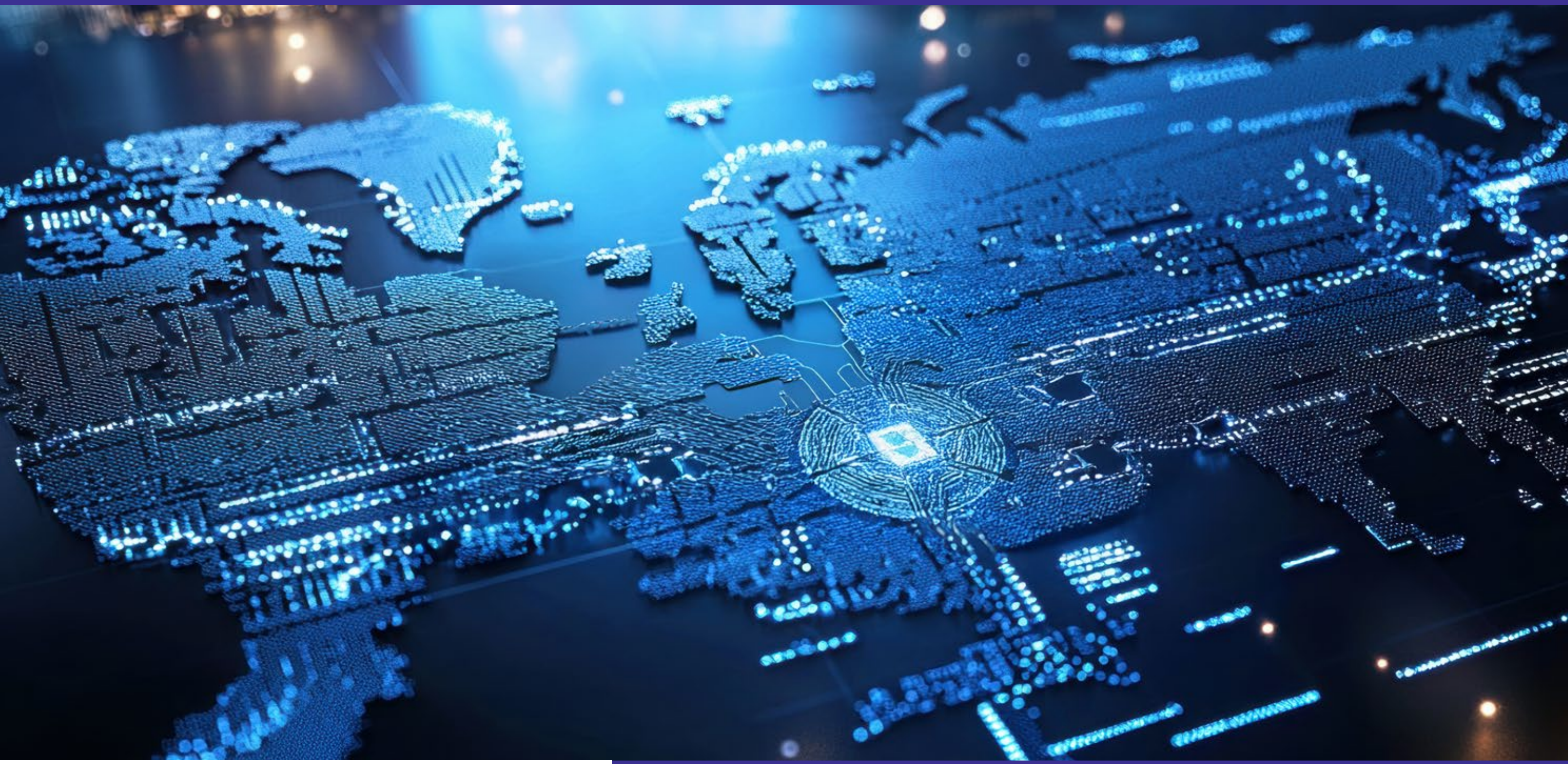
ESCP BUSINESS SCHOOL

IT ALL STARTS HERE

BERLIN I LONDON I MADRID I PARIS I TURIN I WARSAW



LIGHTS - Geopolitics

The role of critical raw materials in the energy transition: an analysis of Europe's AI dependence on China

