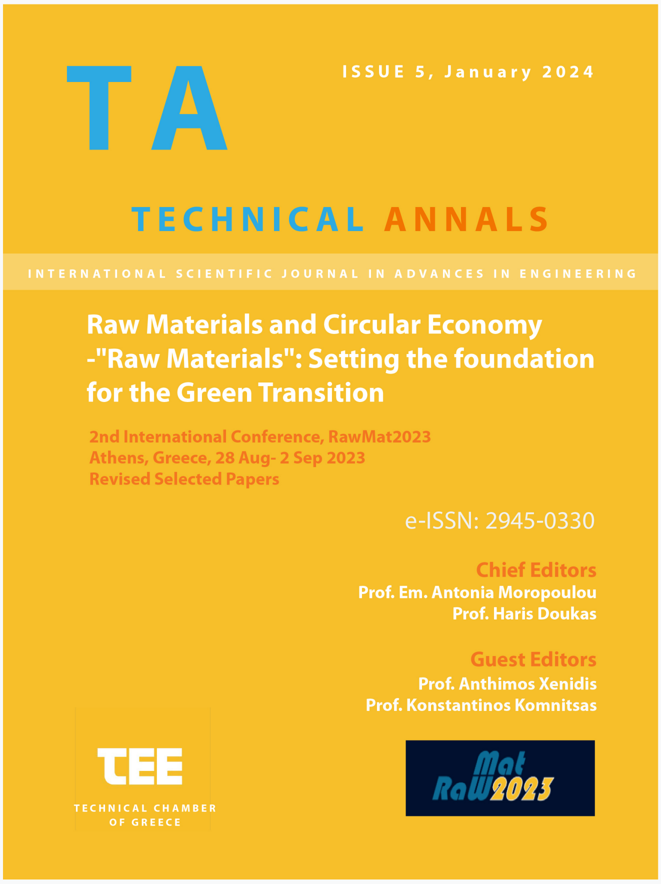
Technical Annals

Vol 1, No 5 (2024)

Technical Annals



Europe's economic geology potential enables reducing its geopolitical dependence on critical and strategic minerals

Nikolaos Arvanitidis

doi: [10.12681/ta.36119](https://doi.org/10.12681/ta.36119)

Europe's economic geology potential enables reducing its geopolitical dependence on critical and strategic minerals

Nikolaos Arvanitidis, Dr Economic Geologist, Chair of the Mineral Raw Materials Committee, Association of Greek Geologists

Skeppstavägen 15, 12430 Bandhagen, Stockholm, Sweden
Nikolaos.Arvanitidis@gmail.com;
greenminerals@nikolaosarvanitidis.eu

Abstract. For many years mineral raw materials were the missing link in the climate debate. A significant number of critical and strategic minerals (CSM) in continuously increasing quantities will be needed to achieve the global economy's need to become free of hydrocarbons. CSMs are utilized in the production of semiconductors, wind turbines, photovoltaics, and lithium batteries, which are employed to store and transfer renewable energy. Nonetheless, the EU depends 75–100% on imports for the majority of CSMs. Additionally, a lot of CSMs are produced and processed in a single nation or region, which puts their geopolitical supply and accessibility at risk. The goal of the Critical Raw Materials Act (CRMA) is to increase Europe's progressive autonomy in CSMs and long-term self-sufficiency. Recycling does not currently generate a substantial amount of resources for several of the CSMs. Europe's geology and metallogenic evolution have considerably favoured the fruitful use of its own CSM resources, which turns out to be the main factor enabling the continent to become resilient, self-sufficient, self-sustaining, and sustainable. Europe will have to establish its channels and means of obtaining the necessary amounts of resources due to China's geopolitical dominance, use of corporate partnerships, collaboration agreements, and investments made globally regarding the exploitation of other nations' CSMs. The predominant targets for the EU are to develop new mineral supply chains, become less dependent on China, and strengthen key technology value chains, including processing, refining, and metallurgy facilities.

Keywords: Critical and strategic minerals, European economic geology, Geopolitical shifts

1. Background

The imperative for a hydrocarbon-free global economy will require a large number of mineral raw materials in steadily growing amounts [1]. It is therefore important to know which and in what quantities they are needed to understand and assess the implications of insufficient access or their inadequacy for the European, and therefore the Greek, economy. During the last twelve years, the "criticality assessment" at the European level aimed to identify those mineral raw materials that are generally evaluated to be at risk of mineral inaccessibility and insufficiency, and to be of great technical, economic, and social importance for several key value chains [2]. For these reasons, they were considered to be critical and strategic minerals (CSM) in terms of meeting and targeting the needs of new challenging technologies.

aluminium/bauxite*	antimony	**arsenic**
baryte	beryllium	bor/borate
flourspat	phosphate rock	phosphorus
feldspar	gallium	germanium
natural graphite	hafnium	**helium**
rare earth elements: HREE and LREE	silicon metal	cobalt
coking coal	copper*	lithium
magnesium	**manganese**	nickel*
niobium	platinum group metals: PGM	scandium
strontium	tantalum	titanium
vanadium	bismuth	tungsten

=Strategic but not critical raw material Synthetic graphite

Fig. 1: The EU has listed 34 minerals and metals as critical and/or of strategic importance for European society and welfare. Copper and nickel are only strategic. Recently, aluminium and synthetic graphite were added to the strategic ones (Source: Geological Survey of Sweden)

Strategic and critical mineral raw materials (Fig. 1) are the foundation upon which modern technology is built [3] from photovoltaics to semiconductors, wind turbines, and lithium batteries to transport and store the renewable energy produced. In addition to lithium, batteries also need cobalt, graphite, nickel, and manganese, while the electrification of cars requires neodymium magnets, which also use other rare earth elements (REE), such as dysprosium and praseodymium, but also increased use of copper, zinc, and lead (Fig. 2, 4, 5), which together with nickel are of special ore geological interest for Greece. CSMs are also essential in the digital technology and electronics industry. Simply put, there can be no energy and digital transition, and no scale-up in the use of e-mobility, without CSMs, which is why the resilience of the relevant value and supply chains are increasingly a priority for most advanced economies [2, 4, 6]. Recent reports by the International Energy Agency [7] and the World Bank indicate that global production of cobalt, lithium, and graphite needs to increase by 500% in the coming decades to enable the transition to a green and digital economy [8]. For example, the EU would need up to 18 times more lithium and 5 times more cobalt by 2030, and almost 60 times more lithium and 15 times more cobalt by 2050, to cope with the increase in electric vehicle battery production, and 10 times more REE for permanent magnets [1].

