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Rare earths. Seeking west's strategic responses to China's dominance

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Vilnius, 2025

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The global struggle for rare-earth elements (REEs) is becoming one of the most important geopolitical and economic challenges of the 21st century. REEs are crucial for high technology and especially for the transition to green energy, including batteries for electric vehicles, wind turbine engines and advanced electronics. Efforts to keep up with the ever-accelerating pace of technological progress are intrinsically bound to these elements, making the stability and security of their supply chains a strategic priority for many countries. The key "future" technologies such as artificial intelligence, quantum technologies, renewable green energy, electric vehicles, advanced chip manufacturing and modern warfare are all, in one way or another, dependent on the REEs. Their production and supply on the global market are now largely controlled by Beijing, making the issue of their availability a huge challenge for the West. Decades of proactive policy and investment in the rare earth sector have enabled China to establish itself on the global market as the unquestioned leader in both extraction and processing, and most importantly, as a leader in the research and industrial application of related niche technologies. The world's dependence on China, which controls more than 80% of the global rare-earth element market, poses significant geopolitical risks. China's ability not only to secure the supply of these resources, but also to control their global prices, gives Beijing powerful technological, economic and political leverage in the international arena, which the Chinese have been recently increasingly exploiting for pushing their interests. For these reasons, the European Union and other Western countries have recently become particularly active in their efforts to reduce their dependence on China-dominated supply chains and have taken steps in seeking alternative sources of supply, investing in new technologies and strategic stockpiling plans. However, there is no easy solution to the problem, and the steadily growing demand for rare earths leads to a difficult question: How to remain technologically competitive and, at the same time, significantly reduce our dependence on China?

The aim of this analytical paper is to provide a comprehensive overview of what rare-earth elements are and to explain how they have become a strategic and an integral resource for high technology. In addition, a case study of China is presented to help understand how and by what strategies the country has achieved its current dominant position and at what cost. Finally, the study will look at recent progress made by the US, Canada, Japan, Australia and the EU in the area of REEs and assess supply chain security, technological development and diversification strategies to address this vital and deep-rooted issue of how to significantly reduce dependence on China. It concludes with an overall assessment of the situation in the West and future prospects for the REE industry and diversification efforts.

I. Rare-earth elements: (not)rare but vital?

Rare-earth elements. What are they?

The discovery of REEs dates back to 1789, when a Swedish lieutenant, Carl Axel Arrhenius, discovered a “hard black stone” in the Swedish town of Ytterby when exploring a local mine. Some time later, “the stone” was passed on to Professor Johan Gadolin, a professor of chemistry, who was unable to identify the materials and called the discovery “rare earth”. Over time, and with the successful continuation of research and the isolation of new materials, some of which were named in honour of the town (the elements yttrium, erbium, terbium, ytterbium). With its first elements discovered at the end of the 18th century, the entire group was identified and classified in the 20th century.

Rare-earth elements[1] are a group of 17 metallic elements[2] that have been critical and inseparable from technological breakthroughs that have touched everyone’s life, that started from the first TV sets and continued to electric vehicles and other high-tech industrial products. This group of elements comprises fifteen lanthanides, separately presented in the periodic table, which have similar atomic compositions as well as physical and chemical states. In addition, scandium and yttrium, which do not belong to this group, are usually included in the rare-earth elements as they have similar chemical and physical properties. The group of rare-earth elements is normally divided into two main categories: the light rare-earth elements (LREEs) and the heavy rare-earth elements (HREEs). The light elements of the group, such as lanthanum, cerium and neodymium, are more common, while the heavy elements, including dysprosium, terbium and ytterbium, are rarer and more complex to extract. Despite their early discovery, the importance of REEs became apparent only after the World War II, when technologies such as televisions entered people’s homes, and their importance has grown over time to make them a critical raw material for the technology industries.

Uses and challenges

Due to their unique chemical and physical properties, the industrial applications of REEs are wide-ranging and covering a variety of sectors and technology types. Most important, however, is the fact that REEs are vital for the global transition to green energy objectives[3], and they also enable the production of more technologically efficient and sustainable electronic products. REE is undoubtedly at the centre of technological advances. As stated by Duchna and Cieslik, “with advances in all fields of engineering, it is predictable that the rare earth elements will play a crucial role” and that the elements enable “new advances, efficiency, miniaturisation, speed, and durability”. The main applications of REEs include the production of catalysts (74%), ceramics and glass industry (10%), metallurgy and alloys (6%), scrubbing (4%), and others (6%).

1 It is common to come across similar concepts with subtle differences. In contrast to rare elements, rare minerals are natural formations found in rocks containing rare elements. Meanwhile, rare metals are substances such as cobalt, zirconium, gallium and lithium.

2 The group consists of the following elements: lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, scandium, and yttrium.

3 For example, neodymium, dysprosium and praseodymium are used to make powerful and heat-resistant magnets for electric vehicle motors and wind turbine generators. Meanwhile, cerium and lanthanum are used in catalysts that help to reduce vehicle emissions, while europium and terbium are found in energy-saving lighting systems and various displays.

Magnets	Metal alloys	Phosphors	Catalysts and chemical industry	Ceramics and glass	Other
• motors and generators • HD drivers • defence applications • microphones and speakers • magnetic refrigeration	• NimH batteries • superalloys • Al-Mg alloys • steel	• LED • lasers • displays • fluorescent lamps • optical sensors • fibre optics	• petroleum refining • automotive catalysts • diesel additives • water treatment plants	• polishing media • UV-resistant glass • thermal glass • capacitors • fireproof materials • fuel cells • superconductors	• fertilisers • pigments • nuclear energy

The main applications of REEs in different categories and products / industrial sectors.

Source: EURARE

In today's context, it is particularly important to highlight the connection between rare-earth elements and the global "fever" for artificial intelligence (AI). With the ongoing rapid advances and increasing applicability of AI in various fields, including the defence industry, the importance of REEs is evident; there is also a clear overlapping across various fields. For example, one of the most striking aspects of the rapid technological development of AI is related to its high energy consumption. According to calculations by the EPRI Research Center, a single ChatGPT query requires 10 times more electricity than Google. Although in the general context, the energy demand associated with AI is still a relatively small part of the overall picture, considering the rapid deployment of AI-based technological products and its use in public institutions, enterprises and households, electricity consumption will undoubtedly grow. All this needs to be viewed in conjunction with ambitious plans for the transition to green energy. In continuing the technological progress in AI and in an effort to keep pace with climate change mitigation targets, a stable supply of REEs to meet growing demand is critical, so the high importance of the elements undoubtedly highlights important challenges.