ESCP Impact Paper No.2025-15-EN

Hamed GHIAIE - ESCP Business School
Corrado RAJOLA - Eni
Filippo GORELLI - Alumni ESCP Business School

ESCP RESEARCH INSTITUTE OF MANAGEMENT (ERIM)

ESCP Impact Paper No.2025-15-EN

The role of critical raw materials in the energy transition: an analysis of Europe's AI dependence on China

Hamed Ghiaie*
Corrado Rajola**
Filippo Gorelli***

ESCP Business School

Abstract

Can Europe go green using AI without China's critical raw materials, particularly rare earths? This question lies at the heart of the ongoing debate on the European Union's (EU) energy transition. The EU faces a twofold challenge: on the one hand, the need to accelerate the shift toward clean energy to meet the climate targets set by the Paris Agreement and the European Green Deal; on the other hand, its strong dependence on imports of critical minerals.

Keywords: geopolitics, China, rare earths

*Professor, ESCP Business School
**Eni, Public Affairs
***Alumni of ESCP Business School

The role of critical raw materials in the energy transition: an analysis of Europe's AI dependence on China

Introduction

Every energy transition has posed new challenges linked to the development of dominant technologies, and the "green" transition is no exception. Clean energy technologies—from wind turbines and solar panels to electric vehicles and battery storage—require a wide range of critical minerals (CRMs), including lithium, cobalt, and rare earths. The growing demand for these minerals over the next 20-30 years, driven by the global shift toward clean energy, has raised concerns about their availability. This demand surge could hinder the ambitious global goal of transitioning to a net-zero energy system while ensuring stable and affordable energy supplies and robust economic growth.

The intensified global competition for CRMs has placed their security at the forefront of political agendas, especially for the EU. As it is significantly dependent on imports—particularly from China, which dominates global production and refining of these materials—the EU faces risks such as supply chain disruptions, price volatility, and geopolitical tensions. Without a secure and reliable supply of rare earths, the EU may struggle to meet its 2030 energy targets, which include the installation of 510 GW of wind power capacity and the production of 18 million electric vehicles.

Through a review of existing literature and data from official statistical sources, industry reports, and policy documents from both Europe and China, this article assesses the risks posed by Europe's reliance on Chinese CRMs, particularly rare earths. The results indicate that without imports from China, Europe would face considerable difficulties in reaching its clean energy targets. In response, this article proposes strategies to enhance supply chain resilience, such as diversifying supply sources, increasing domestic production, and strengthening recycling capabilities, as outlined in the EU's Critical Raw Materials Act.

This article presents a structured analysis, beginning with a comprehensive literature review on the role of critical minerals in the energy transition and Europe's reliance on imports (first section), followed by an in-depth examination of Europe's dependency on Chinese CRMs and its implications for key sectors such as wind energy and electric vehicles (second section). It then outlines policy recommendations and strategies to strengthen Europe's CRM supply resilience and support progress toward its climate goals (third section). A final section explores business implications and provides strategic recommendations for European firms aiming to reduce exposure to supply risks and maintain competitiveness in a resource-constrained global environment (fourth section).

The role of CRMs in the energy transition

In the context of the energy transition, critical minerals assume a central role, serving as fundamental pillars for the development and effectiveness of renewable technologies and progress towards environmental sustainability goals. The growing emphasis on clean energy technologies further highlights their importance, driving demand across multiple industrial sectors. To date, there is no universal definition of the concept of critical raw materials, as it is the public decision-maker who determines their characteristics on the basis of country-specific economic, industrial and strategic priorities. However, CRMs are identified by their economic significance and high risk of supply chain disruption. The EU identifies 34 CRMs, including 17 strategic raw materials (SRMs), crucial for industrial applications, each facing unique supply risks and dependencies. These materials are projected to experience demand growth as they are essential across various sectors such as aerospace, electronics, automotive, and energy-intensive industries,particularly clean technologies.