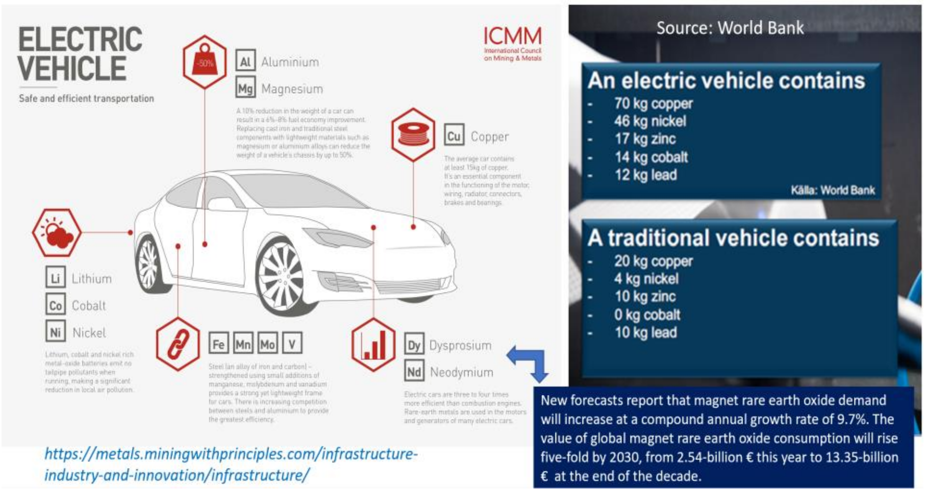


Fig. 2: An electric car produced in Europe contains on average 141 kg of mineral raw materials, compared to just 44 kg in a conventional car. Corresponding quantities of aluminium are 283 kg and 169 kg, respectively, whereas an electric car also requires 2 kg of REE (Source: ICMM).

2. China's geopolitical dominance

The above forecasts are seen as alarming if it is considered that the EU depends by 75 to 100% on imports for most of the CSMs. It also happens that the production and processing of many CSMs is geographically controlled, making their geopolitical access and supply vulnerable, which is accompanied by a series of social, economic, environmental, and other risks. Therefore, some CSMs, along with their related value chains, largely tend to be productively monopolized by specific regions of the planet, sometimes by just one country. For example, about 60% of the world's cobalt comes from the Democratic Republic of the Congo (Fig. 3). In terms of REE, China mines nearly 60% of the raw materials, supplies 85% of related processed/metallurgical products, and domestically consumes nearly 70% of global production.

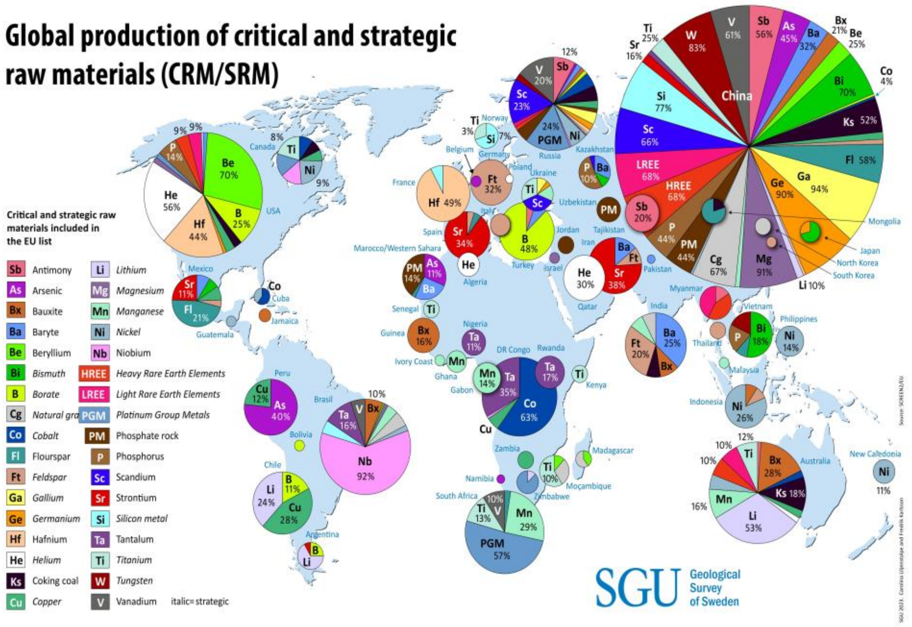


Fig. 3: Map of global CSM production according to the current European list (Source: Geological Survey of Sweden/9)

Many of the countries that mine CSMs choose China as a strategic trading partner since the majority of these countries lack an integrated operation of pertinent key technological value chains which results in the industrial production of neodymium magnets or lithium batteries, among other products that contribute to electrification (Fig. 4). It is clear that contrary to the strategies of the USA and the Soviet Union after the Second World War and until about 1990, which connected their technological research, almost exclusively with the military industry, China chose to invest its technological development in consolidating its geopolitical dominance and position in the global economy.

However, given that the planned battery factories in Europe are expected to start production within the next 12 to 36 months, the continuation of these trade routes may create obstacles to the supply of certain metals, notably lithium, and cobalt, which may cause a slowdown in the production of lithium batteries.

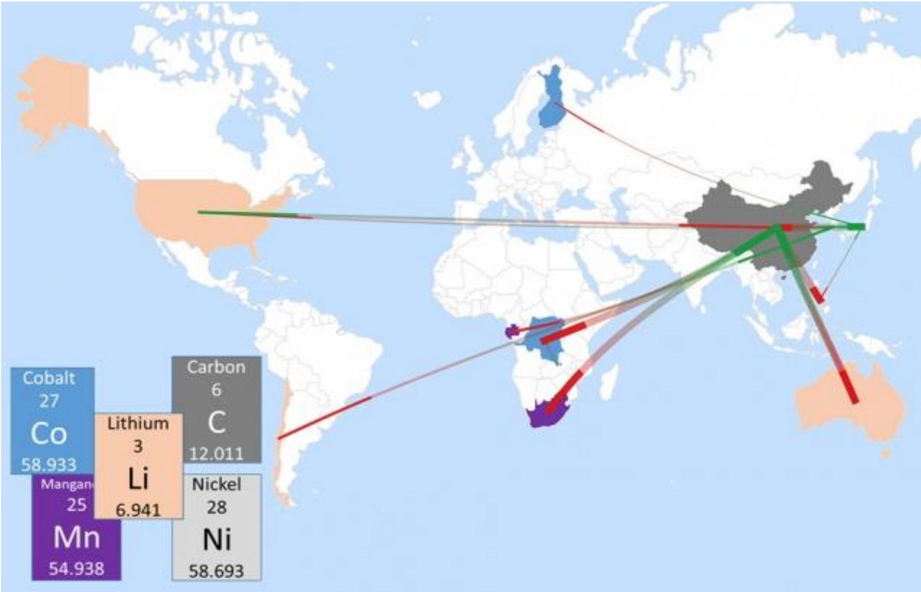


Fig. 4: The map shows today's battery mineral routes, which, while mined in Chile, Australia, Congo, the USA, Finland, South Africa, and others (red), end up in China, where industrial lithium battery production takes place (green) (Joule, 2017/42).

