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The geopolitics of rarity: Mapping strategic trade dependencies for rare earths

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Abstract

Despite diversification initiatives worldwide global value creation in the rare earths sector remains heavily concentrated in China and is therefore fraught with geo-economic risks.

Zusammenfassung

Trotz Diversifizierungsinitiativen weltweit ist die globale Wertschöpfung im Bereich der Seltenen Erden weiterhin stark auf China konzentriert und damit mit geoökonomischen Risiken behaftet.

Abstract:

Rare earth elements (REEs) have become indispensable to modern technologies, from electric vehicles and wind turbines to advanced electronics and defense systems. Their strategic relevance is heightened by China's dominant position across the rare-earth supply chain, where extensive refining capacity and state-directed industrial policy have enabled the country to convert resource advantages into systemic leverage, periodically exercised through export restrictions. Despite diversification initiatives in the United States, the European Union, Japan, and Australia, global REE value creation remains highly concentrated. This paper maps production, processing, and strategic import dependencies for REEs and REE-reliant products across major economies. The analysis reveals persistent vulnerabilities in globalized production and highlights the geoeconomic risks embedded in contemporary critical-mineral supply chains.

1. Between Geology and Geopolitics

Few commodities illustrate the intersection of natural resources, industrial transformation, and geopolitical strategy as clearly as rare earth elements. Once of interest primarily to mineralogists, these 17 metals have become critical inputs for technologies that underpin modern economies, including electric vehicles, wind turbines, digital devices, and military systems (Pawar & Ewing, 2022).

Their economic importance explains their strategic significance. Over the past three decades, China has emerged as the central chokepoint in the global rare-earth supply chain by combining mineral resources with extensive refining and processing capacities. This dominance has repeatedly translated into geopolitical leverage. The 2010 Chinese export embargo on Japan following a maritime dispute demonstrated how control over rare-earth supply could be used as an instrument of state power, triggering dramatic price spikes and exposing the vulnerability of industrial economies (Wübbeke, 2015; Mancheri, 2015). More recently, China's 2023–2024 export restrictions on gallium, germanium, and processing technologies have renewed concerns about the weaponization of economic interdependence (Vigna, 2023).

In response, major economies have launched diversification strategies. The United States has supported domestic mining and processing projects. The European Union has adopted the Critical Raw Materials Act. Japan has pursued supply diversification since 2010. Finally, Australia has expanded its role as a non-Chinese producer. Yet despite these initiatives, critical dependencies persist. Understanding why requires moving beyond geology to examine the structure of rare-earth value chains and the political economy that shapes them.

This paper clarifies where, how, and why such dependencies arose and what they imply for economic security. It does so by systematically mapping rare-earth supply chains and trade patterns across multiple stages of production, from raw materials to high-value manufactured components. Building on the framework developed by Gehringer (2023), the analysis identifies cases of strategic import dependence and traces their structural origins. Beyond documenting trade patterns, the paper situates rare earths within a broader political-economy perspective, showing how industrial policy, environmental trade-offs, and geopolitical strategy interact to transform ordinary minerals into instruments of power.

2. Unearthing the meaning of rarity: The origins and main characteristics of rare earths

The term *rare earth elements* refers to a specific group of metallic elements consisting of the 15 lanthanides (atomic numbers 57–71), together with scandium and yttrium. Although chemically distinct, these 17 elements share similar properties and are therefore commonly treated as a coherent group in both scientific and economic analysis.[1]

The historical origins of the term “rare earths” are misleading by modern standards. When these elements were first identified in the late eighteenth and early nineteenth centuries – most notably in minerals discovered near the village of Ytterby in Sweden – they appeared rare because they could be extracted only in very small quantities using the analytical techniques available at the time. The term “earths” reflected the then-prevailing classification of metal oxides, while “rare” denoted their apparent scarcity in known mineral deposits.

Subsequent geological research has fundamentally revised this perception. Most rare earth elements are not scarce in the Earth’s crust. Some, such as cerium, are more abundant than widely used industrial metals like copper. Their perceived rarity instead arises from economic and technical constraints. Rare earths tend to occur in low concentrations, are chemically similar to one another, and are difficult to separate into individual elements. As a result, only a limited number of deposits can be exploited economically, and doing so requires complex and environmentally demanding processing techniques.

REEs form a chemically coherent family, with four techno-economic characteristics that make them distinct compared to other minerals. First, their unique magnetic, catalytic, and optical properties make them *essential inputs* in a wide range of advanced applications, including renewable energy technologies, digital electronics, and defense systems (USGS, 2014). Second, due to their high specificity, they are

[1] The scientific consensus on what constitutes the rare earth group has been stable since the mid-twentieth century. The International Union of Pure and Applied Chemistry (IUPAC), along with geological agencies such as the United States Geological Survey (USGS) and the British Geological Survey (BGS), uniformly includes the lanthanides, scandium, and yttrium in this category.

difficult to substitute for in production (Graedel et al., 2015).[2] Third, the REEs *supply is very inelastic* that stems from a mix of geological, technical, and economic factors.[3] Expanding production typically requires long lead times, substantial capital investment, and the development of specialized processing infrastructure. Fourth, unlike globally traded commodities such as oil or copper, rare earths *lack transparent benchmark pricing* or liquid futures markets. Transactions occur through bilateral contracts and are often mediated by political or strategic considerations (Alfaro et al., 2025).

These features imply that rare earths are best understood not as geologically scarce resources, but as economically constrained ones. Their importance lies less in their physical availability than in the difficulty of organizing extraction, processing, and trade at scale. This distinction is crucial for the analysis that follows. It explains why rare earth supply chains are particularly vulnerable to concentration and why control over key stages of processing can translate into lasting economic and geopolitical power.

3. Tracing the rare-earth supply chain and trade flows

Unlike most other mineral supply chains, which tend to be more linear and geographically concentrated, rare earths require a far more specialized and interdependent sequence of processes, amplifying both technical complexity and supply vulnerability. The rare-earth supply chain – shown in **Figure 1** – spans multiple transformation stages: from exploration and mining, through beneficiation and concentration, refining and chemical separation, metallurgical processing, to advanced manufacturing. Each stage has its distinct entry barriers and economic as well as environmental costs (Jowitt et al., 2018).

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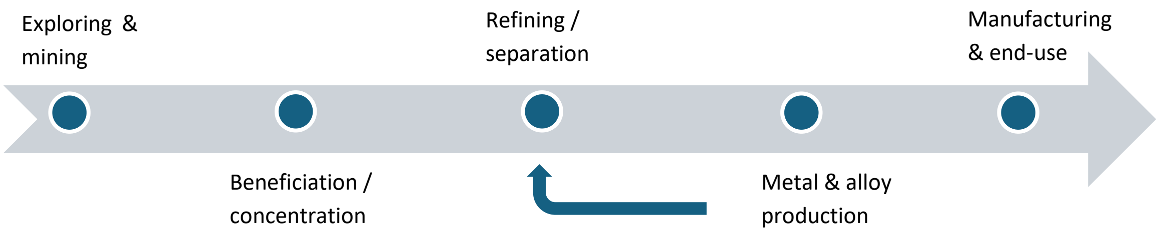
[2] Non-substitutability in production is rarely absolute, because most materials *can* in principle be replaced, albeit at steep cost or performance loss. However, in a few critical technological functions, a specific rare earth provides a quantum-mechanically property that is unique and cannot be replicated by any other element – not even approximately. An example of absolute non-substitutability is europium in red phosphors, essential for screens and LED lighting. No other element replicates this optical property (Alfaro et al., 2025).

[3] Rare earth elements rarely occur in concentrated, economically viable deposits. They are usually comined with other minerals, requiring complex separation processes that differ for each deposit's mineralogy (Balaram, 2019). Additionally, REEs also characterized by high degree of mutual solubility which makes their separation technologically challenging. This technical complexity slows new supply development and increases production costs. Accordingly, REE mining and processing projects take many years (often 10–15) to move from exploration to production. Moreover, rare earth production generates radioactive waste and toxic by-products, especially when associated with thorium and uranium (EPA, 2012). Strict environmental standards in the US, EU, and Japan significantly limit the speed and scale of domestic production expansions. In contrast, China's historically more lenient environmental regulations allowed it to dominate the industry – reinforcing global supply inelasticity. China controls roughly 60% of global mine production and over 85% of refining capacity (USGS, 2024; Mancheri et al., 2019), while a handful of companies mediate access to processed materials for magnet, catalyst, and battery manufacturing.

Figure 1. Rare-earth supply chain



Source: Own elaboration based on Voncken (2016)

This multi-stage structure of the supply chain is broadly reflected in the international trade statistics. The Harmonized System (HS) classification differentiates rare-earth-related goods according to their degree of processing. At the extraction and beneficiation stage, rare-earth–bearing ores and concentrates are distributed across several HS codes at the 6-digit level, mainly 251020 (natural calcium phosphates), 261210 (uranium ores and concentrates), 261220 (thorium ores and concentrates), 261400 (titanium ores and concentrates), and 261510 (zirconium ores and concentrates) – reflecting the diverse mineral hosts from which rare earths are derived.[4] Subsequent stages are captured by more specific HS codes, including 284610 and 284690 for refined oxides and compounds, and 280530 for metallic forms and alloys.[5] At the manufacturing and end-use stage, rare earths enter downstream applications through a range of composite or functional products, such as 850511 (permanent magnets of metal), 854141 (light emitting diodes, LEDs), or 901320 (lasers). These codes embody the transformation of rare earths into technologically sophisticated intermediate and final goods that drive sectors such as renewable energy, electronics, and electric mobility.