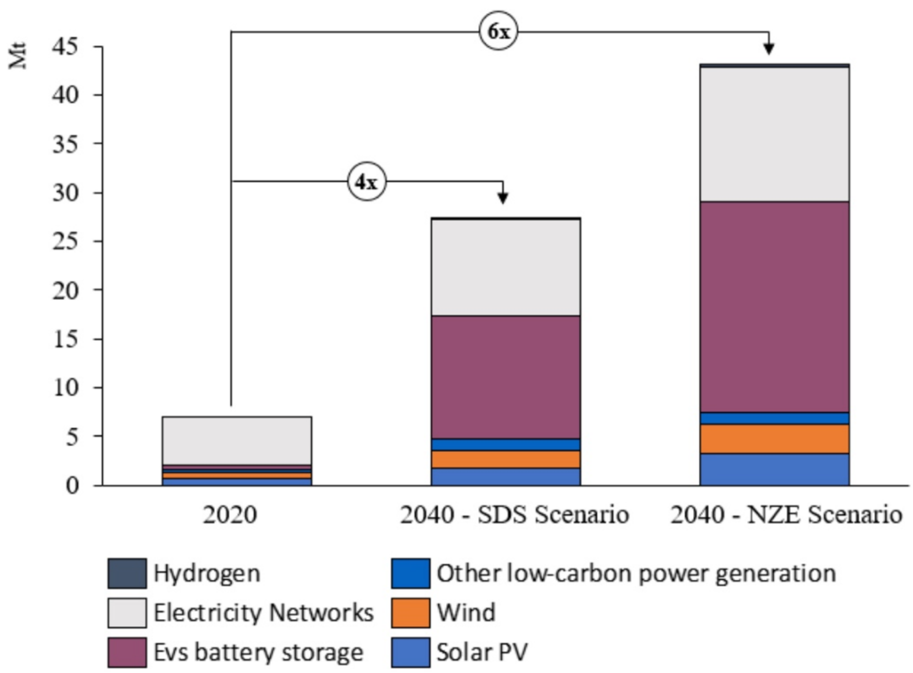
As emphasized by Chazel & Bernard (2023), the transition to a low-carbon energy system significantly increases the demand for critical minerals. Renewable energy sources are notably more “material intensive” than fossil fuels, requiring substantial quantities of minerals such as rare earth elements, lithium, cobalt, and nickel. This material intensity underscores the reliance of green technologies on CRM availability, a trend that intensifies as more countries adopt renewable energy solutions. For instance, electric vehicles and renewable energy infrastructure necessitate significant amounts of these minerals compared to conventional technologies. The International Energy Agency (IEA) data indicates that electric vehicles require over 200 kg of critical minerals per vehicle, six times more than conventional vehicles. Sustainable energy sources such as solar and wind facilities also represent a source of high demand, requiring up to 90 times more aluminum and 50 times more iron, copper, and glass for an equivalent installed capacity (Vidal et al., 2013). This highlights the resource-intensive nature of the transition to sustainable energy systems and emphasizes the pivotal role of CRM availability and security in achieving global climate targets.

The IEA forecasts a spike in demand for CRMs as the global energy transition accelerates. Specifically, the SDS scenario[1] predicts that demand for critical minerals in clean energy technology will increase approximately fourfold by 2040 compared to 2020. In the more ambitious NZE scenario[2], demand is expected to grow approximately sixfold by 2040 compared to 2020. This surge in demand is driven by the ongoing energy transition, which acts as a major catalyst, particularly for minerals such as copper, lithium, nickel, cobalt, and rare earths. These minerals are essential components in the expansion of green technologies and this anticipated growth reveals the scale of the challenge: securing a steady supply of CRMs to sustain the momentum of the energy transition.

[1] Sustainable Development Scenario, stating the necessary steps in a manner that would allow the Paris agreement’s objective to be met.

[2] The Net Zero Emissions by 2050 Scenario is a normative scenario that outlines a means to get net zero CO2 emissions from the world’s energy industry.

Mineral demand for clean energy technologies per scenario in 2040



Source: Personal Elaboration on IEA data, 2021

According to the IEA, the amount of minerals required per new unit of power generation capacity has increased by 50% since 2010, largely due to the rise of new and renewable energy technologies. Looking ahead to 2040, under scenarios aligned with the Paris Agreement targets, global demand for critical minerals is projected to escalate significantly: lithium demand could rise by 42-fold, graphite by 25-fold, cobalt by 21-fold, nickel by 19-fold, and rare earths by 7-fold. Clean energy technologies are expected to drive substantial portions of global mineral demand, with forecasts indicating they could account for more than 40% of copper and rare earth demand, 60-70% of nickel and cobalt demand, and nearly 90% of lithium demand by 2040. Consequently, the availability and security of these resources become critical factors in realizing global climate and energy goals, while the resource-intensive nature of the green transition underscores the urgency of securing reliable CRM supplies and addressing Europe's vulnerabilities, an issue explored below with a focus on its reliance on China.