In the broader context of critical materials, rare-earth elements account for a relatively small part of the raw materials required by high-tech industries. Other raw materials that have strategic importance and increase competitive frictions between countries include materials such as lithium, cobalt, graphite and magnesium. However, the challenge posed by rare earths is multi-faceted and twofold:

a) The world, and in particular the high-tech West, is almost entirely dependent on imports of the elements from China as more than 80% of the global supply of REEs is currently controlled by the country, raising geopolitical concerns about the reliability and security of supply chains. This dependence exposes Western countries, including the US, the EU and Japan, to risks in their supply chains, which particularly threatens their energy and hi-tech industries.

b) The technological lag of Western countries from China in the extraction and processing of rare earth elements is significant. Even countries with significant REE resources do not have the capacity to extract them on an industrial scale that would be both economically sustainable and ecologically acceptable.

Contrary to what the name implies, the rarity of these elements is not the main problem that has led to the concentration of supply in China. On the contrary, they are quite abundant on Earth. The issues and complexities arise from the fact that it is difficult to extract these elements economically and sustainably as they are found in small concentration; environmental impact cannot be underestimated, especially in traditional mining operations. As argued by Nkuna et al., "conventional mining of low-grade ores has shown to cause more environmental issues than it is worth". These elements are often distributed in small concentrations in other minerals, making their separation technically difficult and economically sustainable extraction requires sophisticated specialised mining and processing methods. These processes are not only technologically complex, but also face serious environmental challenges, as seen in previously exploited deposits in China, where the level of environmental pollution is critically high. It is the environmental factor that often results in their processing being outsourced to countries with lower environmental standards, such as China or countries in South-East Asia, for ecological considerations. China has managed to secure its dominance in the global market not only owing to its large resources of rare earth elements, but also because of its lower (or lack of) environmental standards that has allowed the country to extract and process these elements more cheaply. Countries seeking to reduce their dependence on China need to address not only economic but also environmental challenges such as:

- **Release of toxic waste.** For every ton of rare earth produced, the mining process yields 13 kg of dust, 9,600-12,000 cubic metres of waste gas, 75 cubic metres of waste water, and one ton of radioactive residue.
- **Risks to groundwater.** Leaching ponds, full of toxic chemicals, may leak into groundwater when not properly secured and cleaned up. This is particularly true for the simpler open-pit mines in developing countries.
- **Radioactive contamination.** Extracted elements often contain radioactive thorium and uranium, making extraction more difficult and dangerous if environmental concerns are of low priority.
- **Safety of work and impact on surrounding populated areas.** In traditional mines, such as those in South-east Asia, failure to comply with strict safety standards poses a significant health risk to workers due to toxic and radioactive chemicals. Unsafe mining operations, resulting, for example, in radioactive particles carried by the wind, also have long-term consequences for the surrounding population. There are also significant impacts on the soil, making economic activities in the surrounding area hardly possible.

However, especially in the context of the growing competition between democracies and autocracies, to ensure further development of high technologies and competitiveness, the issue of REEs poses a fundamental challenge to Western economic security. The high dependence on supplies from China, the precedents of the imposition of export quotas and restrictions (often politically motivated) are driven by several reasons. Firstly, China's economic coercion and its use for geopolitical purposes poses a serious threat to the stability of supply chains from China and the ability to meet the growing demand for high technology. As the West's trade wars with China flare up, REEs could become a strong bargaining chip for Beijing in negotiations with the West. Secondly, China's influence on the REE market and its ambition to become a global technology leader may lead to strategic control over access to the elements aimed at maintaining and further consolidating China's advantages and undermining the West's capacity for innovation and, consequently, its technological potential.

II. The rise of China. How did China build a world REE empire?

Flying start

The market for rare earth elements began to emerge at the beginning of the 20th century, but gained particular importance only after World War II. This period saw the start of rapid technological progress, which was underpinned by the production of electronics, radar, televisions and other devices. China, like the US, was a quite early entrant into the rare earth sector, but with a particularly strong focus on it. The country began to engage in the rare earth sector as early as the 1950s, but it is in the 1980s when the sector started to receive special attention. Deng Xiaoping, the initiator of China's reforms and opening-up, prompted economic reforms that promoted industrial and technological development, which highlighted the strategic importance of REEs in both the short and long term. Since then, China has begun to develop step by step its rare earth extraction and processing industrial infrastructure. In 1992, Deng Xiaoping famously stated: "The Middle East has oil; China has rare earths."[4] This quote perfectly captures China's far-reaching strategic thinking on the role of rare earths in future technologies, which has been reflected in the country's policy-making, especially during the 1990s, when China started to invest heavily in modernising this sector. Since the 1990s, Beijing has been investing heavily in its REE resource mining, related infrastructure, and technology, which has led to the modernisation, improved efficiency, and increased volume of large deposits, such as the Bayan Obo mine[5], which has one of the world's largest REE reserves. Another factor of significant influence was that China's sprint in the rear earth sector coincided with the introduction of stricter environmental regulations in the West, which placed new obstacles in the way of extraction and processing of REEs and made it economically unviable in countries such as the US, where the main supplier of elements, the Mountain Pass mine[6], was closed in 2002. All this, combined with China's reforms and opening up to the world and cheap labour, has led directly to Beijing's dominant position in the global rare earths market.