The production data of rare earths summarized in **Figure 2** and **Table 1** show that China has become the dominant global producer in absolute terms, accounting for roughly 70 percent of global mine output in 2024. Other countries, including the United States and Australia, contribute significantly smaller shares, while several

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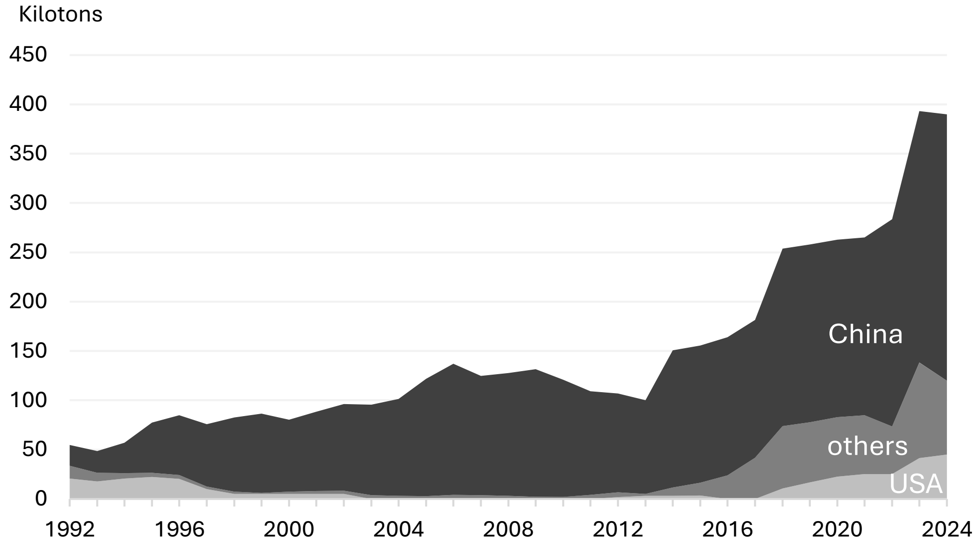
[4] The HS codes 251020, 261210, 261220, 261400 and 261510 refer to mineral categories that are not primarily used for rare-earth extraction, but contain trace amounts of rare earth elements as by-products. Although these codes do not explicitly identify rare-earth minerals, they correspond to HS classifications that indirectly capture the earliest stages of the rare-earth supply chain. Moreover, the first two stages of exploitation and beneficiation are tightly integrated. Consequently, trade statistics do not separate them cleanly: the term "ores and concentrates" in the corresponding HS headings bundles raw extraction and basic beneficiation into one category.

[5] Also HS 253090 captures certain rare-earth–bearing minerals at the extraction stage. However, its link to rare earths remains indirect due to the code's much broader mineral scope than for 284610 or 284690. Analogously, some rare-earth-related trade flows fall under 720299, which involves rare-earth additives. However, the connection is very indirect and mixed.

countries possess substantial reserves that remain largely unexploited. These figures already indicate a high degree of concentration at the extraction stage, but they do not yet capture the more decisive asymmetries that emerge further downstream.

Figure 2. Global production of rare earth elements



Source: For 2023 and 2024 – US Geological Survey, Mineral Commodity Summaries, January 2025, for 1992-2022 – British Geological Survey

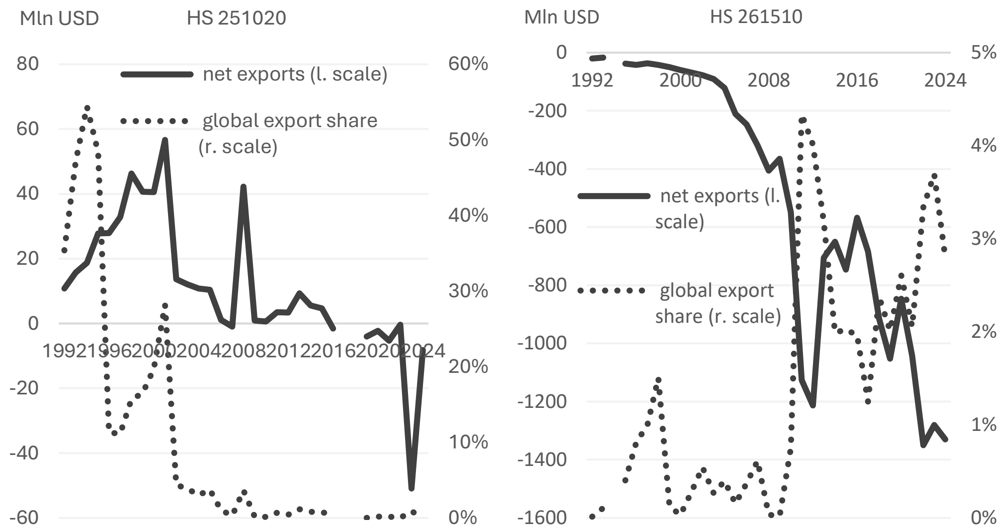
Table 1. Main global producers of rare earths (2023 and 2024) and estimated reserves

Country	Mine production, in kilotons		Reserves, in kilotons
	2023	2024	
China	255.0	270.0	44,000.0
United States	41.6	45.0	1,900.0
Myanmar	43.0	31.0	n.a.
Australia	16.0	13.0	5,700.0
Nigeria	7.2	13.0	n.a.
Thailand	3.6	13.0	4.5
Russia	2.5	2.5	3,800.0
Madagascar	2.1	2.0	n.a.
Vietnam	0.3	0.3	3,500.0
Malaysia	0.3	0.1	n.a.
World total	376.0	390.0	>90,000.0

Source: US Geological Survey, Mineral Commodity Summaries, January 2025

China's dominance over the global rare-earth supply chain is most pronounced at the advanced stages of metal and alloy production, as well as manufactured components rather than in trade of raw ores or compounds. **Figure 3** shows that China's global market share in rare-earth associated ores – corresponding to the first stages of the REE supply chain – are negligibly low and net exports declined over the last three decades. Also China's global position at the refinement stage weakened in more recent years, although its export shares are still sizeable (**Fig. 4**). Instead, China's global dominance at the downstream stage of metal and alloy production remains strong, with the global share of exports at around 60% (**Fig. 5**).

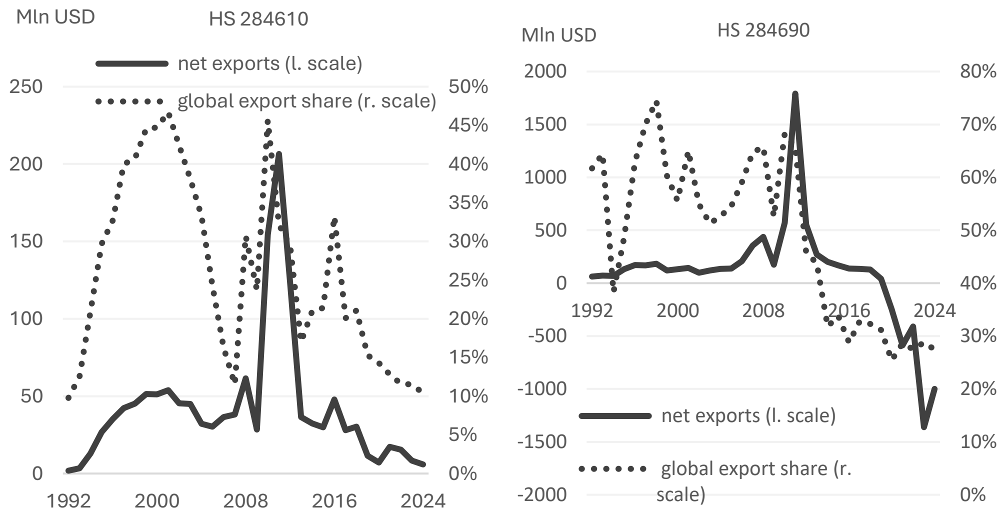
Figure 3. China's net exports and global export share in rare-earth associated ores



Note: HS 251020 – Natural calcium phosphates, natural aluminium calcium phosphates and phosphatic chalk; ground; HS 261510 – Zirconium ores and concentrates

Source: Own elaboration based on UN Comtrade database

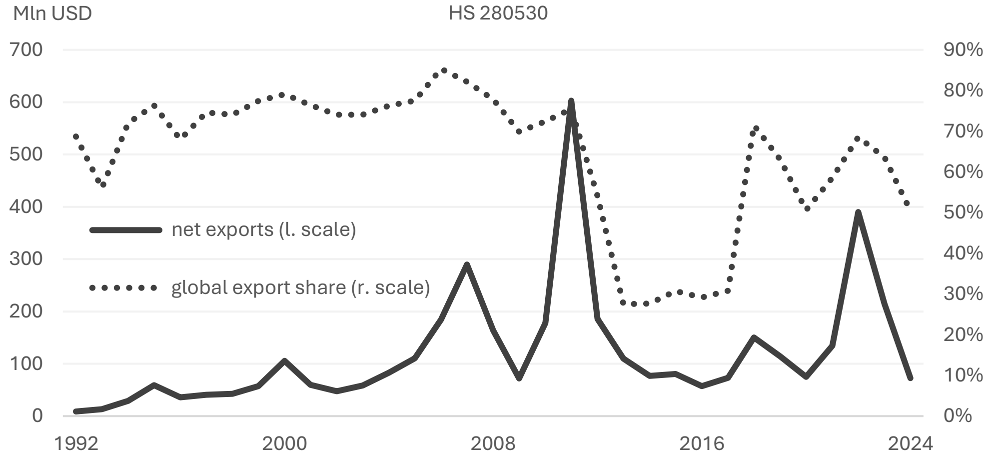
Figure 4. China's net exports and global export share in rare-earth compounds



Note: HS 284610 – Cerium compounds; HS 284690 – Compounds, inorganic or organic (excluding cerium), of rare-earth metals, of yttrium, scandium or of mixtures of these metals

Source: Own elaboration based on UN Comtrade database

Figure 5. China's net exports and global export share in rare-earth metals and alloys



Note: HS 280530 – Earth-metals, rare; scandium and yttrium, whether or not intermixed or interalloyed

Source: Own elaboration based on UN Comtrade database

At the final stage of the supply chain, rare earths enter global trade embedded in a wide range of intermediate and final goods. Because rare earth content is not explicitly identified in standard trade classifications, identifying REE-dependent products requires combining trade data with technical and scientific knowledge. Building on existing work that links rare earth use to industrial sectors (Alfaro et al., 2025), the analysis distinguishes between products that directly incorporate rare earths as functional materials – such as permanent magnets, catalysts, and batteries – and products whose performance depends on REE-containing components. Appendix A describes the underlying methodology in more detail.

The resulting evidence, summarized in **Table 2**, reveals a consistent pattern: China has steadily expanded its global export shares across most REE-intensive product categories over the past two decades. However, there is important variation across HS codes and over time.

In a number of REE-intensive applications, China has emerged as the dominant global supplier. This is particularly evident in air-conditioning, refrigerating & freezing equipment (HS 841510 – 841581, 841590 – 841869, 841869). In most of these categories, China's export shares increased rapidly from low levels at the beginning of 2000s. For example, export shares in window and wall air conditioners (841510) rose from 11% in 2000 to 64% in 2024, while those in refrigerating and freezing equipment parts (841899) increased from 2% to 24% over the same period. Similar trends can be observed for electric motors and generators typically associated with permanent-magnet technologies (HS heading 8501xx), where Chinese export shares often climbed from low single-digit values in 2000 to 20–50% by 2024. However, the most extreme consolidation of global market power is found in rare-earth permanent magnets themselves (850511 and 850519) and nickel–metal hydride batteries (850740), where Chinese export shares reach 67%, 39%, and 76% respectively in 2024.

