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Critical Minerals in Türkiye: Challenges and Preparedness

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Abstract

Critical minerals have become central to energy transition, advanced manufacturing, and national security, increasing global attention on supply-chain preparedness. Many countries regularly define and update lists of critical and strategic minerals based on economic priorities and defense requirements. In this context, Türkiye occupies a distinctive position due to its diverse portfolio of critical and strategic minerals and its growing policy focus on supply security. This article evaluates Türkiye's preparedness from a value-chain perspective, focusing on resource diversity, processing and refining capacity, recycling potential, and institutional coordination. Rare earth elements are used as a reference case to illustrate structural challenges that are common across critical mineral value chains, particularly constraints at midstream stages. The analysis shows that Türkiye's preparedness is limited not by the availability of mineral resources, but by insufficient processing, refining, and integration of secondary resources. Türkiye's experience demonstrates that preparedness depends on the ability to convert resources into reliable and value-added supply rather than on geological endowment alone. The findings highlight the importance of value-chain-oriented strategies and offer practical insights for both resource-rich and resource-constrained economies seeking more resilient critical mineral supply chains.

Keywords: *Critical Minerals, Energy Transition, Policy Framework, Supply Chain Preparedness Türkiye, Value-Chain Strategy*

1. Introduction

Critical minerals are no longer a niche topic in mining policy. They have become central to industrial competitiveness, national security, and the global energy transition. The rapid expansion of clean energy systems, electric vehicles, grid-scale storage, and digital infrastructure is driving demand for a wide range of minerals and metals, often faster than supply chains can adapt. As a result, criticality is shaped not only by the presence of natural resources, but also by supply concentration, processing and refining constraints, limited substitution options, and exposure to geopolitical disruptions. Increasingly, value creation in mineral supply chains occurs in midstream and downstream stages, such as beneficiation, separation, refining, and product qualification, rather than at the mining stage alone.

Globally, countries are developing new policy models based on critical and strategic mineral concepts in response to supply–demand risks, sustainability requirements, economic pressures, and the transition toward greener production systems. Many materials that are essential for manufacturing have low

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substitutability and are largely imported, making them priority raw materials from both economic and security perspectives. These materials are increasingly assessed through a supply-risk lens, where those with higher risk are classified as critical, and those whose disruption could threaten economic or defense security are defined as strategic[1].

For Türkiye, critical minerals represent both an opportunity and a challenge. The country has meaningful geological potential across several mineral groups linked to strategic technologies and is located close to major manufacturing markets and logistics corridors. At the same time, national assessments indicate that the main weakness is usually not the lack of resources, but the difficulty of transforming them into secure, high-value, and environmentally responsible supply. Addressing this gap requires stronger processing and metallurgical capacity, predictable permitting and environmental frameworks, and improved data systems to support investment decisions and regular updates of criticality assessments.

This article uses Türkiye as a case study to explore practical ways to improve preparedness in critical minerals. Rare Earth Elements (REEs) are used as a reference example because they combine high strategic relevance with demanding processing requirements, including multi-stage separation and refining. However, the analysis extends beyond a single mineral group. Türkiye's preparedness is examined across a broader portfolio that includes boron, copper, chromite, titanium-bearing systems, graphite, antimony, battery-related metals, and secondary resources such as industrial by-products, process residues, mining wastes, and end-of-life products.

Preparedness, as used in this study, refers to a country's practical ability to manage supply risks while retaining a greater share of value domestically. It rests on four interrelated elements: reliable and regularly updated resource data; strengthened processing and metallurgical capacity, particularly at midstream stages where global bottlenecks are common; expanded recycling and recovery from secondary sources to reduce import dependence and environmental impacts; and coherent policies that align incentives, permitting, standards, financing, and cooperation between government, industry, and academia.

The rest of paper clarifies the distinction between critical and strategic minerals in a Türkiye-specific context, maps the country's main critical mineral domains and value-chain gaps, and identifies areas where concrete actions can most effectively improve preparedness. It then presents policy and industry recommendations and draws lessons that may also be relevant for other countries, including those with limited domestic resources but strong technological, trading, or logistics capabilities.

2. Conceptual Framework: Critical vs. Strategic Minerals

The terms critical and strategic minerals are often used interchangeably, although they refer to related but distinct policy concerns. Clarifying this distinction is important for setting priorities and designing mineral and supply-security strategies. In general, critical minerals are defined by the combination of high economic importance and high supply risk. Supply risk may result from geological scarcity, concentration of production, limited processing and refining capacity, export restrictions, price volatility, or low substitutability in key applications. Supply disruptions can therefore lead to significant economic and industrial impacts, particularly in clean energy technologies, advanced manufacturing, and digital infrastructure[2].