3. EU critical raw materials act

The Critical Raw Materials Act (CRMA) [11, 12, 13, 14] will become the political and strategic tool, but also the operational platform, that will seek to promote and accomplish the implementation of the European Green Deal [16, 17], the new industrial strategy [18, 19] the implementation plan of the European Innovation Partnership on Raw Materials [19], EU strategies around the energy transition, the circular economy and the resource-efficient intra-European mineral exploitation [20, 21, 22, 23], with the primary objective of achieving a climate-neutral Europe. The recent approval of the CRMA Regulation by the European Parliament [24, 25] will trigger a series of actions, decisions, and practices that are expected to lead to ensuring access to and supply of the increased amounts of CSMs that the European industry will need to achieve a green economy. This regulatory and "potential" legislative initiative is very timely and necessary in the formulation of a policy for the mining of the European CSM raw materials, which will contribute to the creation of investment interest in the direction of dynamic ore deposits exploitation of relevant primary [26, 27] and secondary (e.g. mining waste) [28] resources, including those that may result from the recycling of end-of-life (EoL) products, such as batteries, magnets, but also electronic waste in general.

The main targets and benchmarks of the CRMA until 2030 are (Fig. 5):

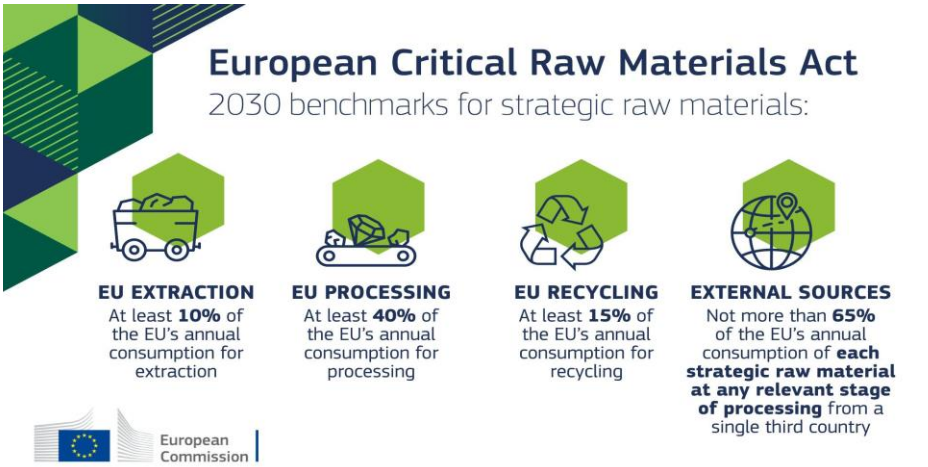


Fig. 5: The first tripartite political decision by the European Commission, the European Council, and the European Parliament that the EU needs to secure the supply of CSMs and the domestic implementation of related strategic value chains (Source: European Commission).

- At least 10% of the annual CSM consumption comes from European deposits.

The reliable, unimpeded, and immediate production of intra-European CSMs is a key condition for technological innovation, green industry, and sustainable development. The problem with insufficient and incomplete CSM mining and production in Europe is neither geological nor metallurgical. Europe's ability to become self-sufficient, self-sustaining, resilient, and sustainable, based on productive exploitation of its own CSM deposits, is greatly favored by its geology and metallogenetic evolution. Economic geological and mineral exploration technologies about [29] CSM deposits must be further developed to have reliable techno-economic approaches, but also relevant estimates for exploitation potential. The national Geological Survey agencies and institutes of the member states have largely re-examined the economic geology of the CSM systems with the aim of more justified and updated ore assessment. Comprehensive economic geological data are now available that 'map' lithium [21] and rare earth mineralisation occurrences in various regions of Europe.

- At least 40% of processed CSMs are produced within the EU.

Increasing Europe's long-term self-sufficiency and gradual autonomy in CSMs, as well as developing sustainable beneficiation and metallurgical downstream technologies, are a prerequisite for the integrated operation of resilient strategic value chains for the energy transition in Europe.

- At least 15% of the annual demand in CSMs should come from recycling.

Most CSMs are found primarily as minor components associated with base metal sulfide and oxide deposits (e.g., copper, lead, zinc, nickel, aluminium, and iron). With mining, production focused overtime on the extraction and processing of base metal minerals, any accompanying CSM concentrations ended up in the various types of mining wastes, such as waste rocks, processing tailings, and metallurgical residues. The historical mining wastes, as they are more broadly called, together mainly with the EoL products (electronic, electrical, batteries, and others), make up secondary raw material resources that through their recycling can potentially lead to the recovery of the CSMs they respectively contain. The EU is at the forefront of the circular economy and has already increased the value of non-mining secondary sources, namely end-of-life consumer products such as waste electronic and electrical waste. In this case, access to environmentally friendly and economically viable recycling technologies and methods is crucial. For example, more than 50% of some metals, such as iron, zinc, or platinum, are recycled and contribute more than 25% of consumer needs in the EU. However, for CSMs needed in renewable energy technologies or high-tech applications, such as REE, lithium, gallium, or indium, the recovery rate from secondary sources is below 1% and thus contributes only very little (Fig. 6) to cover the rapidly growing demand. Even if they were to become more efficient, by 2050 recycling alone would not be able to close the large gap that exists today between the future demand and supply of CSMs.

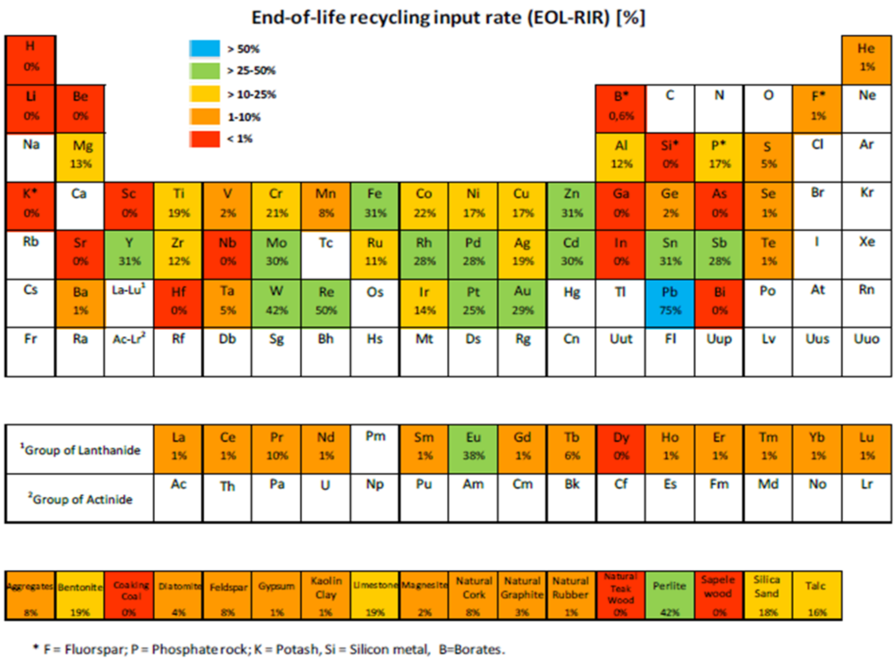


Fig. 6: Some of the CSMs, such as lithium and REE, have recovery rates that are currently sub-1 % [31].

- Less than 65% dependence of each CSM on one country.