Table 2. China's export shares for rare-earth-related HS codes

HS	2000	2005	2010	2015	2020	2024	Global market leader in 2024 other than China
320650	1%	7%	11%	14%	9%	6%	Japan, Germany, USA
381519	0%	2%	3%	5%	8%	12%	USA, Germany
690912	0%	1%	16%	20%	22%	19%	Japan
840140	0%	0%	1%	23%	7%	6%	Germany, France
840991	1%	2%	5%	9%	12%	17%	
840999	1%	2%	5%	7%	7%	10%	Germany
841330	0%	1%	5%	7%	8%	11%	Germany
841430	1%	7%	15%	23%	30%	**35%**	
841510	11%	43%	56%	56%	56%	**64%**	
841520	1%	1%	7%	10%	10%	15%	
841581	21%	23%	26%	29%	23%	19%	
841582	7%	11%	14%	19%	20%	17%	Mexico
841583	1%	19%	19%	3%	5%	8%	Italy, Germany, Canada
841590	3%	9%	18%	21%	27%	**35%**	
841850	2%	5%	8%	15%	21%	26%	
841861	1%	16%	8%	9%	14%	19%	
841869	1%	2%	17%	16%	16%	25%	
841891	2%	2%	1%	0%	0%	8%	USA, Germany, Portugal, Italy
841899	2%	8%	16%	18%	20%	24%	
842123	0%	3%	9%	12%	11%	15%	Germany
842131	0%	1%	4%	11%	13%	15%	
847170	5%	16%	20%	22%	27%	27%	
850110	21%	19%	21%	25%	23%	25%	
850120	6%	11%	16%	16%	16%	18%	
850131	1%	9%	20%	27%	25%	**29%**	
850132	3%	8%	16%	25%	17%	23%	
850133	1%	1%	1%	6%	7%	7%	Germany
850134	0%	1%	6%	7%	13%	14%	Canada, USA
850140	7%	16%	40%	46%	42%	**50%**	
850151	5%	8%	11%	14%	13%	12%	Germany, Japan
850152	6%	10%	13%	16%	15%	18%	Germany
850153	1%	2%	8%	10%	10%	13%	Germany
850161	7%	13%	16%	17%	18%	14%	France
850162	1%	5%	12%	12%	8%	8%	USA, Singapore, UK, France
850163	1%	4%	10%	12%	13%	23%	
850164	0%	1%	6%	11%	21%	18%	
850180	n.a	n.a	n.a	n.a	n.a	**36%**	

Table 2. China's export shares for rare-earth-related HS codes, cont.

HS	2000	2005	2010	2015	2020	2024	Global market leader in 2024 other than China
850231	n.a.	0%	1%	4%	14%	18%	Denmark, Germany
850300	3%	6%	14%	23%	26%	**30%**	
850511	18%	31%	45%	50%	58%	**67%**	
850519	11%	21%	32%	25%	32%	**39%**	
850520	3%	6%	15%	23%	14%	15%	Germany
850720*	9%	24%	31%	35%	31%	24%	
850740*	4%	0%	0%	89%	76%	**76%**	
850790*	5%	7%	8%	6%	15%	28%	
851240	1%	5%	13%	17%	19%	**27%**	
852852	n.a	n.a	n.a	n.a	55%	**56%**	
853210	3%	4%	4%	9%	11%	21%	
853641	7%	11%	17%	18%	17%	19%	
853710	1%	3%	9%	12%	13%	13%	Germany
853951	n.a	n.a	n.a	n.a	n.a	25%	
853952	n.a	n.a	n.a	n.a	n.a	**75%**	
854141	n.a	n.a	n.a	n.a	n.a	22%	
900190	4%	9%	16%	26%	22%	**35%**	
900220	1%	2%	4%	6%	7%	13%	USA
901320	2%	2%	7%	11%	9%	9%	Germany, USA
902213	0%	0%	0%	0%	1%	6%	S. Korea, Finland, Germany
902219	0%	8%	8%	14%	11%	11%	USA, Germany
902221	0%	1%	2%	2%	3%	1%	Germany, Sweden, USA, Neth-erlands, Belgium
902229	0%	0%	2%	5%	5%	6%	Mexico, USA, Germany
903090	1%	1%	5%	5%	4%	4%	Malasia, Japan, USA

* The last available observation is for 2021.

Note: Bold entries correspond to HS codes for which China possesses as the only global market player at least (or very close to) 30% of global market share in 2024. This is one of the three necessary conditions for identifying strategic import dependencies based on methodology by Gehringer (2023).

Source: Own elaboration based on UN Comtrade database

These segments form the technological backbone of the CCP's strategic emerging industries – electric mobility, robotics, wind energy, and high-efficiency industrial machinery – which are explicitly prioritized in national plans to shift China up the global value chain. China managed to displace other economies in these areas – Japan for permanent magnets and Mexico for nickel-metal hydride batteries.

By contrast, China's position in some upstream or specialized REE-related products remains more contested, with advanced economies, especially USA, Germany and Japan, still retaining significant market roles. In luminophores (320650) and supported catalysts (381519), Chinese export shares increased over time but remain relatively moderate (6–12% in 2024), with Japan, Germany, and the United States listed as alternative global leaders. In optical and laser-related goods (900190, 900220, 901320), China has expanded its shares substantially – e.g. from 4% to 35% for optical elements (900190) between 2000 and 2024 – yet still faces strong competition from Japan, Germany, and the USA. Similarly, in medical and nuclear applications (840140, 902213–902229, 903090), Chinese export shares generally remained in the single-digit range by 2024. Market leadership in this area is shared with or dominated by high-technology producers in Europe, North America, and East Asia. These sectors correspond to domains where frontier technological capabilities – rather than production scale – remain decisive, and where China's industrial policy is still in the capability-building stage.

This trade structure reflects a strategic industrial orientation: China imports some raw materials from abroad but captures the highest value-added steps of the REEs transformation chain through its integrated refining, metallurgical, and manufacturing capabilities. Economically, this configuration follows a classic value-capture logic. The profit margins and strategic leverage increase sharply at the metallurgical and component-manufacturing stages. By controlling these downstream segments, China secures both technological rents and geopolitical influence, as foreign manufacturers depend on Chinese exports for critical intermediate REE-based goods.

The observed structure of the global rare-earth supply chain raises the question of why China, rather than other resource-endowed economies, succeeded in occupying these high-value and strategically decisive segments. This outcome cannot be attributed to geological scarcity alone. Although rare earth elements occur in economically relevant quantities in several regions, including the United States, Australia, and parts of Africa and Europe, China's dominance emerged primarily from deliberate industrial and regulatory choices rather than natural endowments.

Since the 1980s, China pursued an explicit strategy of vertical integration across the entire rare-earth value chain, from mining and beneficiation to chemical separation, metallurgical processing, and downstream manufacturing. These stages are not only technologically demanding but also environmentally intensive. In many advanced economies, strict environmental regulation, high compliance costs, and social opposition led to the closure of existing operations or discouraged new investment, as exemplified by the shutdown of the Mountain Pass mine in the United States in 2002. China, by contrast, internalized these costs during a prolonged phase of state-supported industrial expansion, low labor costs, and comparatively weak environmental enforcement.

Rare earths were thus identified early on as strategic inputs for future industries, and capacity was built accordingly. This explains why China today dominates precisely those stages of the supply chain that generate the highest value added and confer the greatest geopolitical leverage. The resulting concentration reflects not market-driven specialization in the Ricardian sense, but a politically guided process of industrial consolidation. Advanced economies still retain important positions in high-end, specialized equipment (optics, lasers, medical imaging, nuclear technology), but the industrial policy ambitions by the Chinese leadership point to a further expansion of global dominance towards these industrial categories.

4. Strategic import dependencies for REE-based products

The preceding analysis of global production and trade patterns already suggests that the consolidation of rare-earth value chains has important implications for economic security. High global export shares combined with concentrated sourcing raise the risk that importing economies may become dependent on a small number of suppliers. This section makes this intuition explicit by identifying strategic import dependencies for rare-earth-based products.

The concept of strategic import dependence builds on the framework developed by Gehringer (2023). At its core, the idea is straightforward: an economy becomes strategically dependent when it relies heavily on imports of a good that is difficult to replace and when those imports are concentrated on a supplier that itself holds substantial power in the global market. In such cases, supply disruptions – whether driven by political decisions, trade restrictions, or geopolitical conflict – can have severe economic consequences.

Operationally, three conditions must be met. First, a country must be a net importer of the product in question, indicating reliance on foreign supply. Second, imports must be highly concentrated on a single supplier, accounting for at least 50% of total imports. Third, this supplier must command a sufficiently large share (over 30%) of global exports to limit the availability of alternative sources. When all three conditions hold simultaneously, import dependence becomes strategic rather than merely commercial.

Applying this framework to the rare-earth-related product categories identified in the previous section reveals a strikingly consistent pattern.[6] Across almost all examined economies and product groups, China emerges as the dominant supplier. **Tables 3 to 5** summarize the results for the European Union, other advanced

[6] The identified HS codes are: HS 841510 (window or wall air conditioning machines), HS 850511 (permanent magnets of metal), HS 850519 (permanent magnets other than of metal), HS 850740 (nickel-iron electric accumulators), HS 852852 (monitors other than cathode-ray tube), und HS 853952 (LED lamps). For other two HS codes (850131, 851240), the global shares were slightly below the threshold of 30% (27% and 29%, respectively). However, they were selected, given the very fast increase in China's export shares for these products over the last two decades. It is important to note that out of the identified 14 HS codes for which China currently possesses substantial global market shares as a single supplier, only six would fall in this classification in 2020 and three in 2010. This underscores the extreme dynamics in the underlying developments. Finally, although China exports 50% of rare earth metals (HS 280530), it is not the only global supplier with a share over 30% (Thailand's share was 35% in 2024). Accordingly, this code was not included in the analysis of strategic import dependencies.

economies, and major developing countries.[7] For every country-product pair, the entries report the highest import shares and the corresponding sourcing partner. Missing entries imply that the country had a trade surplus for a specific product. Finally, in bold are shares of at least 50% coming from China, which is the single dominating global market player for the examined products. In this way, these entries correspond to strategic import dependencies.