China has consolidated its position as a dominant player in the extraction and processing of rare earths owing to its early entry into the industry, long-term planning by the central government and the provision of the necessary resources for research and development. Also, cheap labour, inefficient and lax environmental standards, along with rampant illegal mining and trade have led to prices that Western countries could not compete with. Today, China is the undisputed leader in the extraction of REEs, accounting for about 80% of global supply. This dominance is even more pronounced in the extraction of heavy earth elements, which are more difficult to extract and process, making alternatives even harder to find. In addition to the extraction of raw materials, China has also almost completely monopolised the processing and refining of REEs. In 2022 alone, China produced about 140,000 tonnes of REEs, significantly surpassing other large producers such as the US and Australia. China's dominance and price control are not limited to resource ownership alone. Over the past two decades, China has actively pursued an export policy of quotas and restrictions. For example, in 2010, China severely restricted its exports of REEs to Japan, which led to a price spike on the international market. Through this policy, China seeks to increas-

4 "中东有石油，中国有稀土。"
5 These vast reserves of REEs in the Inner Mongolia region were discovered in 1935 and brought into production in 1957. It is estimated that the deposit accounts for 80% of China's total REE reserves. As many as 15 rare earths are found there. The extracted elements are transported to Baotou, the capital of China's rare earths, 150 kilometres away.
6 This mine was one of the main sources of REEs in the 1960s and 1970s.

ingly control the global supply and prices of REEs, thus strengthening its geopolitical influence. While there is now active talk about China's economic leverage and the use of economic coercion for geopolitical purposes, as the case of Lithuania has shown, China's geopolitical influence in the field of REEs has become apparent even earlier. During the 2010 territorial conflict with Japan, China reduced its exports of REEs by up to 80%, causing a jump in global prices. According to King and Armstrong, the imposition of China's restrictions resulted in a surge of the price of cerium on the world market from USD 4.7/kg to USD 36/kg that year.

Control by the central government

An undoubtedly important factor in China's consolidation in the field of REEs is control by the central government and the creation of policy guidelines that have led to the development of the sector. As early as the 1990s, the Chinese government designated rare earths as "protected and strategic elements". State "protection" meant that foreign capital companies could not engage in their extraction and processing without permission. Since 2010, China has stepped up the development of the REE sector and improvement of its legal framework. Much attention has been paid to curbing the activities of illegal mines and REE trade in China. In addition, export restrictions, quotas, and tariffs have been imposed on both rocks and finished products. China has also started to build up strategic stocks of REEs to protect itself against market fluctuations, geopolitical unrest and to ensure its control over the global market. This top-down approach has allowed China to maintain a competitive edge and influence the supply and prices of REEs on the global market. In addition, Chinese state-owned enterprises have been particularly encouraged to invest heavily in research and development to improve extraction technologies and increase production efficiency. Government intervention and the steady provision of resources has resulted in a technological advantage over potential competitors. According to Leng et al., between 1950 and 2018, China registered over 25,000 rare earth patents, significantly surpassing the US with its 10,000. Moreover, despite the use of primitive and non-environmentally friendly techniques in the early stage of the sector's growth, China has developed significant modern technological solutions, such as the solvent extraction process[7], which, among other innovative technologies, is on the list of prohibited exports. Progress has also been made in other areas, including green mining practices and waste water treatment plants, which allow China to address the environmental degradation associated with conventional REE mining.

The rapid development and growth of the sector has not avoided structural problems, such as the emergence of excessive and often illegal mining and processing. Until then, the fight against illegal mines had been only partially successful, which resulted in inefficient management of the available resources, prompting a change in Beijing's approach. Since 2010, the sector has been undergoing intensive consolidation: in addition to the strict policy on illegal mines, the number of official mines has been reduced from 123 to less than 10, and the number of processing enterprises from 73 to 10. The Council of State continued further reforms in the sector in 2011 and 2012. In 2016, the Ministry of Industry and Information Technology published the Rare Earth Industry Development Plan (2016–2020), which continues the trend towards even greater consolidation: In China, the "Big Six" group emerged, absorbing all the mining and processing companies in the country. This consolidation not only strengthened Beijing's control over the local market, but also increased its influence in global REE supply chains, giving it even more opportunities to use these resources to strengthen its geopolitical influence. In 2021, as consolidation continued, two mega-conglomerates emerged: the Northern Rare Earth Group and the China Rare Earth Group (the latter resulted from the merger of three of the "Big Six" companies).

Environmental protection can wait…

China achieved its early dominance in the REE sector largely due to ignoring environmental regulations, which coincided with the tightening of environmental standards in the Western world. This became a significant advantage and allowed China to extract the elements quickly and cheaply. The political slogan "clear waters and green mountains are as valuable as mountains of gold and silver", rolled out

7 This is an advanced technique used to separate rare earth elements from other minerals, allowing for improved mining efficiency and, most importantly, lower amounts of waste. The inclusion of this technology on the export ban list is logical, as China is desperately striving to maintain its advantage in the world.

by Xi Jinping and actively promoted by the Chinese Communist Party[8], aptly reflects the change in attitude towards environmental issues that occurred just recently. Today, environmental protection is a major focus, and the rare earths industry is no exception. However, decades of systematic environmental destruction have caused enormous damage to nature. Mining, which was dominant for a long time and was poorly controlled (especially open-pit mining), has had long-lasting consequences. For example, the extraction of REEs in Jiangxi Province has led to massive pollution. As Standaert describes the situation, areas of former mines are now dotted with concrete leaching ponds and plastic-lined waste water ponds, which not only pollute the soil but also poses risks the health of the surrounding population. Only some of the waste water ponds are covered, while others are left open to contact with nature and, often, with physically damaged barriers. Meanwhile, according to a study by the Oxford Institute for Energy Studies, the mining process at the Bayan Obo complex in the Northern China contaminated the environment with water which, in addition to high concentrations of pollutants, also contained 5% of radioactive thorium. Pollutants are released into the environment quite easily due to inadequate protective barriers. Unsurprisingly, these extreme conditions have also had a significant impact on occupational safety, with health problems being particularly acute for those working in the smaller, illegal mines, where physical labour prevailed over technical solutions. According to a study by Dai et al, high concentrations of toxic elements were recorded in the hair of local residents in the nearby city of Baotou. Geographically, higher contamination is recorded in southern China, where the extraction method is different from that used in the north, with elements extracted from clay. The small extraction quantities resulted in a large area covered by mining operations, and the contamination generated by them has easily entered the soil and surrounding rivers. In 2011, an active fight against illegal mines was launched, and in 2016, important provisions were adopted to reduce environmental impacts. While the current focus is on waste water treatment plants and initiatives such as afforestation, long-term environmental challenges still remain. China is facing international and public pressure to reduce the ecological footprint of its REE sector, but in the short term, environmental protection may still be in the background (although it is worth acknowledging that progress on environmental protection has been remarkable), as Beijing seeks to maintain its dominant position in the global market.