CSMs have been the missing link in the climate debate for many years. It is now clear that the EU's climate targets cannot be achieved without them. More specifically, any disruptions to the access and adequacy of CSMs have implications for ensuring the energy transition and the achievement of climate goals. Addressing the growing demand for strategic and critical mineral raw materials requires diligence inside the EU, as well as international cooperation, in matters of exploring new ore mineral sources and resource potential. The reliable, unimpeded, and immediate production of intra-European CSMs is a key condition for technological innovation, green industry, and sustainable development.

- Strengthening the resilience of strategic value chains for more effective implementation of the energy and digital transition.

CSM value chains differ from their supply chains. A CSM value chain is the set of activities that add value at each stage and step of their production cycle, thus improving relative competitiveness. The value chains for CSM include upstream exploration, prospecting and mining, midstream processing (concentration, metallurgy), and downstream industrial manufacturing and recycling, with environmental restoration foreseen in each case, at the post-closure stage of the mining cycle. Unfortunately, in Europe today there are limited possibilities for the sustainable and holistic operation of CSM value chains, especially those characterized as strategic for the technologies that support the energy transition, such as, for example, the lithium battery and neodymium magnet value chains (Fig. 7). To create competitive and autonomous value chains in the EU, all the production stages and steps included in them need to operate at a European level. That is, to mine CSMs, produce the required metallurgical products, and manufacture the batteries and magnets within Europe, with the final end-users being the industrial ecosystems of e-mobility, wind turbines, photovoltaics, and digital technology. Such a development creates further dynamic conditions for additional economic growth and employment.

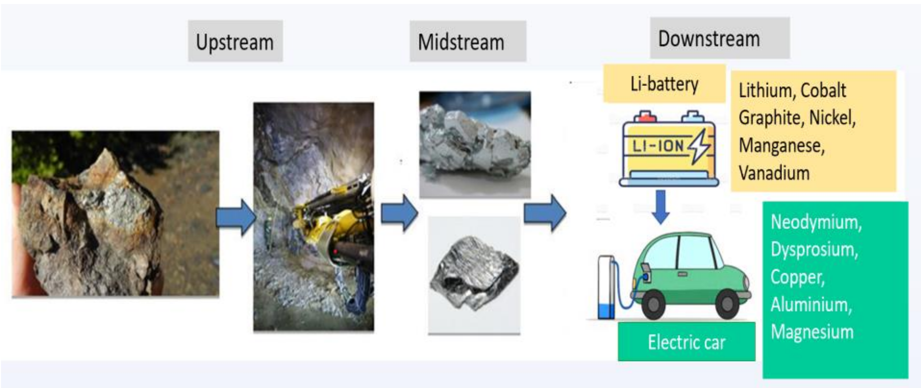


Fig. 7: The mineral value chain spans from upstream geological exploration and mining, midstream processing, and refining, to downstream manufacturing (2).

- Reduction of bureaucracy, and simplification and acceleration of licensing procedures.

The rapidly growing demand for mineral raw materials has also increased the need to update mining policy, as well as research and innovation projects. The CRMA Regulation aims to drastically reduce licensing time, and the Member States will ensure that the licensing process related to such projects becomes faster. The question is how EU countries will respond to this in practice.

- Development of alternative materials and more environmentally friendly mining and production methods.

The Raw Materials Supply Group (RMSG, an expert group including Member States representatives, regional authorities, industry associations, civil society, social partners, and research organisations) and the European Commission have developed and agreed upon a set of voluntary, non-mandatory EU principles for sustainable raw materials [33]. This will serve to create a common European understanding of best practices in the processing and responsible extraction of CSMs [30] in Europe in terms of social, environmental, and economic commitments and applications, and to set a trajectory toward the UN Sustainable Development Goals (SDG/Sustainable Development Goals) [34]. The achievement of many of the goals is highly dependent on relevant activities and uses of CSMs.

- Channeling strategic partnerships between the EU and third countries to ensure sustainable and resilient CSM supply chains.

The CRMA aims to pave the way for long-term partnerships, with knowledge and technology transfer, training, and skills development for new jobs with better working conditions and income, as well as mining and processing according to better ecological standards in the partner countries from which Europe will be able to access and import some of the CSMs needed.

4. "Critical" need for highly capital- and resource-intensive mineral exploration.

Increasing the degree of self-sufficiency in CSM supply from 2-3% to 10% in the EU by 2030 means a 300–40% increase in domestic production in 7 years, which is about the time it takes on average to get a permit in place. This means that massive efforts and an increase in investment in exploration to at least an equivalent degree are required if we are to even come close to that degree of self-sufficiency. It also follows that we need to apply innovative and sustainable approaches, using breakthrough technologies, to improve economic efficiency and obtain information that could not be obtained by conventional methods.

4.1 Exploration as part of Economic Geology

The EU exploration and mineral industry needs to have access to harmonized knowledge-based mineral data and information for both primary (Fig. 8) and secondary mineral resources. With this data currently becoming more available and the innovative research carried out by the Geological Surveys of Europe, there is a better understanding today of the geological setting of CSM systems. Moreover, CSM-fitting exploration technologies and methods (e.g., 3D models integrating geology, geophysics, and geochemistry), have been developed and applied in recent years, which also consider the challenges of brownfield and/or greenfield exploration targets, e.g., the location of deeper-seated ore bodies, and re-mining historical wastes in the case of brownfield exploration. Knowledge about the implementation of the UNFC resource classification system is improving at a rapid rate and is now a dominant priority for the mining authorities and industry in Europe. A full-scale economic geological approach also includes beneficiation testing, suggesting possible processing technology options, and considering the CRMA target that by 2030, 40% of the EU's annual consumption of each CSM, should be refined within the Union. In each case, the mineral exploration activity is completed by considering the possible options of open-pit and/or underground mining and drawing up a pre-feasibility study.

Mineral exploration efforts targeting CSMs must consider the fact that most of them are directly linked to known sulfide and oxide ore deposits. Examples of CSM found associated with known mineral systems are Co with Ni and Cu ores (Fig. 9); Ga, Ge, In, and Sb with base metal sulfides; Platinum Group Metals with Cr, Ni, and Cu; Ga, REE, and Sc with Al deposits; W, Nb, In, and Ta with Sn; and REE with P-minerals. Exploration activities in such cases might be a matter of (i) a feasibility study when it comes to active mines, addressing the volume, grades, and recovery rate of potentially associated CSMs, or (ii) brownfield, often deep, exploration of historical mining fields [Fig. 10], including mining wastes, this time prospecting also for exploitable CSM concentrations (Fig. 11). About this, it is appropriate to mention that brownfield exploration is less expensive, more time-efficient, provides better conditions for permitting, benefits the environment, and might be considered more socially acceptable. As we also deal with historical, currently abandoned mining fields, any stockpiled mining waste makes a secondary mineral resource and a new mineral deposit target.