Rather than reflecting isolated cases, the findings point to systematic and widespread dependence on Chinese supply. For the European Union, the results reveal substantial heterogeneity across member states but a common underlying vulnerability (**Tab. 3**). In many REE-intensive products – such as permanent magnets, batteries, LED components, and energy-efficient appliances – Chinese suppliers account for the largest share of imports, often exceeding 50% and in some cases far more. While a small number of EU countries manage to source certain products from alternative partners within Europe or from non-EU suppliers, these cases remain exceptions rather than the rule.

Among advanced economies outside the EU, strategic dependencies are even more pronounced (**Tab. 4**). Countries such as the United States, Japan, and the United Kingdom – despite their technological sophistication – often rely overwhelmingly on Chinese imports for key rare-earth-based components. This underscores that technological capability alone does not guarantee supply security when critical inputs are embedded in highly concentrated global value chains.

The strongest dependencies appear among developing economies (**Tab. 5**). Here, Chinese import shares frequently exceed 80 or even 90% for several REE-intensive products. These countries typically lack domestic production capacity and have limited access to alternative suppliers, making diversification particularly difficult. As a result, dependence on China is not only widespread but also deeply entrenched across different levels of economic development.

Across all country groups, dependencies are most pronounced in product categories where China's global market dominance is particularly strong. Lithium-ion batteries (850740), permanent magnets (850511), and LED lamps (853952) stand out as the most critical products. In these categories, China not only commands between roughly two-thirds and three-quarters of world exports but also supplies the overwhelming majority of imports in nearly all examined countries. These goods are central components in renewable energy technologies, electric mobility, and advanced electronics, sectors in which China's vertically integrated production

[7] Country selection is based on GDP (in PPP adjusted terms). Advanced countries are composed of United States, Japan, United Kingdom, South Korea, Canada, Australia, Switzerland, Israel, Norway, Singapore, New Zealand, and Iceland. Developing countries comprise India, Brazil, Indonesia, Turkey, Mexico, Saudi Arabia, Thailand, Argentina, and South Africa. Russia would rank the second among the developing countries, but due to data unavailability for the most recent years, the country was excluded from the analysis.

structure reinforces its position as an indispensable global supplier. Other products such as air-conditioning machines (841510) also exhibit widespread dependence, although a limited number of countries source significant shares from alternative suppliers.

The results furthermore show that alternative sourcing partners appear only sporadically and remain regionally or sectorally concentrated. When China is not the principal supplier, countries tend to rely on regional production hubs or specific specialized exporters. Nevertheless, these cases are exceptions rather than evidence of broad diversification. The general pattern remains one of strong concentration, underscoring the limited availability of viable alternative suppliers in REE-dependent value chains.

Table 3. EU-27: the highest import shares coming from a single source for products with the strongest strategic import dependencies

	HS 841510		HS 850511		HS 850519		HS 850740		HS 852852		HS 853952	
China's global share	*64%*		*67%*		*39%*		*76%*		*56%*		*75%*	
Importer	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*
Austria	30%	Thailand	38%	China	**55%**	**China**	62%	Norway	**51%**	**China**	**63%**	**China**
Belgium	23%	Germany	**67%**	**China**	48%	China	**76%**	**China**	34%	Netherlands	35%	Netherlands
Bulgaria	**62%**	**China**	43%	China	37%	Germany	62%	Russia	**72%**	**China**	**92%**	**China**
Croatia	**60%**	**China**	65%	Italy	40%	China	65%	Netherlands	31%	Netherlands	23%	Poland
Cyprus	**50%**	**China**	**61%**	**China**	**58%**	**China**	56%	Belgium	46%	Cyprus	42%	China
Czechia	32%	China	**82%**	**China**	37%	China	**78%**	**China**	**84%**	**China**	**74%**	**China**
Denmark	---	---	**65%**	**China**	42%	China	98%	Czechia	40%	Netherlands	35%	Poland
Estonia	50%	Malasia	**83%**	**China**	45%	China	86%	USA	**54%**	**China**	35%	Poland
Finland	48%	Thailand	---	---	48%	China	---	---	46%	China	**71%**	**China**
France	**51%**	**China**	**68%**	**China**	**58%**	**China**	48%	Germany	**58%**	**China**	**84%**	**China**
Germany	25%	China	**85%**	**China**	**68%**	**China**	**76%**	**China**	**66%**	**China**	**72%**	**China**
Greece	**72%**	**China**	41%	China	**77%**	**China**	60%	Germany	35%	Netherlands	**64%**	**China**
Hungary	**67%**	**China**	**69%**	**China**	29%	China	93%	Hong Kong	27%	Belgium	---	---
Ireland	37%	France	**60%**	**China**	37%	China	46%	UK	**69%**	**China**	**66%**	**China**
Italy	**64%**	**China**	**80%**	**China**	**66%**	**China**	**51%**	**China**	29%	Netherlands	**54%**	**China**
Latvia	30%	China	42%	China	---	---	89%	Netherlands	29%	Slovakia	62%	Poland
Lithuania	48%	China	**63%**	**China**	31%	China	---	---	46%	Netherlands	55%	Poland
Luxembourg	40%	Belgium	---	---	34%	China	41%	Belgium	39%	China	**51%**	**China**
Malta	**73%**	**China**	**82%**	**China**	**72%**	**China**	---	---	24%	China	**53%**	**China**
Netherlands	32%	Germany	43%	China	45%	China	46%	Germany	**56%**	**China**	49%	China
Poland	**73%**	**China**	**83%**	**China**	**66%**	**China**	43%	Japan	**74%**	**China**	**95%**	**China**
Portugal	31%	China	**53%**	**China**	41%	Spain	45%	France	24%	Netherlands	27%	China
Romania	**61%**	**China**	64%	Germany	60%	Germany	81%	Switzerland	25%	China	49%	China
Slovakia	19%	China	**52%**	**China**	40%	China	51%	Czechia	65%	Vietnam	**67%**	**China**
Slovenia	25%	China	**88%**	**China**	---	---	65%	USA	**73%**	**China**	**74%**	**China**
Spain	**77%**	**China**	**68%**	**China**	**75%**	**China**	35%	Netherlands	**56%**	**China**	**83%**	**China**
Sweden	30%	China	**62%**	**China**	---	---	34%	China	51%	Netherlands	41%	China

Source: Own calculations based on UN Comtrade data for 2024

Table 4. Major advanced economies: the highest import shares coming from a single source for products with the strongest strategic import dependencies

	HS 841510		HS 850511		HS 850519		HS 850740		HS 852852		HS 853952	
China's global share	*64%*		*67%*		*39%*		*76%*		*56%*		*75%*	
Importer	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*
Australia	**52%**	**China**	---	---	**79%**	**China**	**92%**	**China**	**77%**	**China**	**89%**	**China**
Canada	**63%**	**China**	**60%**	**China**	28%	Vietnam	45%	China	**60%**	**China**	**92%**	**China**
Iceland	55%	Sweden	33%	China	**66%**	**China**	**90%**	**China**	**82%**	**China**	**79%**	**China**
Israel	**68%**	**China**	**63%**	**China**	---	---	99%	Belgium	15%	Ireland	**76%**	**China**
Japan	**92%**	**China**	33%	Philippines	---	---	---	---	**93%**	**China**	**91%**	**China**
New Zealand	52%	Thailand	---	---	**68%**	**China**	82%	USA	**70%**	**China**	**87%**	**China**
Norway	24%	Thailand	**56%**	**China**	41%	China	---	---	**65%**	**China**	**88%**	**China**
Rep. of Korea	---	---	**87%**	**China**	---	---	55%	USA	**66%**	**China**	**93%**	**China**
Singapore	76%	Thailand	**63%**	**China**	**50%**	**China**	31%	Thailand	**56%**	**China**	**56%**	**China**
Switzerland	22%	Italy	---	---	31%	China	56%	Spain	**52%**	**China**	**84%**	**China**
UK	30%	China	**67%**	**China**	**79%**	**China**	54%	USA	**73%**	**China**	**86%**	**China**
USA	44%	China	**75%**	**China**	47%	China	46%	Mexico	**78%**	**China**	**95%**	**China**

Source: Own calculations based on UN Comtrade data for 2024

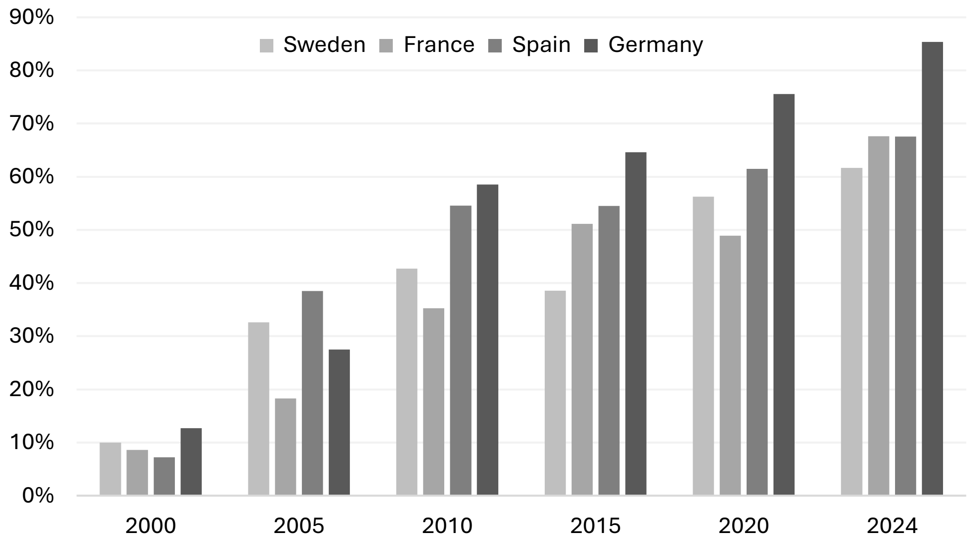
Table 5. Major developing countries: the highest import shares coming from a single source for products with the strongest strategic import dependencies