8 Original phrase: "綠水青山就是金山银山"

Maintaining dominance through control

In recent years, there have also been significant legal developments in the rare earth sector with implications outside the country. In December 2023, a document entitled "China's List of Export Regulatory and Prohibition Technologies" was approved, which states that:

- Restrictions are imposed on the export of rare earth extraction and refining technologies, except for those specifically marked;
- Strict export controls are applied to the technology of rare earth extraction synthesis and formation processes;
- Exports of rare earths modification and additive technologies are strictly controlled;
- Enterprises engaged in the comprehensive exploitation of rare earth resources are prohibited from using unprocessed rare earth minerals in production.

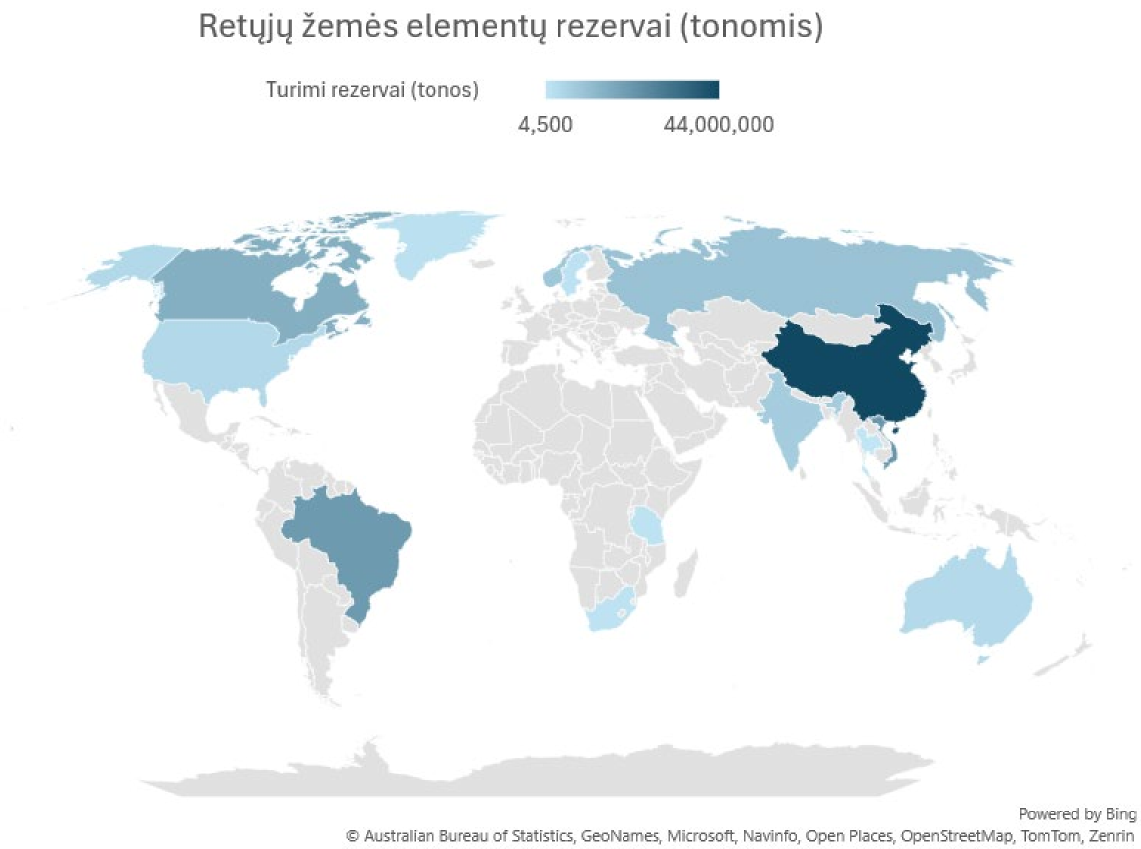
In June 2024, China's State Council approved new guidelines regulating the rare earths industry. The guidelines emphasise, among other things, that:

- Rare earth resources are owned by the state;
- The Ministry of Industry and Information Technology is in charge of the development of the rare earths sector;
- The use of cutting-edge technologies in the rare earths sector is actively promoted;
- Only companies approved by the government can extract and process rare earths;
- Limits are imposed on the amount of extraction and processing;
- Traceability of rare earth products as well as import and export controls are strengthened;

As demand and geopolitical frictions increase, China is actively seeking new REE deposits. In July this year, Chinese geologists announced the discovery of two new minerals in the Bayan Obo deposit, which, according to Li Xianhua of the Chinese Academy of Science, "new minerals contain valuable elements that have significant applications in fields such as new materials, new energy, information technology, aerospace, national defense and military industry, and are of great significance to the country's economic and social development".

III. In search of solutions. Strategies for Western rare earths

The Western world is currently facing one of the greatest supply chain threats related to the strategic elements. Western governments and various international organizations have recognised the strategic importance of REEs, classifying them as critical raw materials, inseparable from economic and national security. The US Department of Energy describes REEs as "essential materials in a broad range of technologies significant to national security, energy systems, medicine, and consumer products". This assessment and, more importantly, the recognition of the problem of heavy dependence on China, has led to increased investment in the search for alternative sources of REEs as well as in mining and processing technologies outside China. According to the Global Critical Minerals Outlook 2024 published by the International *Energy* Agency (IEA), the progress to diversify supply chains is slow; and the production of REE is "among the least geographically diversified of all key energy transition materials". The report emphasises