Europe's reliance on imported CRMs

While demand is expected to increase significantly, the average capacity of EU countries to supply CRMs is low. Although Europe's production of critical minerals is low its primary extraction potential is not negligible. Europe's current domestic production could be boosted by 2030 through the development of identified but undeveloped sites rich in CRMs. This raises important questions about Europe's ability to meet its growing needs internally, especially in light of its dependency on external suppliers.

The trade association Eurometaux estimates that the development of new areas rich in CRM or their rehabilitation in Europe could help increasedomestic production of copper by about 25%, nickel by about 60% and cobalt by about 55%. Such figures suggest a potential to partially alleviate dependence, yet the gap between demand and supply remains substantial.

The combination of a limited (current and future) supply capacity and a high and growing demand for CRMs naturally pushes the EU towards a condition of quasi-dependence on non-EU countries satisfied through a continuous flow of imports. This phenomenoncan trigger critical issues when the supply of CRMs is highly concentrated in one or a few nation-states. As highlighted by a study conducted by the European Commission[3], EU countries show a dependence on imports of critical raw materials of more than 80% as well as an often marginal role in the other stages of the value chains of the clean energy technologies.

China holds an overwhelmingly dominant position among critical minerals-exporting countries to the European Union. In fact, between 2016 and 2020, 44% of the critical minerals exported to the European Union came from China. The latter represents the country carrying the highest supply risk for the EU. In general terms, the vast majority of the EU's CRM imports come from non-OECD countries, generally considered less reliable and stable from an economic and geopolitical perspective. The difficulty in achieving self-sufficiency on the CRM front strongly reduces the possibility of achieving the set environmental standards, as it precludes at least effective management of the ecological transition. These challenges highlight the urgency for Europe to rethink its CRM supply strategies, as explored further in the context of China's dominance.

China's dominance in CRM extraction and processing

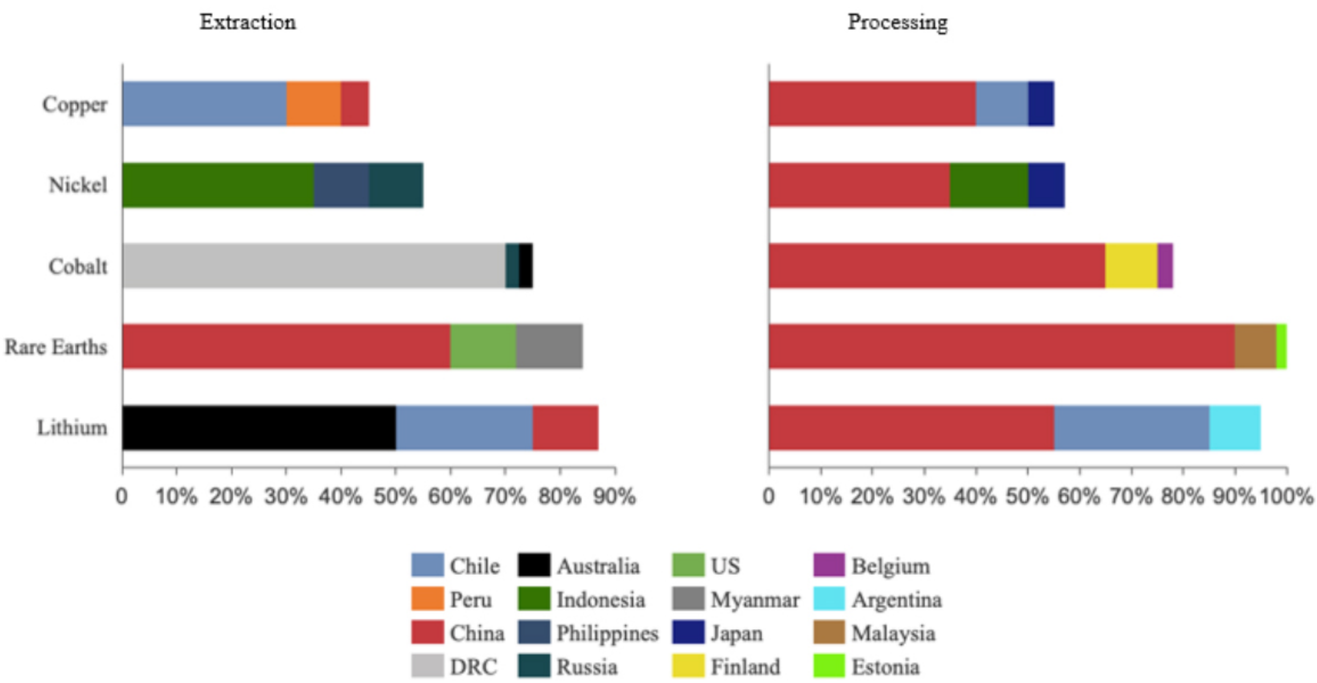
One characteristic of critical raw materials is that their production is very concentrated, geographically speaking. Slightly less, but still at high levels, is the geographical concentration of refining activities. This concentration is particularly pronounced in China, which exerts outsized influence across the entire CRM supply chain.