	HS 841510		HS 850511		HS 850519		HS 850740		HS 852852		HS 853952	
China's global share	*64%*		*67%*		*39%*		*76%*		*56%*		*75%*	
Importer	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*
Argentina	**79%**	**China**	43%	China	**56%**	**China**	**91%**	**China**	**78%**	**China**	**97%**	**China**
Brazil	**71%**	**China**	**81%**	**China**	**59%**	**China**	74%	France	**79%**	**China**	**98%**	**China**
India	96%	Thailand	**82%**	**China**	**64%**	**China**	70%	USA	**83%**	**China**	**69%**	**China**
Indonesia	**56%**	**China**	---	---	**66%**	**China**	54%	India	**84%**	**China**	**99%**	**China**
Mexico	**98%**	**China**	**81%**	**China**	**63%**	**China**	**90%**	**China**	**85%**	**China**	**86%**	**China**
Saudi Arabia	**92%**	**China**	35%	China	40%	China	38%	UK	**71%**	**China**	**93%**	**China**
South Africa	**91%**	**China**	**80%**	**China**	**57%**	**China**	49%	China	**72%**	**China**	**93%**	**China**
Thailand	---	---	46%	China	**51%**	**China**	50%	Germany	**81%**	**China**	**82%**	**China**
Turkey	**84%**	**China**	**76%**	**China**	**61%**	**China**	**86%**	**China**	**68%**	**China**	**95%**	**China**

Source: Own calculations based on UN Comtrade data for 2024

The static perspective discussed above does not capture the dynamic evolution of China's ascent to global dominance in REE-related value chains. Across products and countries, China expanded its market shares rapidly, often within only a few years and frequently by substantial margins. The trajectory for permanent magnets (850511) is illustrative. In Germany, France, Spain, and Sweden, China's share in imports of permanent magnets rose from below or around 10% in 2000 to more than 60% in 2024 – and to nearly 90% in Germany alone (**Fig. 6**). Comparable patterns can be observed in other non-EU economies and in additional product categories where strong strategic import dependencies were identified. Notably, this trend persisted unabated even during periods of heightened policy awareness regarding supply-chain vulnerabilities. In Germany, China's expansion continued despite the government's growing awareness of strategic dependence already well before the 2022 *Zeitenwende* declaration, which emphasized the need to reduce critical dependencies. Similarly, at the EU level, new initiatives aimed at strengthening strategic autonomy and lowering exposure to single suppliers – such as the updated industrial strategy and the Critical Raw Materials Act – have so far not been accompanied by a measurable shift in import patterns.

Figure 6. Development of import shares from China of HS 850511 (permanent magnets) in selected EU countries.



Source: Own elaboration based on UN Comtrade data

5. Turning vulnerability into strategy

The analysis of strategic import dependencies for rare earths and REE-dependent products confirms a high degree of geographical concentration and asymmetric interdependence of the underlying global value chains. China dominates the most important downstream manufacturing segments. These findings are consistent with Hirschman's (1945) theoretical insights, which establish a link between supplier concentration and structural vulnerability. They are also consistent with more recent work on "interdependence as a weapon" (Farrell & Newman, 2019), which highlights the geopolitical risks inherent in globalized networks characterized by chokepoints and central hubs. The empirical evidence presented here shows that such risks are not abstract. Rather, they are embedded in the observable trade patterns of REE-dependent goods in both advanced and developing countries.

The results show China's absolute dominance in terms of what could be described as the geopolitics of scarcity. The country meets all three conditions for strategic import dependency: it controls a dominant share of global exports in the relevant HS categories, accounts for a high and often overwhelming share of countries' import volumes, and operates in markets where substitution options and supplier diversity remain limited. Furthermore, dynamic analysis of import shares in selected product segments shows that these dependencies have not diminished despite increasing geopolitical tensions and explicit political efforts – particularly in Europe and the United States – to reduce dependence on critical suppliers. Instead, China's central role in several downstream REE-based technologies, such as permanent magnets, lithium-ion batteries, LED components, and advanced HVAC equipment, has strengthened. This development is in line with more general observations in the literature on critical minerals, which point to China's long-term industrial strategy and its systematic efforts to consolidate value creation in technologically sophisticated stages of the supply chain (Mancheri, 2015; Carpenter & Fang, 2025).

This constellation represents a case of systemic vulnerability. Such vulnerabilities arise when global production networks depend on highly concentrated suppliers whose market power is reinforced by economies of scale, technological barriers, and political control over critical upstream or downstream nodes (Blackwill & Harris, 2016; Kristeri et al., 2025). The persistence of China-centric supply chains – even after major shocks such as the rare earth embargo against Japan in 2010, the COVID-19 pandemic, and the export restrictions on gallium and germanium in 2023–2024 – suggests that market-driven adjustment mechanisms alone are not sufficient to rebalance REE-intensive value chains. Unlike cyclical disruptions, these dependencies are structural in nature and deeply embedded in the organization of global production.

However, historical experience shows that the dominance of political logic over economic logic entails long-term risks for the dominant supplier itself. The development of OPEC offers a useful parallel: while cartel formation and strategic control had a significant impact for decades, they ultimately led to diversification, substitution, and technological change that undermined quasi-monopoly power. Applied to rare earths, the key question is therefore not whether China's dominance can be challenged, but how quickly alternative value chains can be rebuilt elsewhere.

This highlights the need for a comprehensive resilience and diversification approach that encompasses all stages of the value chain – from extraction, refining, and separation to component manufacturing and integration into end uses (Shih, 2020; Gereffi, 2020). The growing number of political initiatives at EU and national level reflects this diagnosis: with the Critical Raw Materials Act, the EU has for the first time set binding benchmarks for 2030 along the entire value chain and structurally limited dependence on any single third country.

At the same time, the EU continues to adhere to high environmental and social sustainability standards, which significantly limit the rapid development of domestic extraction and processing capacities, thereby revealing a central conflict of objectives between sustainability and strategic sovereignty. This is evident, for example, in the long and complex approval procedures for mining projects under the Environmental Impact Assessment Directive and the Water Framework Directive, which allow only limited exceptions even for projects classified as strategic. Opposition to lithium and rare earth projects in Germany and Portugal also illustrates that nature conservation requirements and local conflicts of use can delay or prevent the implementation of industrial policy goals. In addition, strict requirements for waste, chemical, and emission standards – such as those under the REACH Regulation – make it difficult to establish competitive refining and separation capacities within the EU compared to third countries with lower regulatory hurdles. Germany has updated its raw materials strategy for 2023 and backed it up with targeted funding instruments for domestic lithium projects, refining, and international investments – including through KfW – but these initiatives remain heavily influenced by regulatory restrictions. France, on the other hand, is pooling considerable public funds for extraction, processing, and recycling projects as part of France 2030 and the *Métaux Critiques* initiative, and is supporting these with more active raw materials diplomacy, but it also faces high environmental standards and acceptance requirements. The challenge here is not to relax existing standards across the board, but to prioritize and calibrate regulatory requirements in a targeted manner in order to resolve the trade-off between environmental responsibility and strategic capacity for action at the political level.

Beyond Europe, the United States has also taken steps to rebuild parts of the rare earth and magnet supply chain. The Inflation Reduction Act introduced generous production tax credits for critical minerals, including rare earths, to boost domestic extraction, processing, and recycling. In addition, the Department of Defense has launched a mine-to-magnet strategy and entered into long-term partnerships with companies such as MP Materials to build capacity for processing neodymium-praseodymium (NdPr) and manufacturing permanent magnets on US soil. In addition, US development finance institutions have specifically supported critical minerals projects in allied countries in recent years. This includes projects for breaking up, leaching, and refining rare earths in Australia, in order to establish a geographically diversified and politically reliable “friend-shored” supply base. Even though the scope and continuity of these funding instruments are increasingly influenced by domestic policy priorities and budget debates, international project financing remains a central component of the US strategy for reducing risk in critical raw materials. At the same time, Donald Trump's recent renewed consideration of unilateral influence over Greenland illustrates that nationalistic raw materials and security policies carry the risk of exacerbating tensions with close allies. This undermines the very trust-based cooperation that would be essential for a credible joint derisking strategy in the area of critical minerals.

The efforts of Japan, South Korea, and other Indo-Pacific economies complement this picture: Japan's response to the 2010 embargo – a combination of diversification toward new suppliers, public support for overseas mining projects, and strategic stockpiling – has become a reference point for current policy debates, even though recent findings suggest that true diversification has not yet been fully achieved. For its part, South Korea has adopted a comprehensive roadmap for critical minerals, designated a wide range of critical minerals for strategic monitoring, and leveraged its leadership role in the Minerals Security Partnership and closer cooperation with African producer countries to secure access to key raw materials.

Precisely because establishing alternative value chains is costly, time-consuming, and politically controversial, deeper supranational cooperation between like-minded countries is becoming increasingly important. National and even European industrial policies reach their structural limits where economies of scale, capital requirements, and regulatory restrictions make isolated solutions unlikely. Formats such as the multilateral Minerals Security Partnership strategy launched in 2022 or coordinated raw materials partnerships therefore open up an institutional framework for organizing diversification on a broader basis and further reducing strategic dependencies. Such a multi-level approach involving multiple instruments has been among the core outcomes of the literature on industrial policy in strategic sectors, which emphasizes the need for a coherent policy mix rather than isolated interventions (Aiginger & Rodrik, 2020; Andreoni & Chang, 2019). Without a strategic and broad-based commitment to such comprehensive diversification, existing dependencies are likely to deepen and increase the risk of exposure to China's dark arts of economic influence.

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Appendix A

Because the HS nomenclature does not provide a classification based on REE content, an ad-hoc procedure was followed by combining insights from the scientific literature. Specifically, Alfaro et al. (2025) integrate REEs into an input–output framework and identify nine 4-digit SIC industries with the highest REE intensity. These SIC categories were subsequently matched to their corresponding HS 6-digit product codes, and the resulting concordance is reported in Table A.1 below.

However, the mapping revealed that many HS codes within the matched set correspond to product categories that are not structurally dependent on REEs. For example, several HS codes in Table A.1 refer to heavy machinery, combustion engines, metal fittings, or structural components (e.g., HS 8407xx, 8408xx, 7302xx, 7316xx, 6811xx), which may contain REEs only incidentally, rather than as essential inputs. Conversely, some REE-intensive products do not appear in the SIC-industry-based concordance. Therefore, drawing on additional scientific and technical sources, only HS codes corresponding to products with systematic REE-dependence were retained, and relevant REE-related HS codes not captured by the SIC-based mapping were added. Table A.2 shows the list of the relevant HS codes, the corresponding product descriptions and REE application in the respective HS products.

The REE-related HS codes identified in Table A.2 can be grouped into two broad categories that reflect their position in the rare-earth value chain: 1) products that directly incorporate rare earth elements as essential functional materials, and 2) products whose performance depends on REE-containing components.