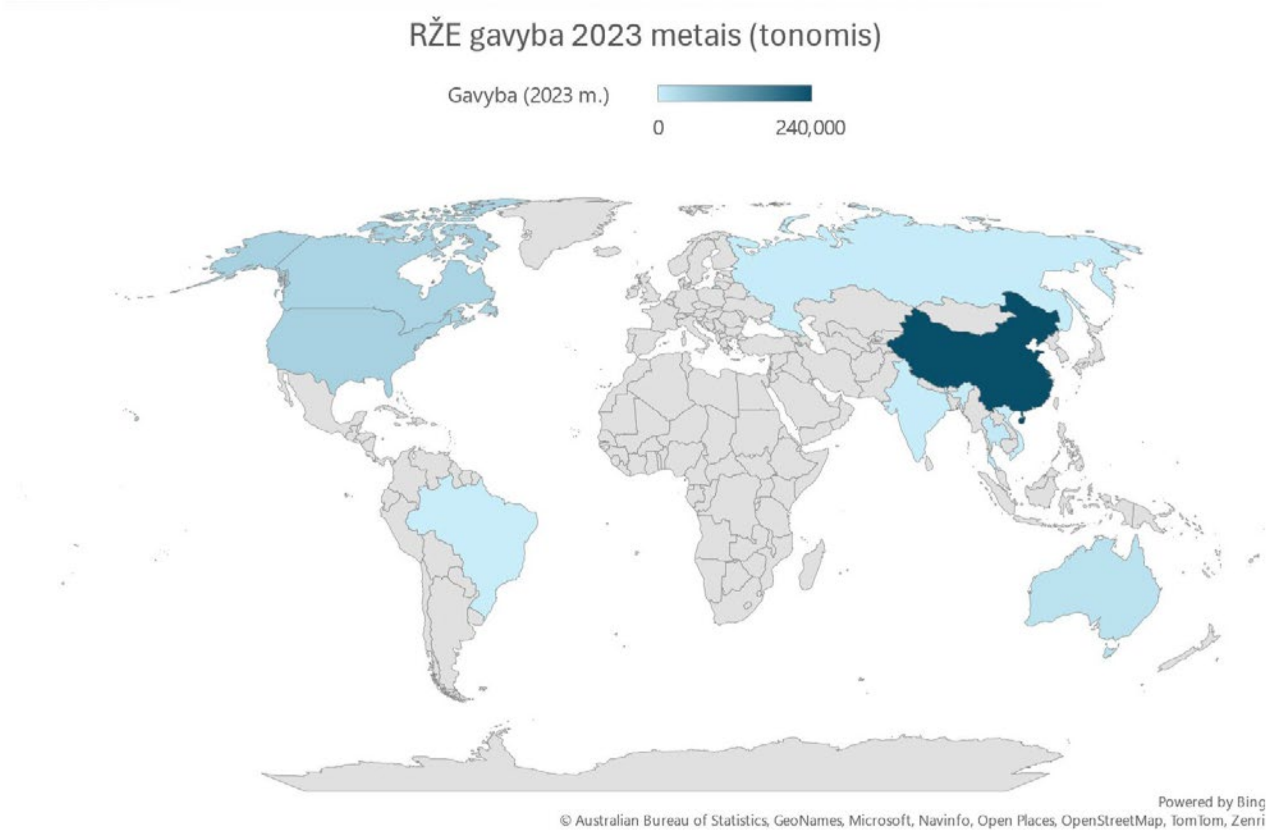


The volume of the US and Canadian reserves include both measured and predicted deposits and are, therefore, preliminary. The discoveries announced in Sweden and Norway in 2023 and 2024 are significant, but exploration is still ongoing, so the industrial potential of these deposits remains incompletely explored.

Source: US Geological Survey, LKAB, Rare Earths Norway, Australian Bureau of Statistics that the main challenges are related to the lack of infrastructure and the need for significant investments required to create new processing capacity, develop technological expertise particularly in North America and Europe.

Developed Western countries that develop high-tech industries share a common risk factor of being dependant on rare earth imports from China. Even those countries with even minimal involvement in REE extraction activities have so far largely sent them to China for processing. This dependence has economic and security implications, especially as demand for REEs grows due to the increasing production of electric vehicles, wind turbines and advanced electronics. The industries are vulnerable to price fluctuations and supply disruptions that can disrupt production and increase costs. This is why many countries have become especially active in diversifying their supply sources, particularly the US, Japan and Australia, where efforts are being made to develop their domestic capacity. In response, governments and international organisations are working to reduce their dependence on Chinese REE supplies by investing in alternative sources and promoting recycling initiatives. Global dependence on Chinese REE supplies poses serious security concerns. Many countries, in particular the US and members of the European Union, see China's dominance as a strategic threat. This is a legitimate fear: with China controlling export quotas and focusing on its domestic supply, the West cannot rest assured about stable supply, especially considering geopolitical challenges. The possibility of supply chain disruptions – whether from trade disputes, environmental regulations or geopolitical tensions – raises fears that China may use its control over REEs as an instrument of economic and political influence.

In the context of China's dominance in REEs, it is possible to identify the West's main recent decisions and initiatives, such as diversification of supply chains, building up of strategic reserves, development of alternative technological solutions, investment in the mining and refining of REEs, cooperation between peer countries in related research initiatives, development of refining technologies, and the search for substitutes. Although Western countries share a common problems of rare earth elements, the impetus and development in this industry and other impetuses towards diversification and industrial recovery/development stand out. Below is an assessment of the selected countries in the context of REEs.



World production of REEs in 2023.

Source: US Geological Survey, Australian Bureau of Statistics

United States of America

In the context of competition with China, the US recognises the need to ensure a stable supply of rare earth elements and other critical minerals for both economic and national security reasons. In this context, the US legal framework is quite strong and allows for an effective response to the challenges that arise. One of the most important pieces of legislation is the Defense Production Act (DPA), which provides the President with a broad set of powers to ensure that domestic industrial resources are available for national defence and domestic security purposes. Passed back in 1950 during the Korean War, this Act is also applied in the modern context, seeking to strengthen US production and processing of REEs. For example, in 2021, the Biden administration announced the use of the DPA in funding projects to strengthen domestic supply chains for critical minerals, including rare earths. In addition to the Defense Production Act, Congress has also enacted other important legal acts such as the Energy Act of 2020, which provides measures to encourage the development of domestic supply chains for critical minerals. The Act encourages the US Department of Energy (DOE) to invest in the research and development of new technologies for the exploration and processing of REEs and actively promotes the recovery of REEs through the recycling of end-of-life products. The 2021 Infrastructure Investment and Jobs Act also provides funding for mining and the processing of materials, including rare earths.

To reduce external dependence on China, the US is placing particular emphasis on alternative sources and technologies. One of the most prominent examples of the revival of the local industry is the revitalisation of the Mountain Pass mine in California, which began in 2017 with the acquisition of this mine by the US company MP Materials. It is the only operating rare earths mine in the US, which was put into operation in 1952 and was once the leading supplier of REEs in the world. The mine was closed in 2002 due to the fierce competition from low-cost extraction and processing in China. Apart from the mine, this time, the great attention of the US government and financial resources have led to the opening of the first REE processing plant in the US, which for the first time will allow a part of the extracted production to be processed in the country without sending it to China.