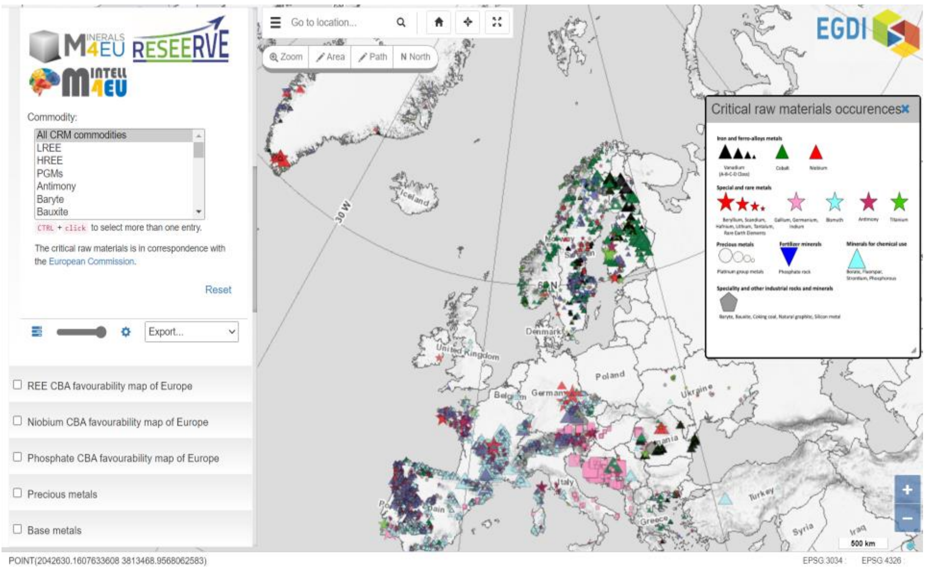


Fig.8: The Geological Surveys of Europe provide regularly updated information on CSMs. EGDI is EuroGeoSurveys' European Geological Data Infrastructure (Source: EGDI/EuroGeoSurveys).

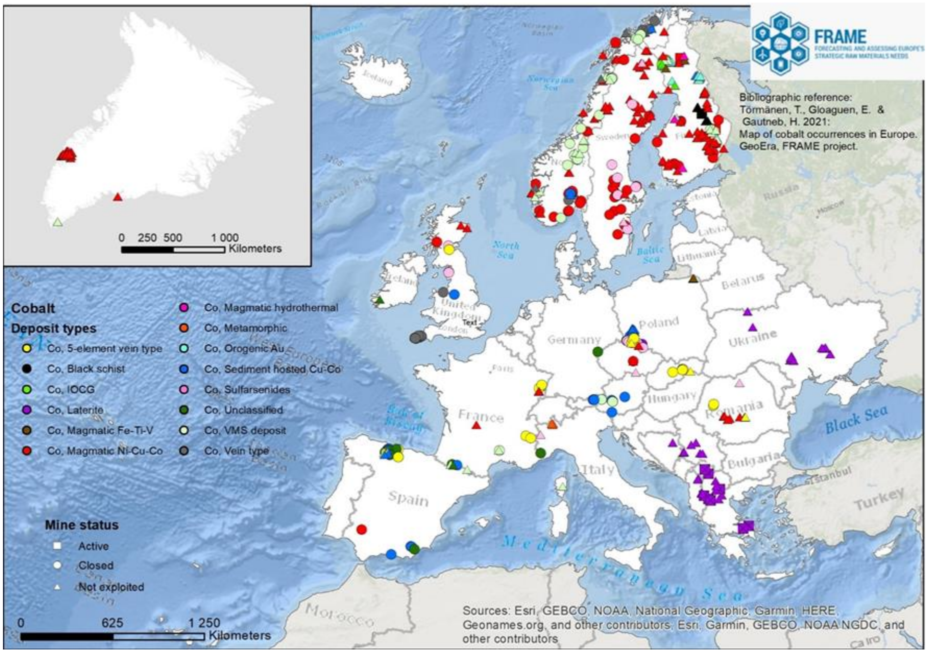


Fig. 9: Potentially exploitable cobalt concentrations in Europe are mainly associated with magmatic nickel sulfide mineral systems in Finland and with lateritic Ni deposits in Greece and other West Balkan countries (Source: FRAME/GeoERA project).

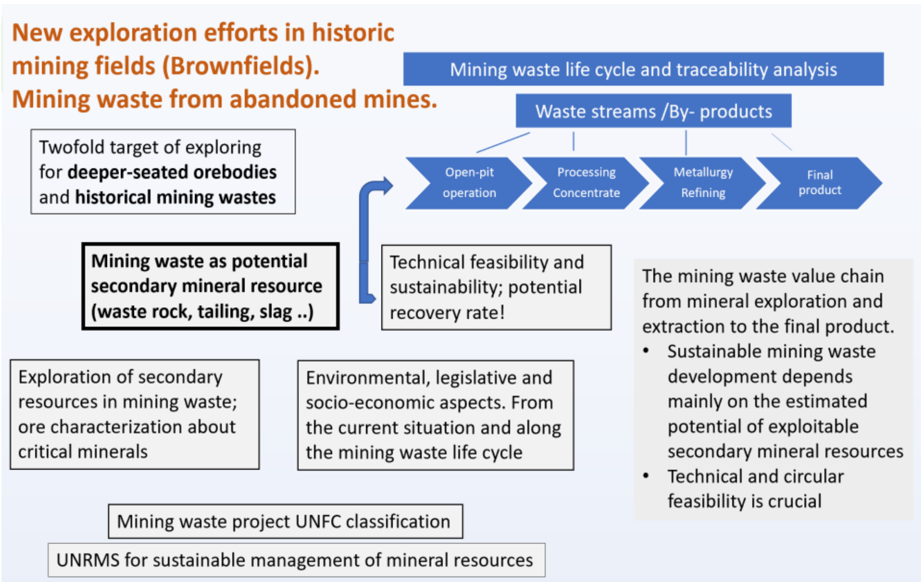


Fig. 10: Proposed methodology when addressing brownfield exploration targeting deeper-seated orebodies and mining wastes in historical mining fields (26).

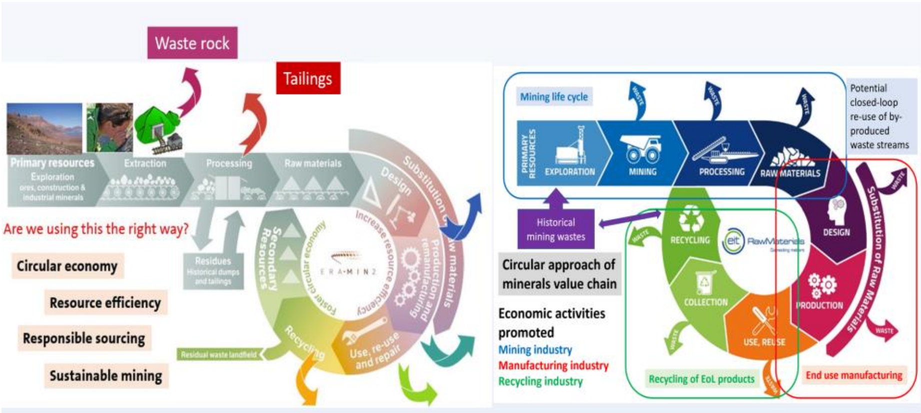


Fig. 11: The potential of recycled CSMs refers to three secondary "feedstock" sources: (1) mining waste, (2) industrial waste, and (3) EoL products. Waste rocks and processing tailings as a potential secondary source for CSMs also need to be further explored (2, 4).