The first group comprises products such as inorganic luminophores (HS 320650), where rare earth activators generate the luminescent properties, and supported catalysts (HS 381519), in which lanthanides act as promoters or active catalytic sites. It also includes high-performance permanent magnets (HS 850511 and 850519), based on neodymium, samarium, or other REE alloys, and NiMH batteries (HS 850740) that rely on REE-based metal hydrides. These products constitute the functional core of REE-based technologies and serve as critical inputs into a wide array of industrial applications.

The second product group consists of manufacturing goods that do not themselves directly contain raw REEs but instead rely on REE-based components to deliver their performance characteristics. Prominent examples include air-conditioning units and heat pumps (HS 841510, 841581–841590), which use REE permanent magnets in high-efficiency compressors and fans. Analogously, refrigeration and freezing equipment (HS 841850, 841861, 841869) depends on REE-based motors or LED lighting. Automotive engine parts and pumps (HS 840991, 840999, 841330) incorporate REE-containing alloys, catalysts, or electronic motors. Additional applications include electromagnetic couplings (HS 850520), control boards and relays (HS 853641, 853710) that embed REE magnets or REE-based capacitors, LED devices (HS 854141) which rely on upstream REE phosphors, and radiation-detection instruments (HS 903090) that integrate REE-dependent scintillators, optics, and permanent magnets.

Table A.1. Conversion of REE-intensive industries SIC-industries in HS codes

SIC Code	SIC Product Description	HS Code	HS 2007 Product Description
3691	Electric accumulators, incl. separators therefor, whether/not rectangular (incl. square), lead-acid, of a kind used for starting piston engines	850720	Electric accumulators, incl. separators thereof, whether/not rectangular (incl. square), lead-acid (excl. of 8507.10)
		850730	Electric accumulators, incl. separators thereof, whether/not rectangular (incl. square), nickel-cadmium
		850740	Electric accumulators, incl. separators thereof, whether/not rectangular (incl. square), nickel-iron
		850780	Electric accumulators, incl. separators thereof, whether/not rectangular (incl. square), n.e.s. in 85.07
		850790	Parts of the electric accumulators & separators thereof of 85.07
		854810	Waste & scrap of primary cells, primary batteries & electric accumulators
3499	Coin (excl. gold coin), not being legal tender	711890	Other coin (excl. of 7118.10)
		730230	Switch blades, crossing frogs, point rods & other crossing pieces of iron/steel
		730240	Fish-plates & sole plates (base plates) of iron/steel
		730290	Railway/tramway track construction material of iron/steel, the following : check-rails & rack rails, sleepers (cross-ties),chairs, chair wedges, rail clips, bedplates, ties & other material specialized for jointing/fixing rails.
		731600	Anchors, grapnels & parts thereof, of iron/steel
		732391	Table/kitchen/other h-hold. articles & parts thereof (excl. of 7323.10), of cast iron, not enamelled
		732392	Table/kitchen/other h-hold. articles & parts thereof (excl. of 7323.10), of cast iron, enamelled
		732393	Table/kitchen/other h-hold. articles & parts thereof (excl. of 7323.10), of stainless steel
		732394	Table/kitchen/other h-hold. articles & parts thereof (excl. of 7323.10), of iron (excl. cast iron)/steel (excl. stainless steel), enamelled
		732399	Table/kitchen/other h-hold. articles & parts thereof (similar to but excl. those of 7323.10-7323.94), of iron/steel
		732611	Grinding balls & similar articles for mills, of iron/steel, forged/stamped but not further worked
		732619	Articles of iron/steel, forged/stamped but not further worked, n.e.s.
		741811	Pot scourers & scouring/polishing pads, gloves & the like, of copper
		761210	Collapsible tubular containters for any material (other than compressed/liquiefied gas), of aluminium
		780600	Other articles of lead.
		790700	Other articles of zinc.
		800700	Other articles of tin.
		811300	Cermets & articles thereof, incl. waste & scrap
		830300	Armoured/reinforcededed safes, strong-boxes & doors & safe deposit lockers for strong-rooms, cash/deed boxes & the like, of base metal
		850511	Permanent magnets & articles intended to become permanent magnets after magnetisation, of metal

		741819	Table, kitchen/other household articles & parts thereof
		830630	Photograph/picture/similar frames, of base metal
3625	Electro-magnetic couplings, clutches & brakes	853340	Electrical resistors (excl. heating resistors, light dependent resistors), n.e.s. in 85.33
		853641	Relays, for a voltage not >60V
		853649	Relays (excl. of 8536.41), for a voltage not >1000V
		853650	Switches other than isolating switches & make-&-break switches, for a voltage not >1000V
		853710	Boards, panels, consoles, desks, cabinets & other bases, equipped with 2/more apparatus of 85.35/85.36, for electric control/distribution of electricity, incld. Those incorporting instruments/apparatus of Ch. 90 & numerical control apparatus, other than
		910700	Time switches with clock/watch movement/with synchronous motor
		853210	Electrical capacitors, fixed, designed for use in 50/60Hz circuits & having a reactive power handling capacity of not <0.5 kvar (power capacitors)
3292	Asbestos products, nspf	681189	Other articles of asbestos-cement, of cellulose fibre-cement/the like, not containing asbestos, other than corrugated sheets/tubes/pipes/pipe fittings.
		681292	Other fabricated asbestos fibres mixtures with a basis of asbestos/with a basis of asbestos & magnesium carbonate
		681293	Other fabricated asbestos fibres mixtures with a basis of asbestos/with a basis of asbestos & magnesium carbonate
		681320	Friction material & articles thereof (eg. sheets, rolls, strips, segments, discs, washers, pads), not mounted, for brakes, for clutches/the like, with a basis of asbestos, of other mineral substances/of cellulose, whether/not combined with textile/other
		681381	Friction material & articles thereof (eg. sheets, rolls, strips, segments, discs, washers, pads), not mounted, for brakes, for clutches/the like, with a basis of asbestos, of other mineral substances/of cellulose, whether/not combined with textile/other
		681389	Other friction material & articles thereof (eg. sheets, rolls, strips, segments, discs, washers, pads), not mounted, for brakes, for clutches/the like, with a basis of asbestos, of other mineral substances/of cellulose, whether/not combined with textile/
		681293	Other fabricated asbestos fibres mixtures with a basis of asbestos/with a basis of asbestos & magnesium carbonate
3714	Spark ignition reciprocating piston engines of a kind used for the propulsion of vehicles of Ch.87, of a cylinder capacity not >50cc	841330	Fuel/lubricating/cooling medium pumps for internal combustion piston engines
		842123	Oil/petrol-filters for internal combustion engines
		842131	Intake air filters for internal combustion engines
		848350	Flywheels & pulleys, incl. pulley blocks
		851240	Windscreen wipers, defrosters & demisters of a kind used for cycles/motor vehicles
3519	Spark-ignition reciprocating/rotary internal combustion piston engines for outboard motors	840729	Spark-ignition reciprocating/rotary internal combustion piston engines for marine propulsion (excl. outboard motors)
		840732	Spark ignition reciprocating piston engines of a kind used for the propulsion of vehicles of Ch.87, of a cylinder capacity >50cc but not >250cc
		840733	Spark ignition reciprocating piston engines of a kind used for the propulsion of vehicles of Ch.87, of a cylinder capacity >250cc but not >1000cc
		840734	Spark ignition reciprocating piston engines of a kind used for the propulsion of vehicles of Ch.87, of a cylinder capacity >1000cc

		840790	Spark-ignition reciprocating/rotary internal combustion piston engines (excl. of 8407.10-8407.29)
		840810	Compression-ignition internal combustion piston engines (diesel/semi-diesel engines) for marine propulsion
		840820	Compression-ignition internal combustion piston engines (diesel/semi-diesel engines) of a kind used for the propulsion of vehicles of Ch.87
		840890	Internal combustion piston engines (diesel/semi-diesel engines) (excl. of 8408.10 & 8408.20)
		840991	Parts suit. for use solely/principally with spark-ignition internal combustion piston engines
		840999	Parts suit. for use solely/principally with the engines of 84.07/84.08 (excl. of 8409.10 & 8409.91)
3585	Compressors of a kind used in refrigerating equip.	841510	Window/wall type air-conditioning machines, self-contained/split-system, comprising a motor-driven fan & elements for changing the temp. & humidity, including those machines in which the humidity cannot be separately regulated
		841520	Air-conditioning machines of a kind used for persons, in motor vehicles
		841581	Air-conditioning machines incorporating a refrigerating unit & a valve for reversal of the cooling/heat cycle (reversible heat pumps)
		841582	Air-conditioning machines (excl. of 8415.10-8415.81), incorporating a refrigerating unit
		841583	Air-conditioning machines (excl. of 8415.10-8415.81), not incorporating a refrigerating unit
		841590	Parts of the air-conditioning machines of 8415.10-8415.83
		841850	Refrigerating/freezing chests, cabinets, display counters, show-cases & similar refrigerating/freezing furniture, electric/other (excl. of 8418.10-8418.40)
		841861	Compression-type refrigerating/freezing equip. whose condensers are heat exchangers
		841891	Furniture designed to receive refrigerating/freezing equip.
		841899	Parts of the refrigerating/freezing equip. & heat pumps of 8418.10-8418.69 (excl. of 8418.91)
		841869	Refrigerating/freezing equip. n.e.s. in 84.18

Source: Own elaboration Flossbach von Storch Research Institute based on Alfaro et al. (2025) and the HS-SIC conversion table by WITS.