The US government and the private sector are also investing heavily in R&D in recycling technologies. For example, the Department of Energy-funded Critical Materials Innovation Hub (formerly the Critical Materials Institute, CMI), is leading efforts to develop economically and environmentally sustainable extraction methods for rare earths. This includes recovery of REEs from electronic waste and finding alternative sources that could reduce the need for Chinese imports in certain technological areas. For example, in September 2024, the US Department of Defense announced funding of USD 4.22 million to Rare Earth Salts, a company engaged in the recovery of rare earths such as terbium by recycling fluorescent light bulbs.

In view of geopolitical risks and possible future supply chain disruptions, the US has also focused on increasing its strategic stocks and reserves, including rare earths. The National Defence Stockpile (NDS), managed by the Defense Logistics Agency (DLA), has been stockpiling critical minerals considered important to national security. In recent years, DLA has accelerated stockpiling to ensure a strong buffer of stocks against potential disruptions. According to a report of Congressional Research Service (CRS), as of the beginning of 2023, the NDS contained USD 912.3 million of stockpiled material.

Strong support from the government and the revitalisation of important industrial facilities such as Mountain Pass show that the US is taking significant steps to restore its REE industry and reduce its dependence on China, while emphasising the importance of national security and technological independence.

Canada

While the US is seeking to rebuild its domestic capacity, Canada strives to exploit its large natural resources and emphasises the importance of partnerships with other countries in order to reduce global dependence on China. Canada is a major player in the global supply chain for critical minerals. According to its government, it is estimated that the country possesses more than 15.2 million tonnes of rare earth oxide (it is worth noting that this figure includes both measured and indicated reserves). Responding to the global moods of diversification, Canada is striving to further strengthen its global positions, which is reflected in the Canadian Critical Minerals Strategy. This strategy, presented in 2022, focuses on sustainable mining, ensuring that the extraction of rear earth resources is conducted in accordance with the highest environmental and social standards. In view of the rising demand for green energy technologies, for which rare earths and other critical minerals are vital, this strategy aims not only at meeting domestic needs in both mining and processing, but also at the country's become a reliable supplier as a counterbalance to China's dominance.

To achieve its goals, Canada places particular emphasis on global partnerships, particularly with the US and the EU, while promoting the exploration and development of new critical minerals through joint projects. These initiatives include both direct investments in geological exploration and technological cooperation focused on new mining and processing methods. For example, Canadian companies cooperate with the US Geological Survey (USGS) and the European Union authorities to identify new REE deposits and develop sustainable extraction technologies. The partners' geological surveys also share significant information and accumulated databases "to enable machine learning for critical material potential and other geosciences applications". International cooperation takes place through cross-border agreements such as the Canada-EU Green and Digital Industries Partnership, which aims at strengthening supply chains and promoting the development of new technologies needed for more efficient extraction and processing of minerals. These partnerships aim not only at strengthening regional cooperation, but also at promoting innovation in the sector of critical minerals. However, despite Canada's huge potential and recent progress, the country is still not a major player on an industrial scale: according to the Saskatchewan Research Council Rare Earth Processing of Saskatchewan Research Council (SRC), which aims to become a major supplier of rare earth minerals, it is expected to hit a production target of 40 tonnes of rare earth metals per month by the end of this year.

Although Canada's REE industry is still in its development state, the country's vast reserves and commitment to sustainability position it as an important partner in the West for diversifying critical minerals supply chains.

Japan

In contrast to resource-rich countries such as the US and Canada, Japan does not have significant REE reserves. Instead, to protect its industries, the country relies on innovation, alternative materials and strategic international partnerships. From the perspective of increasing economic security and resilience against economic coercion, the case of Japan is noteworthy and highlights the importance of ensuring the resilience of supply chains against external risks. Renowned as a country of innovation and technological progress, Japan, however, cannot boast of its own reserves of rare earth elements and is completely dependent on imports. Moreover, Tokyo was one of the first to experience economic pressure from Beijing and was forced to look for ways to reduce its almost total dependence on China. The year 2010 was a turning point in Japan's approach to economic security. Following a collision between Chinese and Japanese ships in the East China Sea, Beijing responded by almost completely cutting off rare earth exports to Japan, which sent shockwaves through the global market. This Chinese shock to Japan's automotive and other high-tech industries was significant: Japan imported as much as 90% of all the rare earths it needed from China. This crisis also affected the global market: after Beijing imposed the restrictions, prices for some elements jumped by as much as 10 times.

In response, the Japanese government put together a JPY 100 billion package of financial and other measures aimed:

- To develop technologies and to support investment in equipment to reduce the use of rare earths.
- To develop technologies to use alternative materials.
- To promote recycling of rare earths through supporting investment in recycling facilities as well as through development of more efficient recycling technologies.
- To develop mines and acquire interests in rare earth mines in Australia and elsewhere. The capacity of providing loan guarantees and equity investments by government-affiliated organizations for such activities was significantly strengthened.
- To start stockpiling rare earths in addition to the policy framework to ensure reserves of critical minerals.

The proactive efforts and strategic planning initiated by the Japanese government, although not leading to complete independence from China, have demonstrated significant progress and tangible results: over a decade, dependence on supplies from China has dropped from 90% to 58%.

Tokyo continues to actively pursue its strategy to diversify supply chains. A key element of this strategy is investment in Southeast Asian countries such as Vietnam, where Japan is working with local governments and companies seeking to develop the rare earths industry. In addition, Japan is supporting infrastructure projects in countries in the South-East

Asia to optimise mineral extraction and processing technologies. Japan has also entered into long-term contracts with other countries, such as Australia, for the supply of the elements in order to maximise the security, resilience and reliability of supply chains.

Another integral part of the efforts to promote Japan's economic security is investment in research into alternative materials and recycling technologies. Its main objective is to reduce the demand for rare earths through the use of alternative materials and the development of advanced recycling technologies. Japanese industrial giants Toyota and Hitachi are actively working on cutting-edge technological solutions to recycle rare earths from products such as electric vehicles and electronic devices. Companies such as Toyota and Hitachi have not only contributed to reducing dependence on traditional suppliers, but are also contributing to the development of other areas such as environmental protection, waste reduction and the promotion of circular economy principles. Japan is so active in searching for new domestic sources: fish fossils with high concentrations of yttrium, europium, terbium and dysprosium have been found the ocean bed at the foot of the island of Minami-tori-shima, almost 2,000 km from Tokyo. However, their industrial extraction from the ocean bed at great depths remains rather theoretical; the impact of commercial extraction on ocean ecosystems also remains unanswered.