In the refining and processing of minerals, China is dominant. This high concentration represents a geopolitical risk to supply security. If we look at refining, China's market share is absolutely outstanding, reaching almost 70% for cobalt and more than 90% for rare earths. Although the processing part seems to be the most exposed to China, in reality this country also plays a dominant role in extraction. China has moved ahead of many other countries by controlling mineral assets in Africa, so that many reserves found in countries such as DRC are managed by Chinese-owned companies. In general, the focus on African minerals has increased. As pointed out by Marais (2020), Africa holds about 30% of the world's mineral reserves, some of which are indispensable for producing the technology needed to carry out the energy transition such as batteries for electric cars, solar panels and wind turbines.

China's current dominance in the domain of critical minerals is the result of several interconnected factors, particularly the rapid growth in clean energy technology production and strategic policy support for the mining sector. The rapid increase in the production of electric vehicles (EVs) has made upstream supply chain integration essential. The electric vehicle market in China is expanding exponentially. From 2020 to 2022, annual EV sales in China surged from 1.3 million to 6.8 million, marking 2022 as the eighth consecutive year in which China led the global EV market (Yang, 2023). China's leadership extends beyond EVs to the production of photovoltaic systems and wind energy, both of which require large quantities of critical minerals.

[3] Eynard U., et al. (2020), 'Study on the EU's list of Critical Raw Materials (Final Report)', *European Commission*

Share of CRM extraction and processing by country



Source: Personal Elaboration on IEA data, 2022

On the policy front, the Chinese government has systematically supported the development of the mining sector through various strategic initiatives:

1. **Early Development (1975-1990)**: The Chinese government initially encouraged mining industry growth and exports. The establishment of the National Rare Earth Development and Application Leading Group and export tax refunds in 1975 spurred production. Increased funding in the 1980s improved the quality of refined metals and reduced production costs;
2. **Strategic Protection (1991-1998)**: From the early 1990s, China restricted foreign investments and classified rare earths as "protected and strategic minerals." Foreign extraction could only occur through joint ventures with Chinese companies, ensuring control over supply**;**
3. **Increased Control and Export Restrictions (1999-2009)**: China introduced export quotas, production caps, bans on rare earth concentrate exports, and export taxes on rare earth oxides and metals. These measures boosted global prices and highlighted the strategic vulnerability of industrialized nations to China's policies;
4. **Strengthening Value Chain Dominance (2010-present)**: The last decade has seen China focusing on the downstream stages of the rare earth value chain, producing high value-added components essential for clean technologies.

This historical trajectory of policy and industrial alignment demonstrates how China has methodically established itself as a dominant force in the CRM sector. The EU's heavy reliance on external suppliers, especially China, underscores the urgent need for Europe to diversify its supply chains. This issue is pivotal to the long-term success of the EU's green transition, as explored in the following section.

The impact of a possible disruption of China's supply of rare earths to Europe on the wind energy and electric vehicle sectors

As we have seen above, critical minerals are essential elements in the development of clean energy technologies. With demand for critical minerals growing strongly, the EU is unable to meet its needs internally and is therefore highly dependent on supplies from outside the union. According to analyses by the European Commission, 44% of the critical minerals imported into Europe come from China.