Strategic minerals are more directly associated with national security and long-term geopolitical considerations. A strategic mineral does not necessarily have a large market size, but its absence can create serious vulnerabilities in defense systems, energy infrastructure, or critical industrial applications. Strategic importance is therefore determined not only by market value, but also by functional necessity and risk exposure[3]. Approaches to these categories vary across countries. Resource-poor but technology-intensive economies tend to frame criticality in terms of import dependence and supply diversification, whereas resource-rich countries more often treat

Table 1. Critical strategic minerals list of Türkiye[2]

High-priority critical minerals	Lithium, Silver, **Titanium, Iron, Manganese, Zinc,** Copper, **Aluminum**
Important critical minerals	**Nickel,** REE, Coal, Palladium, **Cobalt,** Bismuth, Arsenic, **Molybdenum,** Gallium, Lead, Cadmium, Indium, Germanium, **Niobium,** Tin, Mercury, Antimony, Barite, Graphite
Potentially Critical Minerals	Beryllium, Fluorite, **Chromium,** Boron, Platinum, Magnesite, Feldspar, Kaolin, Trona, Bentonite

minerals as strategic assets and emphasize domestic production and value-chain upgrading.

In Türkiye, recent policy efforts have introduced a clearer and more data-driven differentiation between critical and strategic minerals. National assessments apply multi-parameter approaches that consider supply risk, demand trends, price volatility, recycling constraints, and domestic technological relevance. Based on these criteria, minerals are grouped as high-priority critical minerals, important critical minerals, and strategic minerals, with some overlap between the latter two categories[2]. As a result of a study conducted by the Ministry of Energy and Natural Resources, a list of critical and strategic minerals in Türkiye was prepared and published in 2025 (Table 1). Of the 37 minerals grouped in this report, the 10 minerals marked in bold in the table are considered both critical and strategic.

An important outcome of these assessments is that criticality is not a fixed condition. Changes in technology, markets, substitution options, production geography, and geopolitical conditions can alter the status of a mineral over relatively short periods. For this reason, mineral lists should be treated as dynamic policy tools that require regular review and updating. Geological resource availability alone does not create strategic strength. Value and supply security increase progressively with beneficiation, processing, refining, and downstream manufacturing capacity. Minerals that are exported mainly as raw ore or low-grade concentrates provide limited economic benefit and little protection against supply risk, even when reserves are large. This is particularly relevant for minerals that require complex separation or chemical processing, where technological capability represents the main bottleneck. The growing role of secondary resources and recycling further reshapes criticality, as many critical and strategic metals are produced as by-products or recovered from industrial residues, mine wastes, and end-of-life products. In this context, recycling constraints represent both a supply risk and a strategic opportunity[3].

From a preparedness perspective, the critical–strategic distinction must therefore be considered within a value-chain-oriented approach. Preparedness should not be assessed only on the basis of resource endowment, but on a country's ability to process, refine, and reliably supply materials to industry. For Türkiye, this implies shifting attention from individual minerals toward the structural and technological capabilities that convert critical and strategic minerals into value-added economic and strategic assets.

3. Türkiye's Critical Minerals Portfolio

3.1 Rare Earth Elements as a Reference Case

REEs play a key role in clean energy technologies, digital infrastructure, medical, and defense applications. Permanent magnets for wind turbines and electric vehicles, advanced electronics, and military systems depend on elements such as neodymium, praseodymium, dysprosium, samarium, and terbium. Limited substitution options and the strong concentration of processing and refining capacities in certain countries have therefore made REEs a major global supply-security concern.