5. European initiatives for geopolitical balance and the gradual autonomy of CSMs

As it follows from the CRMA, the implementation of a multidimensional search strategy for new supply markets for CSMs is a dynamic European objective. For example, with the significant CSM reserves that they have and sustainably and responsibly mine, countries such as Canada and Australia can be safe and reliable CSM production partners and related value-added products for global markets, including the EU. Improving the holistic and resource-efficient exploitation of CSMs is part of the action plan for the circular economy and the current EU directive on mining waste. In addition, the directive provides for compliance with specific terms for both the minimization and recycling of mining waste. The EU considers that the implementation of circularity through the strengthening of recycling will have a significant contribution to the geopolitical balance and will strengthen the strategic autonomy of CSMs. All new mining and mineral production projects should, from the very beginning, be designed based on the circular economy and the holistic recovery of main and by-products within the loop of the same production cycle before they are sent to waste.

Given China's geopolitical dominance and the extent of corporate partnerships, collaborations, and investments that it has launched (Fig. 4) around the world about the exploitation of other countries' CSMs, Europe will be tasked with finding its roads and ways of accessing the resources it needs. In fact, at a time when the Russian invasion of Ukraine is ongoing, a difficult geopolitical reality has become even more difficult since some of the minerals that are today characterised as strategic and critical for the EU are mined from the Russian and Ukrainian bedrock basements [16]. Russia, for example, produces 8% of the world's nickel, 23% of vanadium, 41% of palladium, 5% of cobalt, 4% of copper, and 6% of aluminium, while Ukraine mines 3% of the world's iron ore and is respectively the eighth largest producer of manganese. It also produces smaller amounts of other CSMs, such as titanium, graphite, and silicon, and mines zircon and uranium.

Faced with these particularly difficult and determined geopolitical conditions, which have been "largely" shaped and controlled by China, the EU, as well as other countries dealing with problems of access to CSMs, are undertaking dynamic initiatives to build stronger partnerships at the global level, based on trust, openness, and mutual benefit. On its behalf, the EU has recently concluded trade agreements with Chile, while upcoming agreements are underway with Indonesia and other countries (Fig. 12), which will help support sustainable and resilient supply chains. The goal is to create a global gathering for CSMs with trusted partners who also wish to develop their own CSM value chains as well as related CSM industries. Closer and more diversified commercial ties and partnerships will help the EU to reduce dependencies, which currently exist mainly from China, but also any weaknesses that this entails. What is required for the EU is to secure the CSMs, which are of fundamental importance for its competitiveness, focusing on its aim to be a pioneer in the green industries of the future.

More broadly, globally, the US, Canada, and Australia are collaborating on CSM exploration and resource characterization and classification [35]. Japan and the US have signed an agreement that is expected to create strong and sustainable CSM value and supply chains in cooperation with other countries as well [36]. Particularly dynamic and important is the international Mineral Security Partnership (MSP) initiative, which involves the cooperation of 13 countries and the EU to promote and implement public and private investments in responsible mineral security value and supply chains worldwide. This partnership aims to accelerate the development of diverse and sustainable CSM supply and value chains but also to support diplomatically and economically related strategic projects through government and industry collaboration. The 13 participating partners include Australia, Canada, Finland, France, Germany, India, Italy, Japan, Norway, the Republic of Korea, Sweden, the United Kingdom, the United States, and the European Union (represented by the European Commission] [37].

The EU and other countries that rely on CSM imports must act quickly and effectively to reduce their dependence primarily on China, which currently geopolitically dominates CSM supply and value chains globally. If nothing else, to diversify today's trade "routes" to their advantage. A typical example of the influence that China continues to have on global CSM markets is its recent decision to restrict exports of gallium and germanium [38, 39, 40]. So given that China produces about 80% of the world's gallium (primary gallium production in China is a by-product of bauxite or zinc processing) and about 60% of the germanium, and the fact that the two elements are used in a large range of applications and products, including semiconductors, computer chips, and photovoltaics, their zero export in August had major implications for the respective EU, Japanese, and US industries. For example, as far as Japan is concerned, about 40% of its gallium supply depends on China. Also, China's announcement of limited exports in early July led to a nearly 20% increase in the price of gallium in the US and Europe.

So, the answer to the question, of whether the EU and other affected countries will succeed in working together to remove or better reduce their dependence on China, is difficult for the moment to give concretely and clearly when it comes mainly to the time it will take.

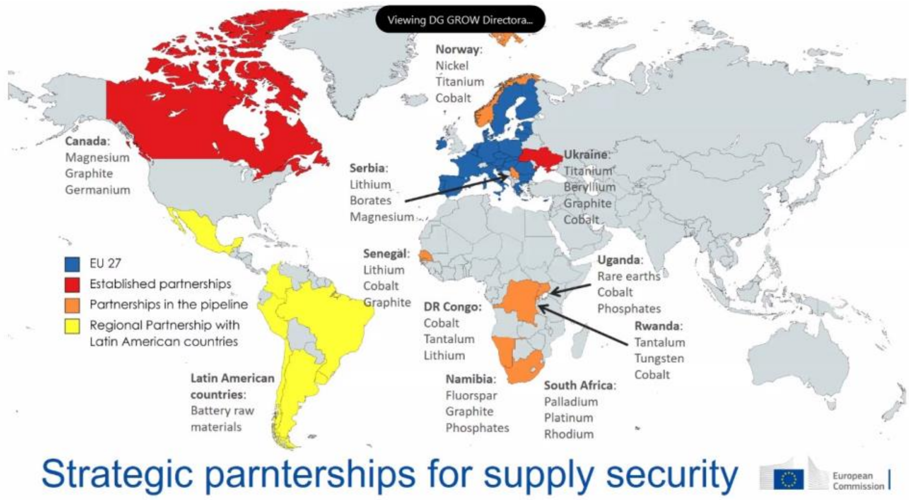


Fig. 12: EU Strategic Partnerships to Secure CSM Supply Chains and thereby Strengthen the Resilience of Domestic Value Chains (Source: European Commission).

5.1 CSM availability challenging EU 2030 goals

There are growing global and EU concerns regarding CSM availability, considering that.

- Mineral intensity issues about Green Deal targets to be achieved by 2030, e.g., cutting greenhouse gas emissions by at least 55%.
- The EU estimates that the penetration of electric cars amounts to 7-8 million per year. This means that by 2030, more battery and magnet minerals will be needed in terms of large quantities of manganese, lithium, cobalt, graphite, rare earths, nickel, and copper if car manufacturers are to hit their very ambitious production targets.
- Lithium demand has risen very strongly in the last few years, and it is expected to go higher, especially as the planned battery giga factories appear to be coming online in the next 12 to 36 months.
- By 2030, demand for graphite is expected to reach 4 m.t. per year, with 75% going to lithium battery anodes. A shortfall of around 780,000 tons per year is estimated by 2030. Most of the graphite comes from China.
- According to CRMA, by 2030, 10% of the Union’s consumption of strategic mineral raw materials should be mined in the EU.
- 2030 is only seven years away. Just about 10 years or so is the amount of time it takes to bring a new mine into production. Consider also that almost 1% of mineral occurrences found will become mines.