In the context of the EU's high dependency on the supply of critical minerals from China, rare earths present the highest supply risk. Given this consideration, the analysis has a dual objective:

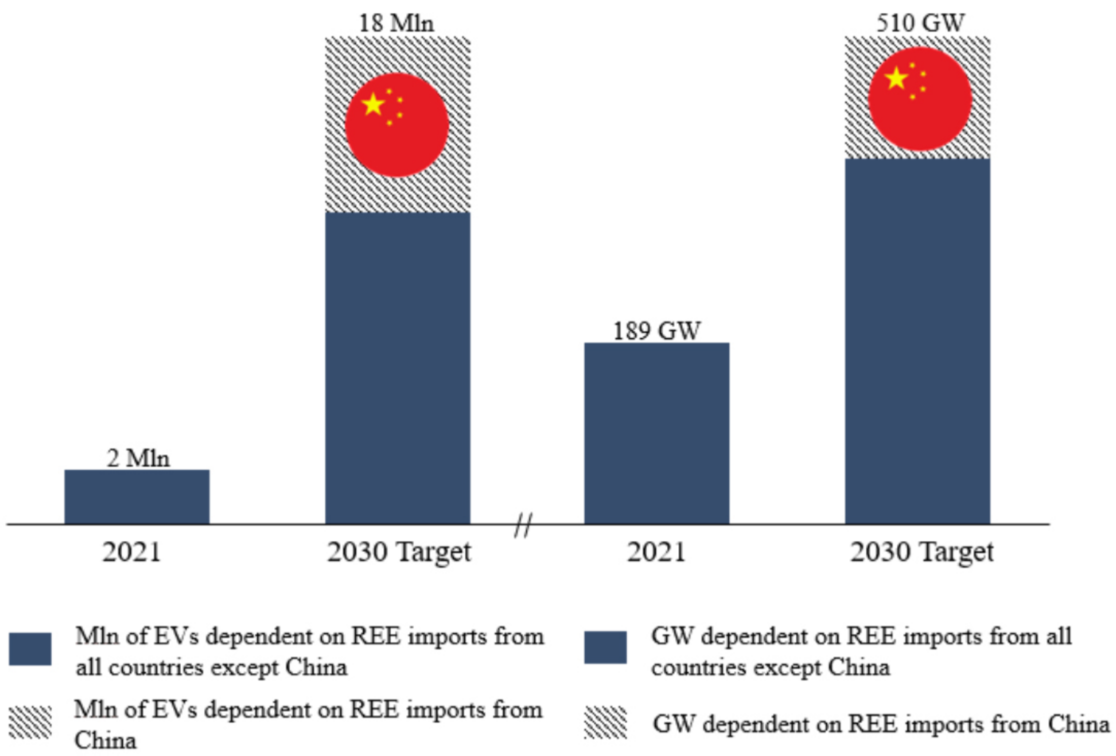
1. To quantify the impacts of a potential disruption in the supply of rare earths from China;
2. To understand if the EU can go green, in the examined industrial sectors, without importing rare earths from China.

The study, which is based on a secondary data analysis, is characterized by four phases:

1. Analysis of the main technologies in which rare earths fall, i.e. wind power and electric vehicles;
2. Analysis of the current material intensity (in ton/GW and ton/electric vehicle) (assuming it remains the same between now and 2030) for wind and electric vehicle technologies;
3. Quantification of the rare earth requirements needed to reach the European Commission's 2030 targets for wind power (510 GW) and electric vehicles (18 million electric vehicles);
4. Quantification of rare earths from China, assuming that Europe's current dependence on China (40% based on Eurostat Data) remains constant between now and 2030.

The analysis shows how the disruption of the supply of rare earths to Europe would have a significant impact on reaching the energy targets in 2030. For instance, in the case of wind technology, it is estimated that 510 GW will be needed to reach the European targets in 2030 (compared to 189 GW in 2021). Of these, about 128 GW are dependent on China and would be unfeasible in the event of a supply disruption. The situation is similar for electric vehicles, whose European production is expected to be 18 million by 2030 compared to 2 million produced in 2021. Of these, more than 6 million vehicles would be unfeasible in the event of a rare earth supply disruption from China.