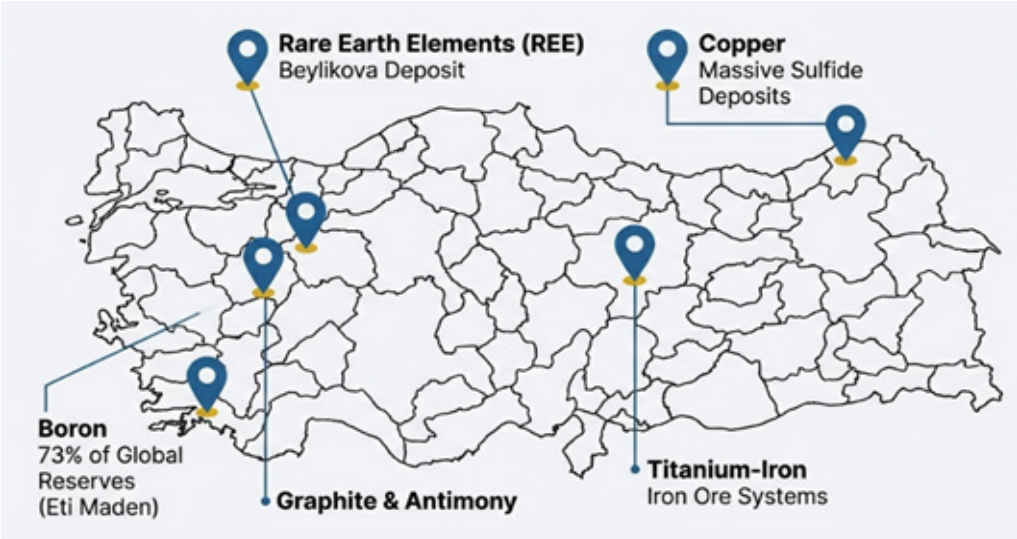


Figure 1. Major critical and strategic mineral occurrences in Türkiye.

In this study, REEs are used as a reference case rather than the main focus of Türkiye's critical minerals strategy. They provide a useful example because they reflect challenges common to many critical and strategic minerals, including complex mineralogy, demanding separation processes, midstream concentration, and sensitivity to geopolitical risks. Lessons from the REE value chain are therefore relevant for other mineral groups, such as battery metals, specialty alloys, and strategic by-product metals. Figure 1 presents the geographic distribution of major critical and strategic mineral resources in Türkiye, highlighting the spatial diversity of the country's mineral endowment.

Türkiye has notable REE potential, with the Eskişehir–Beylikova deposit representing the most significant and best-documented primary resource[4]. National exploration and resource assessment studies indicate that Beylikova hosts approximately 694 million tonnes of total estimated resource, dominated by light REEs, mainly La, Ce, Nd, and Pr. These elements are directly linked to permanent magnet production and clean energy technologies, reinforcing the strategic relevance of the deposit. However, international experience shows that resource size alone does not create strategic advantage in the REE sector. Most value is generated during beneficiation, chemical separation, and downstream manufacturing, rather than at the mining stage. These stages are highly concentrated globally, creating structural vulnerabilities that also shape Türkiye's REE challenge.

Beyond Beylikova, several additional REE-bearing settings have been identified across Türkiye. The Malatya–Kuluncak region is one of the most studied examples, associated with alkaline–magmatic systems. Geochemical data indicate Total Rare Earth Oxide (TREO) contents of about 3,000–4,000 g/t, with a dominance of light REEs and a notable contribution from yttrium. Mineralogical studies show that REEs are hosted in multiple mineral phases, including fluorocarbonates and phosphate-bearing minerals, which implies more complex processing behavior than single-mineral systems[5].

Other REE indications in regions such as Isparta, Sivas, and parts of Central Anatolia are generally smaller or lower-grade. While they are not stand-alone candidates for large-scale primary production, they add to Türkiye's overall resource diversity. They may gain relevance through targeted exploration or as by-product resources. Taken together, available evidence suggests that Türkiye's REE potential should be considered as a portfolio of resources rather than a single flagship deposit. Beylikova remains the core primary asset, while Malatya–Kuluncak and secondary sources play complementary roles. This diversity

strengthens the case for flexible and integrated processing strategies, providing insights that are also applicable to other critical and strategic minerals in Türkiye.

Secondary sources are also gaining importance in Türkiye's REE base. Coal preparation wastes, coal combustion residues, and selected industrial by-products contain REEs concentrated in fine-grained mineral phases. Experimental studies indicate that, under optimized beneficiation and hydrometallurgical conditions, some waste streams can achieve REE recovery efficiencies of up to 80–90%. Although grades are lower than in primary deposits, the large volumes and continuous generation of these materials make them a stable and strategically relevant complement to primary supply[3,6,7].

Recent experimental work on coal combustion residues from Türkiye has demonstrated that REE recoveries approaching 85–87% can be achieved under optimized sequential alkaline and acid leaching conditions. In that study, alkaline pretreatment was carried out using 5 mol/L NaOH at 90°C for 4 h with a liquid-to-solid ratio of 8:1, followed by hydrochloric acid leaching using 4–5 mol/L HCl at 90°C for 3 h and a liquid-to-solid ratio of 10:1. The highest recoveries were obtained for the fine fraction (−0.106 mm), while the − 0.3 mm fraction provided a more practical balance between recovery, grinding requirements, acid consumption, and process selectivity. These findings indicate that sequential alkaline–acid leaching is a promising approach for recovering REEs from coal combustion residues, although the optimum operating conditions remain strongly dependent on the mineralogical characteristics of each secondary resource[8].