Japan's response to the 2010 REE crisis demonstrated the importance of innovation and international partnerships in securing critical supply chains, which allowed it to reduce dependence on China by almost half over a decade.

Australia

While Japan's approach focuses on technological innovation and supply chain resilience, Australia, as one of the world leaders in rare earth resources, has focused on the development of mining and processing capacity to become a key player in the global REE market. Australia is one of the world leaders in critical minerals, including rare earths. This position should not come as a surprise: the country has significant resources and a fairly developed mining industry. Australia's rare earth oxide reserves are estimated to be around 3.2 million tonnes. The country's more remarkable distinction in the global context is that it is one of the few countries capable of both extracting and processing raw materials (although this industry is still not significantly developed). As a result, the country is playing an increasingly important role in the global market as one of the leading exporters, but still nowhere near the scale of China's industry.

Australia has several companies with global operations that are leading the overall development of the country's minerals industry. One of them is Lynas Rare Earths Ltd., which is the largest producer of rare earth elements outside of China and has mines and processing facilities overseas. Another growing player is Iluka Resources, which is actively developing processing projects to strengthen its position in the rare earths industry. Australian Strategic Materials is also rapidly expanding its operations, paying particular attention to the improvement of related technologies.

Recognising the importance of critical materials to the country's economic and national security, the Australian government has initiated a range of policy measures to promote the development of this industry. In 2023, Australia updated its Critical Minerals Strategy 2023–2030, which outlines priority areas that will help to improve the country's competitiveness in the global market. This strategy emphasises the promotion of technological innovation to increase the efficiency of minerals extraction and processing as well as to reduce environmental impacts. This strategy also envisages the development of infrastructure and strengthening public-private cooperation aimed at increasing the country's capacity in the critical minerals sector. Lynas Rare Earths Ltd, an Australian company, operates the Mt. Weld mine, which extracted 19,000 tonnes of rare earth oxides in 2023. Responding to the growing demand, the Australian government allocated additional AUD2 billion to the strategy, bringing the total to AUD6 billion. Over the past few years, the implementation of various financial incentives has been started in the exploration and extraction of critical minerals. For example, through the Critical Minerals Development Program (CMDP), the government is providing up to AUS 50 million to related projects over three years.

Responding to the concerns of many countries about the continuity of green technological progress and ensuring a stable supply of raw materials, Australia is strengthening its position in global supply chains and actively forging international partnerships. The country has forged strong ties with the US, Japan, Canada and the European Union to ensure that the supply of critical minerals is stable and as resilient as possible to tools of economic pressure. This cooperation includes joint R&D projects to strengthen supply chains for critical minerals as well as cooperation on new technologies. Australia is seen as a reliable partner in these global supply chains, and the country continues to strengthen its role in the global market for critical minerals as an alternative to China's dominance.

European Union

Despite technological progress and significant initial efforts in the field of green technologies, unlike the countries discussed above, the European Union (EU) cannot boast of rare earth reserves or a strong industrial base. It is actively developing strategies to reduce its dependence on China, which is particularly pronounced. According to the Council of Europe, China provides 100% of the EU's supply of heavy rare earth elements. The risks associated with the supply of EU with various critical raw materials vary quite drastically. The European Commission's (EC) most recent 2023 Study on the Critical Raw Materials for the EU 2023 identified a total of 51 materials to be considered as critical, including rare earths. Overall, China is identified as the main supplier in as many as 33 raw material categories (7th at the extraction stage and 26th in processing). Furthermore, the situation with rare earths is even more critical: the dependence of Chinese supply of heavy rare earth elements (at the processing stage) is as high as 100%, while that of light rare earth elements (at the processing stage) is 85%.

The European Union recognised the importance and future significance of rare earths at quite an early stage: In 2008, the European Union launched the Raw Materials Initiative (RMI) to ensure a sustainable supply of raw materials to the EU economy. This initiative came as a response to growing concerns about the heavy dependence of European industry on imports of raw materials from third countries such as China. The RMI provides for comprehensive measures to enhance the security of supply chains for raw materials, strengthen the EU's internal sources of supply and expand international cooperation. The document places a strong emphasis on rare earths, arguing that, despite the small quantities required in production, these raw materials are critical for technologically advanced products, which are being upgraded at an ever increasing pace. The initiative also highlights the importance of sustainable extraction of raw materials to reduce environmental impact and promote the circular economy.

Together with the Raw Materials Initiative, the European Commission initiated the establishment of lists of critical raw material. Already in the first Critical Raw Materials List, which was published in 2011 and contained 14 items, also included a group of rare earth elements, particularly emphasising the risks arising from high levels of supply dependency when the majority of global production comes from China. In 2020, the European Commission presented the Action Plan on Critical Raw Materials, which aims to reduce the EU's dependence on third countries, diversify supply from both primary and secondary sources and improve resource efficiency and circularity. This Action Plan provides for a range of measures, including investment in the extraction of raw materials within the EU, the development of technologies for recycling and waste management, and the strengthening of strategic partnerships with other countries. The Action Plan is also aimed at stimulating innovation to replace or reduce the use of critical raw materials in production as well as to build sustainable and resilient supply chains.

Since 2011, the European Commission has been periodically updating the Critical Raw Materials Lists, which identify the raw materials essential for European industry and assess the risks associated with supply disruptions and geopolitical challenges. The latest, fifth list was published in 2023 and includes raw materials such as rare earths, cobalt, lithium and graphite, which are essential for the production of batteries for electric vehicles and other advanced technologies.

Although the EU cannot boast of an abundance of rare earth resources, a few countries, such as Sweden, Denmark, Finland and Greece, can offer hope. Greenland is also considered to have particularly large deposits of critical raw materials, including uranium and thorium, but the local government has imposed strict restrictions on both extraction and further geological exploration. Sweden is another place that potentially may help the EU to reduce external dependencies. The Norra Kärr deposit has a high concentration of rare earths and, according to a statement from Leading Edge Materials Corp, marking the company's application to the EC for the Norra Kärr project to be designated as a "strategic project", the site "could potentially contribute to Europe's security of supply of REE for decades to come". New geological discoveries have also been made in Sweden's Kiruna region. Norway, meanwhile, also announced in June this year the discovery of Europe's largest deposit of rare earth metals. However, without adequate investment and a more efficient and faster-acting bureaucracy, the extraction of these resources may not begin soon.

