www.europe-geology.eu/ [Accsessed: June 30, 2023]

[89] Flindt, Jørgensen L, Wittenberg A, Deady E, Kumelj Š, Tulstrup J. European mineral intelligence - collecting, harmonising, and sharing data on European raw materials. Geological Society, London, Special Publications. 2022;**526**:51-67. DOI: 10.1144/SP526-2022-179

[90] CRIRSCO. International Reporting Template for the Public Reporting of Exploration Results, Mineral Resources and Mineral Reserves. Committee for Mineral Reserves International Reporting Standards (CRIRSCO). USA: International Council of Mining & Metals. Global; 2019. 78 p. http://www.crirsco.com/templates/CRIRSCO_International_Reporting_Template_October_2019.pdf

[91] Lusty PAJ, Gunn AG. Challenges to global mineral resource security and options for future supply. In: Jenkin GRT, Lusty PAJ, McDonald I, Smith MP, Boyce AJ, Wilkinson JJ, editors. Ore Deposits in an Evolving Earth. London: Geological Society; 2015. pp. 265-276. DOI: 10.1144/SP393.13

[92] Meadows DH, Meadows DL, Randers J, Behrens WW III. The Limits to Growth; a Report for the Club of Rome's Project on the Predicament of Mankind. New York: Universe Books; 1972. p. 205 https://www.clubofrome.org/publication/the-limits-to-growth/

[93] Meinert DL, Robinson RG, Nassar TN. Mineral resources: Reserves, peak production and the future. Resources. 2016;**5**(1):14. DOI: 10.3390/resources5010014

[94] Rupprecht SM. SAMREC CODE 2016 - the application of modifying factors. In: Proceedings of the SAREC/SAMVAL Companion Volume Conference Emperors Palace; 17-18 May 2016. Johannesburg: Southern African Institute of Mining and Metallurgy; 2016. pp. 187-194

[95] Winterstetter A, Laner D, Rechberger H, Fellner J. Evaluation and classification of different types of anthropogenic resources: The cases of old landfills, obsolete computers and in-use wind turbines. Journal of Cleaner Production. 2016;**133**:599-615. DOI: 10.1016/j.jclepro.2016.05.083

[96] Henley S, Allington R. PERC, CRIRSCO, and UNFC: Minerals reporting standards and classifications. European Geologist. 2013;**36**:49-54

[97] Bide T, Brown TJ, Gunn AG, Mankelow JM. Utilisation of multiple current and legacy datasets to create a national minerals inventory: A UK case study. Resources Policy. 2020;**66**:101654. DOI: 10.1016/j.resourpol.2020.101654

[98] UNECE. United Nations framework classification for resources update 2019. In: UNECE Energy Series 61. Geneva: United Nations; 2019. 28p. https://unece.org/sustainable-energy/publications/united-nations-framework-classification-resources-update-2019-ece

[99] EIT RawMaterials. Developing Raw Materials into a Major Strength

for Europe [Internet]. Availible from: https://eitrawmaterials.eu/ [Accessed: September 7, 2023]

[100] Bide T, Brown TJ, Gunn AG, Deady E. Development of decision-making tools to create a harmonised UK national mineral resource inventory using the United Nations framework classification. Resources Policy. 2022;**76**:102558. DOI: 10.1016/j.resourpol.2022.102558

[101] Nassar NT, Graedel TE, Harper EM. By-product metals are technologically essential but have problematic supply. Science Advances. 2015;**1**(3):e1400180. DOI: 10.1126/sciadv.1400180

[102] Afflerbach P, Fridgen G, Keller R, Rathgeber AW, Strobel F. The by-product effect on metal markets – New insights to the price behavior of minor metals. Resources Policy. 2014;**42**:35-44. DOI: 10.1016/j.resourpol.2014.08.003

[103] Campbell GA. The role of co-products in stabilizing the metal mining industry. Resources Policy. 1985;**11**(4):267-274. DOI: 10.1016/0301-4207(85)90044-3

[104] UNECE. UNFC GUIDANCE EUROPE. In: Chanes R, Hokka J, Eilu P, Heiberg S, Jones A, Falck H, Kral U, editors. Guidance for the Application of the United Nations Framework Classification for Resources (UNFC) for Mineral and Anthropogenic Resources in Europe. Geneva: UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE; 2022. 66 p. https://unece.org/sites/default/files/2022-10/Revised_UNFC_Guidance_Europe_as_of_19.October.2022.pdf

[105] Mykhailov VA, Malyuk BI, de Oliveira D, Wittenberg A, et al. Strategic Minerals of Ukraine and their Investment Attractiveness [in Press]. Orleans: BRGM; 2023. p. 293

[106] Sadeghi M, Pereira A, Bertrand G, Arvanitidis N, de Oliveira D, Decrée S, Sievers H, Quental L, Bergman T, Hallberg A, McGrath E, Lynch E, Delgado Arenas P, Timón Sanchez SM, Teran K, Munreanu M, Horváth Z, Gtorok K, Jonson E, Salgueira R, Kovács G, Vigh C, González J, Marino E, Somoza L, Medialdea T, Blasco I, Kuhn T, Ferreira P, Magalhães V, Malyuk B. Providing a data platform, digital version of metallogenic map and related description report highlighting the endowment and exploration potential of CRM in Europe. FRAME Deliverable 3.2 Report [unpublished]. 2020. p. 29

[107] Anastasiu N. Resursele minerale – un potențial uitat! 2015. Bucharest, Romania: Academiei Române; 2015. p. 12