So, the central question is: where will all these battery and magnet minerals need to come from? Will the EU manage to reach the 10% target? Because, certainly, the CSM of batteries and magnets is not enough to ensure the increasing production of wind energy and electric cars.

6. EU’s economic geology sets the spot for exploitable resources in CSMs

- Europe’s opportunity to become self-sufficient, resilient, and sustainable in critical and strategic mineral supply from its resources is strongly favoured by its geological setting and metallogenetic evolution.
- Predictive mapping, along with updated geological knowledge and improved mineral intelligence, results in areas of high regional-scale exploration potential to enable targeting prospective mineral resources of REE, lithium, cobalt, graphite, and nickel in Europe. Sweden, Norway, and Finland have undertaken joint efforts to provide a common approach and assessment on raising the exploration and resource potential of battery and magnet minerals in the Fennoscandian mineral belt.
- EU Member States (MS) should promote national and/or transboundary CSM exploration, focusing on brownfield areas with the twofold target of exploring deeper-seated orebodies and historical mining wastes.
- Recycling alone is not yet sufficient to meet the EU’s and the world’s current growth in demand for mineral raw materials. However, it constitutes a potential exploration target, considering the CRMA target that by 2030, 15% of the EU’s annual consumption of each CSM should come from recycling.
- The fast-growing demand for mineral raw materials has also raised the need for policy updates and innovation. For example, it will take at least 10–15 years before the Swedish company LKAB can begin mining and delivering REE products to the market.
- The CRMA aims at reducing the permitting time drastically, as MS ensures that the permit-granting process related to such projects will get faster. The question is, how will MS respond to this?
- Strategic projects addressing CSM will be identified and financed by the EC, together with a European Critical Raw Materials Board that is about to be established. It has been drafted that “private investment alone is not sufficient” and that the effective roll-out of projects along the CRM value chains may require public support (so-called state aid).

7. Concluding remarks

Upon these particularly difficult geopolitical conditions, which have been "largely" shaped and controlled by China, the EU is facing CSM access problems, and apart from relying on its own CSM resources, is undertaking dynamic initiatives to build stronger partnerships at the global level, based on trust, openness, and mutual benefit. In this respect, the EU has recently concluded trade agreements with Chile, Argentina, Canada, Greenland, Ukraine, Kazakhstan, DRC, Zambia, and Namibia while upcoming agreements are underway with Norway, Indonesia, Australia, and other countries, which will help support sustainable and resilient supply chains. The goal is to create a global gathering for CSM, with trusted partners who also wish to develop their own CSM value chains as well as related CSM industries. With closer and more diversified commercial routes and partnerships, designed to reduce dependencies, which currently exist mainly from China (42), this will help to reduce any weaknesses and risks that these dependencies entail. What is required for the EU is to secure the CSMs, which are of fundamental importance for its competitiveness, focusing on its aim to be a pioneer in the green industries of the future. At the same time, the improvement of the holistic and resource-efficient exploitation of CSM is part of the action plan for the circular economy. The EU considers that the implementation of circularity through the strengthening of recycling will have a significant contribution to the geopolitical balance and will strengthen the strategic autonomy of CSM. All new mining and mineral production projects should, from the very beginning, be designed based on the circular economy and the holistic exploitation of main and by-products.

References

1. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2021): 3rd Raw Materials Scoreboard – European innovation partnership on raw materials, Publications Office, 2021, https://data.europa.eu/doi/10.2873/567799
2. Arvanitidis N. and Constantinides D. (2023): Exploitation of critical mineral deposits in the EU: The key to indigenous, holistic and sustainable value chains (in Greek). Newsletter, RAWMATHUB. https://rawmathub.gr/epistimonika-kai-epixeirimatika-afieromata/krisimes-oryktes-protes-yles-ena-stoixima-gia-tin-evropi/ekmetallefsi-koitasmaton-kopy-stin-ee-to-polykleido-gia-gigeneis-olistikes-kai-viosimes-alysides-aksias
3. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2023): Critical Raw Materials. https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en
4. Arvanitidis N. (2021): Lithium batteries and neodymium magnets renew the energy in electromobility (in Greek). Newsletter, Greek Association of Mining Enterprises. https://www.sme.gr/bataries-lithiou-kai-magnites-neodymiou-ananeonoun-tin-energeia-stin-ilektrokinisi/
5. Arvanitidis N. (2021): The new age of copper is also "courting" Greece (in Greek). Newsletter, Greek Association of Mining Enterprises. https://www.sme.gr/h-nea-epochi-tou-chalkou-flertarei-kai-tin-ellada/

6. Dimitriadis D. and Arvanitidis N. (2023): Considerations and views on the Greek Mining Policy (in Greek). Newsletter, RAWMATHUB. https://rawmathub.gr/synentefkseis-kai-arthra-gia-protes-yles/arthra-gia-protes-yles/oi-nees-energeiakes-texnologikes-prokliseis-antimetopizontai-me-viosimes-oryktes-protes-yles
7. International Energy Agency (2022): Global Supply Chains of EV Batteries. https://iea.blob.core.windows.net/assets/4eb8c252-76b1-4710-8f5e-867e751c8dda/GlobalSupplyChainsofEVBatteries.pdf
8. Kirsten H. La Porta D., Fabregas T. P., Laing T. and Drexhage J. (20209: Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition. The World Bank Group. World Bank Publications. https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf
9. Geological Survey of Sweden (2023): Critical and strategic raw materials. Mineral Resources. https://www.sgu.se/en/mineral-resources/critical-raw-materials/
10. U.S. Department of Energy (2022): Rare Earth Permanent Magnets. Supply Chain Deep Dive Assessment. U.S. Department of Energy Response to Executive Order 14017, “America’s Supply Chains”.https://www.energy.gov/sites/default/files/2022-02/Neodymium%20Magnets%20Supply%20Chain%20Report%20-%20Final.pdf
11. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2023): Critical Raw Materials Act. https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en\
12. Arvanitidis N. (2022): Critical Raw Materials Act. Practical application or another theoretical rhetorical approach? (in Greek). Newsletter, Greek Association of Mining Enterprises. https://www.sme.gr/protovoulia-gia-tis-krisimes-oriktes-protes-iles/
13. Arvanitidis N. (2022): Critical Raw Materials Act. Practical application or another theoretical rhetorical approach? (in Greek). Newsletter. RAWMATHUB. https://rawmathub.gr/synentefkseis-kai-arthra-gia-protes-yles/arthra-gia-protes-yles/protovoulia-gia-tis-krisimes-oryktes-protes-yles-praktiki-efarmogi-i-alli-mia-theoritiki-ritoriki-proseggisi
14. Arvanitidis N. (2023): Views on the sustainable operation of the National Committee on strategic and critical minerals (in Greek). Newsletter. RAWMATHUB. https://rawmathub.gr/synentefkseis-kai-arthra-gia-protes-yles/arthra-gia-protes-yles/dr-n-arvanitidis-skepseis-sxetika-me-ti-viosimi-leitourgia-ethnikis-epitropis-opy
15. European Commission, Strategy and Policy (2021). The European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
16. Arvanitidis N. (2022): Ukraine and Russia can contribute to the realization of the European Green Deal (in Greek). Newsletter. RAWMATHUB. https://rawmathub.gr/synentefkseis-kai-arthra-gia-protes-yles/arthra-gia-protes-yles/dr-n-arvanitidis-me-rosia-kai-oukrania-i-evropaiki-prasini-symfonia-kerdizei-edafos
17. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2021): European industrial strategy. https://single-market-economy.ec.europa.eu/industry/strategy_en
18. European Commission, Strategy and Policy (2021): The European Commission’s priorities. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en

19. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2020): Strategic implementation plan (SIP). European Innovation Partnership (EIP) on raw materials. https://single-market-economy.ec.europa.eu/sectors/raw-materials/eip/strategic-implementation-plan-sip_en
20. SCRREEN project (2023): European Union's Horizon Europe Research and Innovation Programme under Grant Agreement N° 101138060. https://scrreen.eu/
21. GeoERA project (2021): Forecasting and Assessing Europe's Strategic Raw Materials needs (FRAME). European Union's Horizon 2020 research and innovation program under grant agreement No 731166. https://geoera.eu/projects/frame2/
22. European Geological Data Infrastructure (EGDI) (2024): Geological Service for Europe. EuroGeoSurveys (EGS). .https://www.europe-geology.eu/
23. GSEU project (2023): Geological Service for Europe. European Union's Horizon Europe. https://www.geologicalservice.eu/
24. European Parliament (2023): Critical raw materials: MEPs back plans to secure EU's own supply and sovereignty. Press Releases. News. https://www.europarl.europa.eu/news/en/press-room/20230904IPR04618/critical-raw-materials-meps-back-plans-to-secure-eu-own-supply-and-sovereignty
25. Arvanitidis N. (2023): The European Parliament votes in favor of the Critical Raw Materials Act Regulation (in Greek). Newsletter. RAWMATHUB. https://rawmathub.gr/synentefkseis-kai-arthra-gia-protes-yles/arthra-gia-protes-yles/dr-n-arvanitidis-to-evropaiko-koinovoylio-psifizei-yper-tou-kanonismoy-gia-tis-skopy
26. Arvanitidis N. (2023): Geopolitical developments and sustainable EU access to Strategic and Critical Mineral Raw Materials (in Greek). Greek Mineral Wealth. https://rawmathub.gr/synentefkseis-kai-arthra-gia-protes-yles/arthra-gia-protes-yles/dr-n-arvanitidis-epistameni-kai-estiasmeni-geologiki-erevna-gia-koitasmatologiki-aksiopoiisi-endoevropaikon-apothematon-kopy
27. Arvanitidis N. (2022): United Nations system for universal classification of mineral deposits (in Greek). Newsletter, Greek Association of Mining Enterprises. https://www.sme.gr/sistima-inomenon-ethnon-gia-oikoumeniki-taxinomisi-koitasmaton/
28. Arvanitidis N. (2021): Mining wastes- the new mineral exploration challenge (in Greek). Newsletter, Greek Association of Mining Enterprises. https://www.sme.gr/metalleftika-apovlita/
29. Arvanitidis N. (2022): Intensified and focused mineral exploration of intra-European critical raw materials resources (in Greek). Newsletter. RAWMATHUB. https://rawmathub.gr/synentefkseis-kai-arthra-gia-protes-yles/arthra-gia-protes-yles/dr-n-arvanitidis-epistameni-kai-estiasmeni-geologiki-erevna-gia-koitasmatologiki-aksiopoiisi-endoevropaikon-apothematon-kopy
30. Arvanitidis N. (2019): Europe's dependence on Critical Raw Materials (CRM) and growing supply needs for battery minerals-based value chains. Newsletter, Greek Association of Mining Enterprises. https://www.sme.gr/europes-dependence-on-critical-raw-materials-crm-and-growing-supply-needs-for-battery-minerals-based-value-chains/
31. Arvanitidis N., J. Boon, P. Nurmi, G. Di Capua (2017): White Paper on Responsible Mining. IAPG Task Group on Responsible Mining. With the contribution of V. Correia, R. Lencina, D. Ovadia, M. Rachovides and I. Thomson. International Association for Promoting Geoethics. https://www.researchgate.net/publication/321715310_White_Paper_on_Responsible_Mining
32. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (2023): Critical Raw Materials. https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

33. Bobba, S., Carrara, S., Huisman, J., Mathieux, F. and Pavel, C (2020): Critical Raw Materials for Strategic Technologies and Sectors in the EU -A Foresight Study. European Commission, Joint Research Centre. https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf
34. European Commission, Raw Materials Supply Group (2021): EU principles for sustainable raw materials. Publications Office of the European Union. https://tem.fi/documents/1410877/2851374/EU_principles_for_sustainable_raw_materials+–+kopio.pdf/4687cf52-7ca7-bb90-854b-832ea19d24c5/EU_principles_for_sustainable_raw_materials+–+kopio.pdf?t=1639642622731
35. United Nations (2015): The 2030 Agenda for Sustainable Development. Department of Economic and Social Affairs. https://sdgs.un.org/goals
36. USGS (2020): Critical Cooperation- How Australia, Canada and United States are working together to support critical mineral discovery. https://www.usgs.gov/news/featured-story/critical-cooperation-how-australia-canada-and-united-states-are-working
37. Ministry of Foreign Affairs of Japan (2023): Signing of the Japan-U.S. Critical Minerals Agreement (CMA). Press Releases. https://www.mofa.go.jp/press/release/press1e_000400.html
38. US Department of State (2023): Minerals Security Partnership. State for Economic Growth, Energy and the Environment. https://www.state.gov/minerals-security-partnership/
39. Reuters (2023): China exported no germanium, gallium in August after export curbs. https://www.reuters.com/world/china/china-exported-no-germanium-gallium-aug-due-export-curbs-2023-09-20/
40. Center for Strategic and International Studies (2023): Understanding China’s Gallium Sanctions. https://www.csis.org/analysis/understanding-chinas-gallium-sanctions
41. Cytera C. (2023). Gallium, Germanium, and China — The Minerals Inflaming the Global Chip War. Center for European Policy Analysis (CEPA). https://cepa.org/article/china-gallium-and-germanium-the-minerals-inflaming-the-global-chip-war/
42. Elsa A. Olivetti, Gerbrand Ceder, Gabrielle G. Gaustad, Xinkai Fu, (2017): Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals, Joule, Volume 1, Issue 2, 2017, Pages 229-243, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2017.08.019; https://www.sciencedirect.com/science/article/pii/S2542435117300442