Table A.2. HS codes of REE-related products and REE application thereof

HS	Product description	REE application
320650	Colouring matter; inorganic products of a kind used as luminophores	REEs serve as the primary activators or host materials responsible for their luminescent properties (Lucas et al., 2015).
381519	Catalysts, supported; reaction initiators, reaction accelerators and catalytic preparations, with an active substance other than nickel or precious metals or their compounds, n.e.c. or included	REEs function as promoters and/or the active catalytic substance itself. These catalysts are used in petroleum refining, pollution abatement and chemical processing for specific hydrofunctionalization reactions, olefin polymerizations, or ammonia synthesis (Akah, 2024)
690912	Ceramic wares; for laboratory, chemical or other technical uses, articles having a hardness equivalent to 9 or more on the Mohs scale	REEs improve resistance to heat and physical stress in certain special ceramics (Alam et a., 2012).
840140	Nuclear reactors; parts thereof	The primary application of rare earths in a nuclear reactor is within the control rods, which are used to regulate the rate of the nuclear chain reaction or to shut down the reactor entirely if needed (Kılıç & Yilmaz, 2025).
840991	Engines; parts, suitable for use solely or principally with spark-ignition internal combustion piston engines (for other than aircraft)	REEs are used in some specific components that fall under this general category, primarily to enhance material performance and lifespan.
840999	Engines; parts for internal combustion piston engines (excluding spark-ignition)	REEs are primarily used as alloying additives to improve material properties and in diesel fuel additives (Akah, 2024).
841330	Pumps; fuel, lubricating or cooling medium pumps for internal combustion piston engines	The relevance of REEs is indirect, in motors and electronics as well as alloys and catalysts (USGS, 2011).
841430	Compressors; of a kind used in refrigerating equipment	REEs can play a significant, though not universal, role in these products, specifically within the electric motors that power the compressors.
841510	Window or wall air conditioning machines, self-contained or 'split-system'; comprising a motor-driven fan and elements for changing the temperature and humidity	Rare earth elements are used in the magnets of motors within air conditioning machines (Vegireddy & Sampathirao, 2024).
841520	Air conditioning machines of a kind used for persons in motor vehicles	The main role of REEs in this category is for electric motors, catalysis, metallurgy, and electronics & lighting (Filho et al., 2023).
841581	Air conditioning machines; containing a motor driven fan, other than window or wall types, incorporating a refrigerating unit and a valve for reversal of the cooling/heat cycle (reversible heat pumps)	REEs are primarily used in the high-efficiency permanent magnet motors found in modern compressors and fans (Filho et al., 2023).
841582	Air conditioning machines; containing a motor driven fan, other than window or wall types, incorporating a refrigerating unit	REEs are used in permanent magnet motors and sensors (Filho et al., 2023).
841583	Air conditioning machines; containing a motor driven fan, other than window or wall types, not incorporating a refrigerating unit	REEs are used in the permanent magnet motors that drive fans and compressors (Filho et al., 2023).

Table A.2. HS codes of REE-related products and REE application thereof, cont.

841590	Air conditioning machines; with motor driven fan and elements for temperature control, parts thereof	REEs are used in the permanent magnet motors that drive fans and compressors (Filho et al., 2023).
841850	Furniture incorporating refrigerating or freezing equipment; for storage and display, n.e.c. in item no. 8418.1, 8418.2, 8418.3 or 8418.4 (chests, cabinets, display counters, show-cases and the like)	REEs are found in the electric motors and potential advanced magnetic refrigeration systems of refrigerating or freezing chests, display counters and similar equipment (Gschneidner & Pecharsky, 2006).
841861	Heat pumps; other than air conditioning machines of heading no. 8415	REEs are primarily found in the electric motors of components like compressors, fans, and pumps (Zils & Hopkinson, 2024).
841869	Refrigerating or freezing equipment; n.e.c. in heading no. 8418	REEs are primarily found in the electric motors and display/lighting components (Saravacos & Kostaropoulos, 2015).
841891	Refrigerating or freezing equipment; parts, furniture designed to receive refrigerating or freezing equipment	REEs are primarily found in the electric motors and display/lighting components (Saravacos & Kostaropoulos, 2015).
841899	Refrigerating or freezing equipment; parts thereof, other than furniture	REEs are primarily found in the electric motors and display/lighting components (Saravacos & Kostaropoulos, 2015).
842123	Machinery; filtering or purifying machinery, oil or petrol filters for internal combustion engines	Filters falling under HS 842123 are components of internal combustion engines.
842131	Machinery; intake air filters for internal combustion engines	REEs are in the washcoat (or coating) of the catalyst component (Ding et al., 2000).
847170	Units of automatic data processing machines; storage units	REEs are used in the powerful magnets within hard disk drives (HDDs) for the read/write heads and spindle motors.
850110	Electric motors; of an output not exceeding 37.5W	Small motors (fans, pumps, electronics) often use neodymium-iron-boron (NdFeB) permanent magnets.
850120	Electric motors; universal AC/DC of an output exceeding 37.5W	Some variants of universal AC/DC motors use REE permanent magnets
850131	Electric motors and generators; DC, of an output not exceeding 750W	DC motors and generators are widely used for brushless DC motors, in which REE magnets are common.
850132	Electric motors and generators; DC, of an output exceeding 750W but not exceeding 75kW	DC motors and generators are widely used for brushless DC motors, in which REE magnets are common.
850133	Electric motors and generators; DC, of an output exceeding 75kW but not exceeding 375kW	DC motors and generators are widely used for brushless DC motors, in which REE magnets are common.
850134	Electric motors and generators; DC, of an output exceeding 375kW	DC motors and generators are widely used for brushless DC motors, in which REE magnets are common.
850140	Electric motors; AC motors, single-phase	Certain high-efficiency types of AC single-phase motors use NdFeB PM rotors.
850151	Electric motors; AC motors, multi-phase, of an output not exceeding 750W	Multi-phase AC motors are used as EV traction motors, in HVAC compressors, robots and industrial drives. In all these applications, REE magnets are standard.

Table A.2. HS codes of REE-related products and REE application thereof, cont.

850152	Electric motors; AC motors, multi-phase, of an output exceeding 750W but not exceeding 75kW	Multi-phase AC motors are used as EV traction motors, in HVAC compressors, robots and industrial drives. In all these applications, REE magnets are standard.
850153	Electric motors; AC motors, multi-phase, of an output exceeding 75kW	Multi-phase AC motors are used as EV traction motors, in HVAC compressors, robots and industrial drives. In all these applications, REE magnets are standard.
850161	Generators; AC generators, (alternators), other than photovoltaic generators, of an output not exceeding 75kVA	Generators are used for wind turbines, microturbines, portable generators, in which REE magnets are used in cases where high power density is required.
850162	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 75kVA but not exceeding 375kVA	Generators are used for wind turbines, microturbines, portable generators, in which REE magnets are used in cases where high power density is required.
850163	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 375kVA but not exceeding 750kVA	Generators are used for wind turbines, microturbines, portable generators, in which REE magnets are used in cases where high power density is required.
850164	Electric generators; AC generators, (alternators), other than photovoltaic generators, of an output exceeding 750kVA	Generators are used for wind turbines, microturbines, portable generators, in which REE magnets are used in cases where high power density is required.
850180	Electric generators; (excluding generating sets), photovoltaic AC generators (alternators)	This residual category includes servo motors, drone motors, and high-efficiency permanent-magnet motors, where REE magnets are widely used.
850231	Electric generating sets; wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines)	Large direct-drive wind turbines use significant quantities of REE permanent magnet generators.
850300	Electric motors and generators; parts suitable for use solely or principally with the machines of heading no. 8501 or 8502	The code covers rotors, stators, and housings that may include NdFeB magnet assemblies.
850511	Magnets; permanent magnets and articles intended to become permanent magnets after magnetisation, of metal	REEs are integral components of the metal alloy in specific types of high-performance permanents magnets, Neodymium-Iron-Boron (NdFeB) magnets, Samarium-Cobalt (SmCo) magnets (Bailey et al., 2021).
850519	Magnets; permanent magnets and articles intended to become permanent magnets after magnetisation, other than of metal	REEs are used in the permanent magnet components (USGS, 2020).
850520	Magnets; electro-magnetic couplings, clutches and brakes	REEs are found in the permanent magnets used within certain high-performance or compact electromagnetic couplings, clutches, and brakes (USGS, 2020).
850740	Electric accumulators; nickel-iron, including separators, whether or not rectangular (including square)	REEs are a critical component in the negative electrode (anode) of nickel-metal hybride (NiMH) batteries (Ait-Meddour et al., 2025).
850790	Electric accumulators; other than lead-acid, nickel-cadmium, nickel-metal hydride and lithium-ion, including separators, whether or not rectangular (including square)	REEs might be found in electrodes of battery components if specifically designed for NiMH batteries, or in associated battery management systems or control electronics
851240	Windscreen wipers, defrosters and demisters; electrical, of kinds used for cycles or motor vehicles	REEs are found in the electric motors for deforestation/demisters that use permanent magnets.

Table A.2. HS codes of REE-related products and REE application thereof, cont.

852852	Monitors; other than cathode-ray tube; capable of directly connecting to and designed for use with an automatic data processing machine of heading 84.71	REEs are used in phosphors for many display technologies (LCD, older CRT) and backlighting, as well as in the magnets used in speakers and other components within these devices (USGS, 2014).
853210	Electrical capacitors; fixed, designed for use in 50/60 Hz circuits and having a reactive power handling capacity of not less than 0.5 kvar (power capacitors)	REEs are used as doping agents or additives in the dielectric material component of certain fixed electrical capacitators, especially in ceramic and film capacitators (Alam et al., 2012).
853951	Lamps; light-emitting diode (LED) light sources, light-emitting diode (LED) modules	REEs such as yttrium, cerium, terbium, and europium are used as phosphors in LEDs to convert the emitted light into visible white light or various colors efficiently (Wilburn, 2012).
853952	Lamps; light-emitting diode (LED) light sources, light-emitting diode (LED) lamps	REEs such as yttrium, cerium, terbium, and europium are used as phosphors in LEDs to convert the emitted light into visible white light or various colors efficiently (Wilburn, 2012).
853641	Electrical apparatus; relays, (for a voltage not exceeding 60 volts)	REEs are used in relays within the permanent magnets that facilitate their operation (Verkroost et al., 2024).
853710	Boards, panels, consoles, desks and other bases; for electric control or the distribution of electricity, (other than switching apparatus of heading no. 8517), for a voltage not exceeding 1000 volts	REEs are components of permanent magnets, capacitors, displays and indicator lghts, and integrated circuits that might be components of products classified under HS 853710.
854141	Electrical apparatus; photosensitive semiconductor devices, light emitting diodes (LED)	REEs in LEDs are typically found in the phosphor component, which is used to create white light or specific colors (USGS, 2020).
900190	Optical elements; lenses n.e.c. in heading no. 9001, prisms, mirrors and other optical elements, unmounted, of any material (excluding elements of glass not optically worked)	REEs are crucial additives in the production of specialized glass and other optical materials (USGS, 1993). They are contained in the lenses, prisms, mirrors, and color filters that are covered by this HS code.
900220	Filters; mounted as parts or fittings for instruments or apparatus, of any material (excluding elements of glass not optically worked)	REEs are likely present in the optical elements (filters and lenses), where used as additives to the glass or other materials to achieve specific optical properties (USGS, 1993).
901320	Lasers; other than laser diodes	Rare earth elements can be found in the gain medium (or laser crystal/rod) and the optical components (lenses, mirrors, and displays) of certain lasers classified under this code (Kim & Jariwala, 2021).