Supply risk in EU associated with China's interruption of the supply of REE in the EV and wind power sector



Source: Personal elaboration on JRC and IEA data, 2022

Although an interruption of rare earth supplies from China to Europe may seem an unlikely event, we have seen in the previous section how China's trade policy on CRMs has often been characterized by protectionist measures. Therefore, given the great importance of critical minerals for the development of clean technologies in a variety of sectors, China could interrupt exports to secure a competitive advantage for its industry.

At the beginning of this section, we also set ourselves the goal of trying to answer the following question: Can Europe go green in wind energy and electric vehicles without sourcing rare earths from China?

This is a complex question that needs to take several aspects into consideration. However, the short answer is no. We have seen how in both the wind and electric vehicle sectors, rare earths imported from China have a significant impact. In fact, without their supply, the EU would not be able to meet both the target of 510 GW of installed wind power capacity by 2030 and the 18 million electric vehicles produced “made in Europe”.

Policy recommendations

Investment in recycling technologies and circular economy

The analysis underscores the critical need for rare earths for both wind energy and electric vehicles. To mitigate supply risks, the EU should invest heavily in advanced recycling technologies and promote a circular economy approach for rare earths. This involves funding research and development for efficient recovery of rare earth elements from end-of-life (EOL) products such as wind turbines and electric vehicle batteries. The EOL recycling rate of rare earths in pure form, and of the permanent magnets for which they are used, is still very limited. However, large wind turbine magnets have good recycling potential, while the process seems more difficult for electric vehicle magnets. Nevertheless, establishing a network of specialized recycling facilities across Europe will ensure that rare earths can be reused, thereby reducing the need for new imports. Also, it is important to fund research and development for alternative less critical minerals and to reduce the percentage of CRMs through innovative manufacturing. Such initiatives, together with investments in alternative materials and innovative manufacturing techniques, will not only decrease dependency on external suppliers but also support sustainable resource management.

Enhancing the Critical Raw Materials Act (CRMA)

The CRMA is a legislative framework designed to ensure a secure and sustainable supply of critical raw materials essential for the EU's economy and green transition. In light of the risks discussed above, the EU, to address the issue of its reliance on rare earth supplies from China, should enhance the CRMA to prioritize strategic investments in domestic rare earths mining and processing, supported by substantial R&D funding. The EU should also streamline regulatory processes to accelerate project approvals, making it easier and faster to develop new mining and processing facilities. Additionally, the Act should facilitate international partnerships and long-term agreements with non-EU countries rich in rare earths, ensuring a diversified and resilient supply chain. Strengthening the Critical Raw Materials Act in these ways will significantly enhance the EU's resilience and ensure the availability of critical minerals necessary for green technology projects, thereby supporting the EU's broader energy and sustainability goals.

Development of domestic rare earth supply chains

Given the significant impact of potential supply disruptions on the EU's ability to meet its energy goals, it is imperative to develop domestic supply chains for rare earths. This includes streamlining regulatory processes as per previous policy recommendations. Additionally, support should be extended to research initiatives aimed at enhancing the efficiency and environmental sustainability of rare earth extraction and processing within Europe.

In this context, the latest discovery announced on 6 June 2024 by the Norwegian mining group Rare Earths Norway (REN) is particularly noteworthy. REN has identified the largest rare earth deposit in Europe, located in the Fen Complex near Oslo. Although the actual volumes that can be mined and processed are still to be confirmed, REN plans to commence the first development phase by 2030, with an emphasis on establishing a comprehensive production chain, including the manufacture of permanent magnets, while minimizing environmental impact. Further drilling and economic evaluations are Such developments, if supported by policy, can further reduce reliance on external sources.

The European Raw Materials Alliance has identified potential investments of €1.7 billion for the extraction, refining, and recycling of rare earths, as well as for the production of magnets, which would guarantee the supply of 20% of European demand along the value chain by 2030. Strengthening domestic supply capabilities, in conjunction with these strategic investments, will enhance the EU's strategic autonomy and resilience against external shocks. This paper highlights that such measures are crucial for ensuring the EU's ability to navigate future supply disruptions effectively.

Business implications and strategic recommendations for European firms

The growing risk of supply disruptions of critical raw materials (CRMs), particularly from China, has direct operational and financial consequences for European industrial players. Beyond policy interventions, companies—especially in the automotive, energy, and OEM sectors—must adopt proactive mitigation strategies.