3.2 Other Key Critical and Strategic Minerals in Türkiye

While rare earth elements provide a useful reference case, Türkiye's critical minerals agenda extends well

Table 2. Türkiye's critical and strategic minerals: resource–processing gap overview

Mineral	Resource Base	Annual Production	Processing Capacity	Import Dependence	Strategic Bottleneck	Preparedness Priority
REEs	High (Beylikova ~694 Mt)	Limited	Very limited separation	High	Chemical separation capability	Very High
Boron	~73% of global reserves	>2.5 Mt boron products	Developed (Eti Maden)	Low	Advanced materials and Li co-recovery	High
Copper	High (massive sulfide deposits)	~550 kt concentrate	Limited smelting (~70 kt refined)	High (refined Cu imports)	Smelting and refining capacity	Very High
Chromite	~200 Mt resources	8–9 Mt ROM	250–300 kt FeCr	Medium	Ferrochrome gap	High
Manganese	10–15 Mt resources	150–200 kt ore	Very limited alloy production	High	Ferromanganese/ silicomanganese	High
Graphite	30–40 Mt resources	Limited	Very limited battery-grade processing	High	Purification and spheroidization	Very High
Antimony	50–60 kt Sb content	Irregular	Limited smelting	High	Smelting and refining	High

beyond REEs. The country hosts a diverse portfolio of minerals that are essential for energy transition technologies, advanced manufacturing, defense applications, and industrial competitiveness. In most cases, the main challenge is not the absence of geological resources but the limited development of value-added processing, refining, and integrated supply chains.

In this regard, as seen in Table 2, boron represents Türkiye's most strategically dominant mineral, and Türkiye holds approximately 73% of the world's known boron reserves and accounts for nearly 45–50% of global B_2O_3 production, placing the country in a leading global position. Annual boron production exceeds 2.5 million tons, and refined boron chemicals form the basis of both domestic use and exports. Through Eti Maden, Türkiye produces a wide range of refined products, including borax, boric acid, sodium perborate, colemanite-based concentrates, and specialty borates used in glass, ceramics, detergents, agriculture, insulation materials, and metallurgy. National policy assessments emphasize that Türkiye's future advantage in boron depends less on raw material control and more on downstream upgrading and advanced material applications. Priority areas include boron-based ceramics, high-performance composites, magnet-related applications, neutron-absorbing materials for nuclear use, and defense-related products. An additional emerging area is lithium recovery from boron production residues and associated brines, particularly in the Kırka and Bigadiç systems. Pilot-scale studies indicate that lithium recovery from these streams could support annual Lithium Carbonate Equivalent (LCE) production of several thousand tons, linking Türkiye's boron base with battery supply chains.

A generalized process concept for lithium recovery from boron production residues is presented in Figure 2, illustrating the principal processing stages, including residue conditioning, leaching, solution purification, lithium precipitation, and lithium carbonate production. The diagram is intended as a conceptual framework rather than a plant-specific process flowsheet for the Kırka or Bigadiç operations. Despite its strong position in primary and refined boron markets, the main challenge remains technological upgrading toward higher value-added products and better integration of co-product recovery. From a preparedness perspective, boron shows how geological strength can be turned into long-term economic and strategic value when downstream capacity and lithium recovery are treated as core priorities rather than side activities[3,9].

Chromite is another important strategic mineral for Türkiye due to its essential role in stainless steel and specialty alloy production. Türkiye hosts significant chromite resources, estimated at approximately 200 million tons, and is among the world's leading chromite exporters, accounting for roughly 15–20% of global chromite ore exports. Annual production is on the order of 8–9 million tons, with a large share exported as raw ore or concentrate. Despite this strong upstream position, Türkiye's chromite value chain remains focused on low-value-added exports. Domestic ferrochrome production capacity, estimated at around 250–300 kt per year, is limited compared to ore output, creating a gap between mining and metallurgical