When it comes to the manufacturing sector, the situation in Europe is little different from that in the US:

previously, there were achievements and lead in this area. For example, more than three decades ago, the manufacturing plant in La Rochelle, France, was one of the largest suppliers of components for colour televisions and cameras but also failed to compete effectively with China. However, Solvay announces ambitious plans to revive the factory, but it has a long way to go: last year's supplies amounted to 4,000 tonnes (compared to China's volumes of 298,000 tonnes). Estonia is another country with great potential for REE processing. Estonia-based NPM SILMET OÜ is a previously little-known company that has recently attracted attention due to its expansion plans. Established during the years of Soviet occupation, this rare earth processing complex is now managed by Canadian-capital company Neo Performance Materials. One of Europe's leading complexes, it consists of rare metals, rare earth and metallurgical facilities. The magnet facility, currently under construction, is scheduled to start production next year. In 2024, the Australian company Hastings Technology Metals signed a memorandum of understanding with the Estonian Investment Agency, according to which the company will explore the possibilities of establishing a rare earths hydrometallurgical plant. Estonia's potential is truly great. According to Jiyeong Go, there are only two commercial-scale rare-earth processing facilities outside China: one is in Estonia; the other is in Malaysia. However, according Frank Jüris, Neo Performance Materials has a significant footprint in China and a not fully explored relationship with Beijing, which could potentially pose additional security challenges in the future.

Although the EU is heavily dependent on imports, it is actively supporting and developing ambitious projects that could strengthen the resilience of the supply chain. However, it will take a long time before the newly discovered reserves and processing facilities start to significantly contribute to the EU's economic security and continued technological progress.

Conclusions. Dethroning of China in the rare earths – mission impossible (at least for now)?

Rare earths are an integral part of today's technology ecosystem, encompassing everything from smartphones to electric vehicles, from the green energy sector to the defence industry. Their strategic importance is growing, along with the associated geopolitical challenges, which are becoming key issues in global supply chain policy. The challenges related to their extraction and supply highlight the need for a sustainable and diversified supply to meet future demand while minimising environmental impacts. However, although these elements are not particularly rare, the specifics of their extraction and processing require significant and targeted investments in niche technologies and designation as the highest priority by the central government. In developed Western countries with high environmental standards, this is even more difficult to achieve. China's dominance in the RE market should not come as a surprise. Early recognition of the strategic importance of these elements, decades of focused development of this industrial sector, continued investment in R&D of niche technologies as well as tight control and consolidation led by the central government have helped Beijing to establish monopoly in this sphere. China has not only invested in extraction processes, but has also developed cutting-edge extraction and processing technologies that have given it a huge advantage over the West. Meanwhile, Western countries, which had a good starting position, have followed a different path: the last decades have been dominated by short-sightedness, based on the principles of "the cheaper, the better" and "let's leave technological progress to the initiatives of private companies".

In the short term, the heavy focus on rare-earths sector by the Chinese central government will remain: completing consolidation processes, improving the efficiency of these state-owned enterprises and, most importantly, ensuring a stable supply of rare earth elements for its critical material-hungry hi-tech sector. There is no doubt that, despite the efforts of foreign countries to increase production, the majority of raw REE will still go to China for processing, and the extent is likely to grow as this is the only way to meet the ever-increasing demand in the high-tech sector. Meanwhile, it would be difficult to expect more significant exports from China due to its growing domestic demand. Moreover, in the context of bans and other restrictions imposed in the West, Beijing may further tighten its policy on rare earth elements as one of the retaliatory measures. Meanwhile, the West must realise that to dethrone China in the rare earths sector, it needs not only financial and technological support, but also a coordinated, long-term and strategic vision that encompasses the entire supply chain, from extraction and processing to innovation. This vision must also be underpinned by close international cooperation that brings together like-minded countries. Partnerships and joint investments in research, technology and infrastructure will become key to reducing dependence on China and ensuring the resilience of supply chains. Recently, more optimistic developments can be seen: the West is taking a much more strategic approach to the REE sector, developing long-term strategies backed by increasing financial resources, conducting active geological explorations, and investing in technologies, especially those related to processing. The REE industry of Western countries, which has been strangled by Chinese competition, is slowly being revived. If the West abandons fragmentation and reactivity, if it consistently pursues long-term strategies based on stable financial resources and strong international cooperation, diversification away from China will become a tangible possibility. Although a significant de-coupling from China seems like a rather distant dream at the moment, recent positive developments suggest that the global structure of the REE market may change in the future. Combined with innovation and technological advancements, this transformation could be achieved in the coming decades.

In the de-risking debate in the West, the role of REE is undoubtedly significant. With China's continued dominance in both extraction and processing, sudden de-coupling is unlikely due to the lack of alternatives. At the same time, however, this does not mean that China can destroy Western industry at any moment. Beijing is also constrained in its own way: despite instances of China's use of economic coercion, extreme undertakings, especially in relation to the supply of REEs for the West, are likely to be avoided. Causing a major shock in REEs would potentially lead to a strong impetus for the West to build up its own industry, which would be disadvantageous for China and cause a crisis in its own domestic industry. Meanwhile, maintaining a dominant position and, when necessary, strategic and small-scale use of REE-linked disruptions as an instrument of pressure would be more preferable to China. So, in this situation, the hands of both the West and China are tied. Considering the active steps taken to revive and/or develop the REE industry, it can be argued that the West is now actively moving towards mitigating the risks related to REEs, but that this process is time-consuming. However, it is worth noting that the West will not necessarily have to follow China's example and spend decades building its own industry. In this case, new technologies may be the key to a faster momentum in closing the gap with China. For example, AI tools for large-scale analysis and modelling can help to significantly save time and efficiently use available resources. As stated in a report published by the US Department of Energy in 2023, AI can efficiently analyse vast geological databases of rare earth elements and provide data-driven insights into location, concentration of the elements or, for example, the cost-effectiveness of extraction. However, in the short term, China's dominance is not going away and REE will remain Beijing's strong trump card against the West.

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