1. **Secure alternative supply contracts:** European manufacturers should actively seek long-term offtake agreements with CRM producers in countries such as Australia, Canada, and Norway. Contracting early volumes can lock in pricing and reduce volatility exposure;
2. **Localise key steps of the CRM value chain:** Mid-size companies should explore backward integration—such as acquiring minority stakes in refining facilities or recycling operations within the EU;
3. **Re-engineer product design to reduce CRM dependence:** Automotive Tier-1 suppliers can shift to induction motors for EVs (which do not use rare earths), already adopted by Renault in the Mégane E-Tech. Similarly, in the wind sector, some manufacturers are moving to direct-drive turbines that use less CRM content;
4. **Participate in EU-funded industrial alliances:** Firms should actively engage with initiatives such as the European Raw Materials Alliance (ERMA) and Horizon Europe calls focused on CRM circularity. These platforms offer not only funding, but also visibility and influence in shaping future regulatory frameworks;
5. **Implement supply chain traceability systems:** Companies can deploy traceability tools—such as RFID (Radio-Frequency Identification), blockchain, and AI-powered analytics systems—to map the origin of critical raw materials and monitor compliance with emerging ESG regulations, such as the European Union's Corporate Sustainability Due Diligence Directive (CSDDD).

In sum, securing resilience against CRM risks is not solely a policy matter: it is a competitive imperative. European companies that act early to internalize these vulnerabilities—through sourcing, design, and strategic partnerships—will be better positioned to maintain output continuity, reduce exposure to geopolitical risk, and meet climate targets profitably.

Conclusion

The following paper has set out to summarize, without claiming to be exhaustive, certain aspects of the issues surround linked to critical raw materials, which are often considered one of the bottlenecks in the energy transition process. The topic is of great significance, alive even outside the traditional circuits of scientific literature and capable of fueling a debate rich in economic, geopolitical and social articulations.

Reflecting on the key findings, a central issue is the critical role of minerals such as copper, nickel, lithium, cobalt, and rare earths in enabling clean technologies like wind turbines and electric vehicles. While demand for these resources is expected to surge, the EU faces a significant challenge: it heavily depends on external suppliers, with China dominating not only the extraction but also the processing of these materials. This reliance creates vulnerabilities, as supply disruptions could seriously jeopardize the EU's ability to meet its 2030 climate and energy targets. In response to these risks, the EU has introduced measures, particularly through the Critical Raw Material Act, aimed at reducing dependence on imports. These efforts include diversifying supply sources by forging strategic partnerships, increasing domestic production capacity, and investing in recycling technologies to create a more sustainable and resilient supply chain for these essential minerals. By addressing these challenges, the EU aims to secure its transition to a cleaner energy future while reducing the geopolitical and economic risks tied to mineral supply.

Reference

Carrara, S., et al. (2020), The role of rare earth elements in wind energy and electric mobility, *JRC Science for Policy Report* (European Commission).

Chazel, S., Bernard, S. (2023), Energy transition under mineral constraints and recycling: A low-carbon supply peak, *Resource and Energy Economics*, vol.72.

Eynard, U., et al. (2020), "Study on the EU's list of Critical Raw Materials (Final Report)", European Commission Publishing.

Gregoir, L., et al. (2022), "Metals for Clean Energy: Pathways to solving Europe's raw materials challenge", KU Luven Publishing (Commisioned by Eurometaux).

Hove, A., et al. (2023), "China's rare earths dominance and policy responses", The Oxford Institute for Energy Studies.

IEA. (2024), "Global Minerals Outlook 2024", IEA Publishing.

Legendre, C., et al. (2023), "Raw Materials Critical for the Green Transition: Production, International Trade and Export Restrictions", OCDE Publishing.

Mancheri, N. (2015), "World trade in rare earths, Chinese export restrictions, and implications", Resources Policy.

Marais, D. (2022), "Africa's mineral resources are critical for the green energy transition", South Africa Institute of international Affairs (SAIIA).

Nakano, J. (2021), "The Chinese Dominance of the Global Critical Minerals Supply Chains", Center for Strategic and International Studies (CSIS).

Shen, Y., et al. (2020), "China's public policies towards rare earths, 1975-2018", *Mineral Economics*, vol.33.

Vidal, O., et al. (2013), "Metals for a Low-Carbon Society", Nature Geoscience.

Yang, Z. (2023), How did China come to dominate the world of electric cars, *MIT Technology Review.*