Table A.2. HS codes of REE-related products and REE application thereof, cont.

902213	Apparatus based on the use of x-rays; including radiography or radiotherapy apparatus, for dental uses, excluding computed tomography apparatus	REEs are primarily found in the phosphors of intensifying screens used in older film-based radiography systems, especially in computer tomography scanners, and as contrast agents in magnetic resonance imaging (Wu et al., 2022).
902219	Apparatus based on the use of x-rays, including radiography or radiotherapy apparatus; for other than medical, surgical, dental or veterinary uses	In film-based extraoral radiography (e.g., panoramic and cephalometric), intensifying screens utilize phosphors containing gadolinium and lanthanum (Duwal, 2023).
902221	Apparatus based on the use of alpha, beta, gamma or other ionising radiations, including radiography or radiotherapy apparatus; for medical, surgical, dental or veterinary uses	Certain scintillation detectors used in the equipment that detects gamma radiation can incorporate REEs to convert radiation into detectable light (Xu et al., 2021).
902229	Apparatus based on the use of alpha, beta, gamma or other ionising radiations, including radiography or radiotherapy apparatus; (for other than medical, surgical, dental or veterinary uses)	Certain scintillation detectors used in the equipment that detects gamma radiation can incorporate REEs to convert radiation into detectable light (Xu et al., 2021).
903090	Instruments, apparatus for measuring, checking electrical quantities, not meters of heading no. 9028; parts and accessories, for measuring or detecting alpha, beta, gamma, x-ray, cosmic and other radiations	Components based on REEs are permanent magnets, electronic displays and LEDs, batteries, detectors & sensors, integrated circuits & printed circuit assemblies, and specialized glass & optics (USGS, 2020).

Source: Own elaboration based on various sources as listed in the table

Appendix B

Tables B.1a- B.3b show the results of the calculations of the highest import shares across the REE-related product categories with relatively weaker strategic import dependencies. These tables complement the main results shown in Tables 3-5 above.

Table B.1a. EU-27: the highest import shares coming from a single source for REE-related products, part 1

	HS 841430		HS 841590		HS 850131		HS 850140	
China's global share	*35%*		*35%*		*29%*		*50%*	
Importer	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*
Austria	27%	Germany	---	---	31%	Hungary	47%	Germany
Belgium	19%	Germany	---	---	22%	Germany	47%	Netherlands
Bulgaria	**71%**	**China**	---	---	52%	Hungary	---	---
Croatia	30%	Germany	28%	Australia	29%	Germany	26%	Poland
Cyprus	34%	Netherlands	27%	China	57%	China	78%	France
Czechia	18%	Poland	---	---	20%	Germany	---	---
Denmark	42%	USA	20%	Germany	---	---	23%	Germany
Estonia	17%	China	13%	Thailand	46%	China	41%	Germany
Finland	32%	Germany	19%	Sweden	25%	UK	35%	Germany
France	29%	China	18%	Spain	21%	Germany	32%	Germany
Germany	19%	Portugal	22%	Czechia	32%	Hungary	26%	Tunisia
Greece	26%	Germany	55%	Greece	30%	Germany	33%	France
Hungary	---	---	---	---	22%	Germany	---	---
Ireland	66%	Czechia	19%	Ireland	51%	USA	27%	China
Italy	26%	Germany	18%	China	40%	China	---	---
Latvia	43%	Poland	21%	Belgium	35%	China	---	---
Lithuania	45%	Germany	41%	Poland	36%	Germany	30%	Poland
Luxembourg	41%	Germany	31%	Belgium	31%	Germany	63%	Germany
Malta	51%	Germany	38%	Italy	32%	USA	62%	Italy
Netherlands	24%	Germany	---	---	39%	China	---	---
Poland	31%	China	**51%**	**China**	29%	Germany	---	---
Portugal	35%	Netherlands	32%	Germany	34%	Germany	39%	China
Romania	23%	China	20%	Austria	28%	Germany	44%	China
Slovakia	49%	S. Korea	---	---	21%	Germany	---	---
Slovenia	22%	Czechia	21%	Czechia	**52%**	**China**	**51%**	**China**
Spain	26%	China	21%	Thailand	21%	China	38%	China
Sweden	46%	Germany	13%	Thailand	27%	Slovakia	22%	Italy

Source: Own calculations based on UN Comtrade data for 2024

Table B.1b. EU-27: the highest import shares coming from a single source for REE-related products, part 2

	HS 850300		HS 851240		HS 900190	
China's global share	*30%*		*27%*		*35%*	
Importer	*share*	*source*	*share*	*source*	*share*	*source*
Austria	---	---	33%	Germany	32%	China
Belgium	30%	Netherlands	37%	France	28%	China
Bulgaria	---	---	42%	China	---	---
Croatia	---	---	34%	Italy	24%	Slovenia
Cyprus	42%	China	34%	China	46%	Slovenia
Czechia	---	---	37%	Belgium	29%	Germany
Denmark	37%	Germany	21%	Spain	---	---
Estonia	---	---	30%	Finland	30%	China
Finland	---	---	25%	Spain	28%	China
France	18%	Denmark	19%	Poland	23%	Germany
Germany	22%	China	---	---	22%	USA
Greece	44%	India	47%	China	37%	Germany
Hungary	---	---	---	---	43%	S. Korea
Ireland	89%	USA	57%	Germany	51%	USA
Italy	---	---	---	---	27%	Germany
Latvia	22%	Poland	35%	Poland	---	---
Lithuania	---	---	43%	Finland	---	---
Luxembourg	49%	Germany	23%	Germany	71%	China
Malta	29%	Germany	21%	Germany	43%	USA
Netherlands	---	---	40%	France	45%	Germany
Poland	24%	Germany	34%	China	**54%**	**China**
Portugal	---	---	46%	Morocco	38%	China
Romania	---	---	---	---	---	---
Slovakia	36%	Germany	57%	Serbia	33%	S. Korea
Slovenia	---	---	---	---	33%	Germany
Spain	33%	China	58%	France	20%	Netherlands
Sweden	78%	Germany	45%	Germany	40%	China

Source: Own calculations based on UN Comtrade data for 2024

Table B.2a. Major advanced economies: the highest import shares coming from a single source for REE-related products, part 1

	HS 841430		HS 841590		HS 850131		HS 850140	
China's global share	*35%*		*35%*		*29%*		*50%*	
Importer	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*
Australia	26%	China	68%	Thailand	36%	China	34%	China
Canada	57%	USA	49%	USA	32%	USA	47%	USA
Iceland	38%	Denmark	29%	Sweden	95%	Finland	41%	UK
Israel	30%	China	32%	China	21%	Germany	38%	China
Japan	---	---	**70%**	**China**	---	---	40%	China
New Zealand	27%	Thailand	48%	Thailand	33%	China	26%	China
Norway	19%	Germany	25%	Czechia	22%	Germany	40%	France
S. Korea	**65%**	**China**	---	---	**57%**	**China**	**72%**	**China**
Singapore	---	---	---	---	28%	USA	---	---
Switzerland	36%	Germany	30%	Austria	---	---	39%	Germany
UK	21%	China	23%	Czechia	19%	USA	25%	China
USA	31%	Mexico	55%	Mexico	33%	Mexico	48%	Mexico

Source: Own calculations based on UN Comtrade data for 2024

Table B.2b. Major advanced economies: the highest import shares coming from a single source for REE-related products, part 2

	HS 850300		HS 851240		HS 900190	
China's global share	*30%*		*27%*		*35%*	
Importer	*share*	*source*	*share*	*source*	*share*	*source*
Australia	**58%**	**China**	60%	Australia	30%	USA
Canada	---	---	47%	Mexico	52%	USA
Iceland	38%	Finland	19%	Germany	29%	Denmark
Israel	21%	Germany	**66%**	**China**	24%	China
Japan	---	---	43%	Indonesia	---	---
New Zealand	64%	USA	38%	China	27%	Australia
Norway	17%	Austria	33%	UK	44%	UK
S. Korea	**54%**	**China**	---	---	---	---
Singapore	28%	USA	17%	UK	---	---
Switzerland	---	---	---	---	---	---
UK	18%	USA	28%	France	30%	USA
USA	21%	Japan	51%	Mexico	---	---

Source: Own calculations based on UN Comtrade data for 2024

Table B.3a. Major developing economies: the highest import shares coming from a single source for REE-related products, part 1

	HS 841430		HS 841590		HS 850131		HS 850140	
China's global share	*35%*		*35%*		*29%*		*50%*	
Importer	*share*	*source*	*share*	*source*	*share*	*source*	*share*	*source*
Argentina	47%	China	**79%**	**China**	17%	China	**83%**	**China**
Brazil	**70%**	**China**	**73%**	**China**	32%	China	**90%**	**China**
India	**76%**	**China**	38%	Thailand	**56%**	**China**	**91%**	**China**
Indonesia	**62%**	**China**	**64%**	**China**	30%	China	**94%**	**China**
Mexico	41%	USA	---	---	27%	China	---	---
Saudi Arabia	n.a	n.a.	**50%**	**China**	34%	China	44%	China
South Africa	**51%**	**China**	---	---	26%	Germany	**77%**	**China**
Thailand	**84%**	**China**	---	---	**56%**	**China**	**78%**	**China**
Türkiye	**57%**	**China**	---	---	36%	China	**71%**	**China**

Source: Own calculations based on UN Comtrade data for 2024

Table B.3b. Major developing economies: the highest import shares coming from a single source for REE-related products, part 2

	HS 850300		HS 851240		HS 900190	
China's global share	*30%*		*27%*		*35%*	
Importer	*share*	*source*	*share*	*source*	*share*	*source*
Argentina	41%	China	70%	Brazil	48%	China
Brazil	40%	China	---	---	**51%**	**China**
India	---	---	38%	China	46%	Russia
Indonesia	**57%**	**China**	---	---	42%	Japan
Mexico	---	---	---	---	**62%**	**China**
Russia	---	---	---	---	**67%**	**China**
Saudi Arabia	**50%**	**China**	33%	China	**56%**	**China**
South Africa	27%	Brazil	---	---	---	---
Thailand	43%	China	---	---	49%	Japan
Türkiye	---	---	34%	Poland	**81%**	**China**

Source: Own calculations based on UN Comtrade data for 2024

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