[108] Makkonen HV, Halkoaho T, Konnunaho J, Rasilainen K, Kontinen A, Eilu P. Ni-(Cu-PGE) deposits in Finland – Geology and exploration potential. Ore Geology Reviews. 2017;**90**:667-696. DOI: 10.1016/j.oregeorev.2017.06.008

[109] Asch KE. The International Geological Map of Europe and Adjacent Areas 1:5000000, IGME 5000: More than Just a Map - a Multinational GIS Project. Hannover: BGR; 2005. p. 1

[110] Bertrand G, Sadeghi M, de Oliveira D, Tourliere B, Arvanitidis N, Gautneb H, et al. Mineral PROSPECTIVITY mapping for critical raw materials AT the EUROPEAN scale with the CBA method. Special Paper - Geological Survey of Finland. 2021;**57**:79-82

[111] Bertrand G, Sadeghi M, Arvanitidis N, de Oliveira D, Gautneb H, Gloaguen E, et al. Prospectivity maps of critical raw materials in Europe. FRAME DELIVERABLE. 2021;**D3**(5):68 www.frame.lneg.pt

[112] Sanjuan B, Gourcerol B, Millot R, Rettenmaier D, Jeandel E, Rombaut A. Lithium-rich geothermal brines in Europe: An up-date about geochemical characteristics and implications for potential Li resources. Geothermics. 2022;**101**:102385. DOI: 10.1016/j.geothermics.2022.102385

[113] Thomitzek M, Cerdas F, Thiede S, Herrmann C. Cradle-to-gate analysis of the embodied energy in lithium ion batteries. Procedia CIRP. 2019;**80**:304-309. DOI: 10.1016/j.procir.2019.01.099

[114] Cabello J. Reservas, recursos y exploracion de litio en Salares del Norte de Chile (reserves, resources and lithium exploration in the salt flats of northern Chile). Andean Geology (Online). 2022;**49**(3):297-306. DOI: 10.5027/andgeov49n2-3444

[115] Cabello J. Lithium brine production, reserves, resources and exploration in Chile: An updated review. Ore Geology Reviews. 2021;**128**:103883. DOI: 10.1016/j.oregeorev.2020.103883

[116] Munk LA, Hynek SA, Bradley DC, Boutt D, Labay K, Jochens H, et al. Lithium brines: A global perspective. In: Verplanck PL, Hitzman MW, editors. Rare Earth and Critical Elements in Ore Deposits. Boulder: Society of Economic Geologists; 2016. pp. 339-365. DOI: 10.5382/Rev.18.14

[117] Sarchi C, Lucassen F, Meixner A, Caffe PJ, Becchio R, Kasemann SA. Lithium enrichment in the Salar de Diablillos, Argentina, and the influence of Cenozoic volcanism in a basin dominated by Paleozoic basement. Mineralium Deposita. 2023;**58**:1351-1370. DOI: 10.1007/s00126-023-01181-z

[118] Lithium in Geothermal Waters - GeoCubed [Internet]. Available from: https://cornishlithium.com/projects/lithium-in-geothermal-waters/geocubed/ [Accsessed: September 7, 2023]

[119] Cornish Lithium Announces Maiden JORC Resource For The Trelavour Project [Internet]. Availible from: https://cornishlithium.com/company-announcements/cornish-lithium-announces-maiden-jorc-resource-for-the-trelavour-project/ [Accsessed: September 7, 2023]

[120] Met4Tech. UNRMS: A Cornwall Case Study [Internet]. 2023. Available from: https://met4tech.org/unrms-a-cornwall-case-study/ [Accessed: September 7, 2023]

[121] Carranza EJM, Zuo R. Introduction to the thematic issue: Analysis of exploration geochemical data for mapping of anomalies. Geochemistry, Exploration, Environment, Analysis. 2017;**17**(3):183-185. DOI: 10.1144/geochem2017-901

[122] Carranza EJM. Geochemical anomaly and mineral Prospectivity mapping in GIS. Handbook of Exploration and Environmental Geochemistry. 2008;**11**:368

[123] Bilham NT. Responsible mining and responsible sourcing of minerals: Opportunities and challenges for cooperation across value chains, In Di Capua G, Bobrowsky PT, Kieffer SW, Palinkas C, editors. Geoethics: Status and Future Perspectives, Geological Society, London, Special Publications. 2020;508. DOI: 10.1144/sp508-2020-130

[124] Gurskiy DS. Conceptual Principles of the State Mineral Resources Policy on the Use of Strategically Important Minerals for the Country's Economy. Lviv, Ukraine: ZUKC; 2008. p. 192

[125] Malyuk BI. Ukraine: Mineral Policy. In: Tiess G, Majumder T,

Cameron P, editors. Encyclopedia of Mineral and Energy Policy. Berlin: Springer-Verlag GmbH; 2023. pp. 798-804. DOI: 10.1007/978-3-642-40871-7_49-1

[126] Hoover HC, Hoover LH. GEORGIUS Agricola de RE Metallica - Translated from the First Latin Edition of 1556. New York: Dover Publications Inc; 1950. p. 638

[127] Horváth Z, de Oliveira D, Aslaksen Aasly K, Simoni M, Flindt Jørgensen L, Whitehead D, et al. UN Framework Classification - a Tool for Sustainable Resource Management. Utrecht, The Netherlands: GeoUtrecht; 2020. p. 2020. DOI: 10.48380/dggv-dakj-bn91

[128] BGR Budesanstalt für Geowissenschaften und Rohstoff. Fachinformationssystem Rohstoffe, BGR. without date: Hannover. [not public]