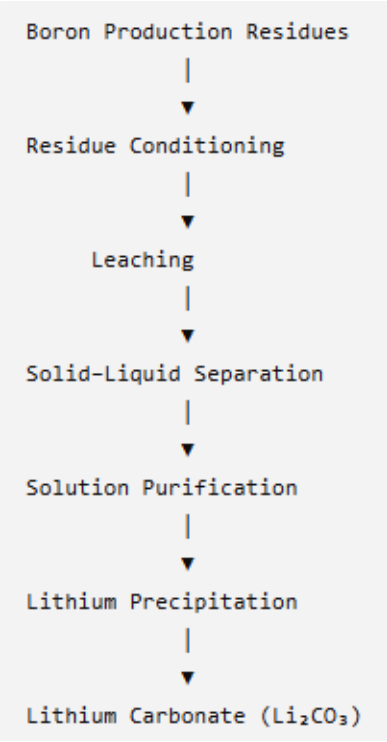


Figure 2. Conceptual block flow diagram for lithium recovery from boron production residues.

processing. As a result, Türkiye remains dependent on imports of ferrochrome and stainless steel, exposing downstream industries to external risks and price fluctuations. Expanding domestic smelting capacity offers a clear opportunity to turn upstream strength into more stable industrial and strategic benefits.

Copper has become one of the most important industrial metals under current energy transition trends. Growth in electric vehicles, renewable energy systems, and grid infrastructure is expected to sustain long-term copper demand. Türkiye hosts considerable copper resources, mainly in massive sulfide–type deposits, where ore characteristics are generally favorable for physical beneficiation. Copper mining in Anatolia has a long history of nearly 7,000 years, while modern production began in 1905 at the Kuvarshan Copper Mine (Artvin). Today, Türkiye produces about 550,000 tons of copper concentrate per year, corresponding to roughly 110,000 tons of contained copper. Around 350,000 tons of concentrate are processed at the Samsun smelter, which has a capacity of about 70,000 tons of refined copper, while the remaining 200,000 tons are exported due to limited domestic smelting capacity. With new deposits coming into production, concentrate output could rise to around 1 million tons per year[9]. Processing this material domestically would reduce dependence on refined copper imports and would strengthen Türkiye's supply security. The gap between mining output and smelting–refining capacity therefore remains a key weakness in Türkiye's copper value chain[3].

The current imbalance between copper concentrate production and domestic smelting capacity also has important economic implications. Publicly available industry data indicate that the construction of a modern copper smelter with an annual capacity of approximately 300,000–500,000 tons of concentrate would require a capital investment on the order of US$1–2 billion, depending on the selected technology, environmental control systems, and associated refining infrastructure. Although such an investment is substantial, expanding domestic smelting capacity would enable a larger proportion of Türkiye's copper concentrates to be processed locally, thereby reducing refined copper imports, increasing value addition, creating skilled employment, and improving supply security. Beyond direct economic returns, additional smelting capacity would strengthen downstream industries such as electrical equipment, renewable energy technologies, and defense manufacturing, making copper processing a strategic component of Türkiye's critical minerals policy. Such investment should therefore be evaluated not only on financial grounds but also from the perspective of national supply security and long-term industrial competitiveness.

Manganese is a strategic mineral for Türkiye because of its role in steel production, specialty alloys, and battery technologies, as well as the concentration of global supply. Türkiye hosts manganese deposits in regions such as Denizli, Muğla, Adana, Kahramanmaraş, and Balıkesir, with total resources estimated at 10–15 million tons. While these deposits are generally of moderate grade and limited scale compared to major global producers, they represent a meaningful domestic resource base for selected industrial applications. Annual production remains limited, at about 150,000–200,000 tons, and is mainly used in low value-added applications. Türkiye therefore depends on imports of ferromanganese and silicomanganese, which are critical inputs for the steel industry. This gap between domestic ore production and alloy manufacturing mirrors challenges observed in other critical mineral value chains. The main opportunity lies in developing domestic alloy production capacity rather than expanding ore extraction. Investment in ferromanganese and silicomanganese smelting would allow Türkiye to reduce import dependence, improve supply security for the steel sector, and capture higher value domestically. As emphasized in national policy assessments, manganese illustrates how even moderate resource endowments can generate strategic value when supported by metallurgical upgrading and value-chain integration[9].

Titanium and vanadium illustrate the importance of multi-product and by-product–based mineral systems. These metals are required for aerospace, defense, energy storage, and advanced alloys. In Türkiye, titanium- and vanadium-bearing formations associated with iron ore systems occur in regions such as Kırıkkale, Sivas, and Kayseri, with combined resources estimated at 30–50

million tons of ore. Despite this potential, Türkiye has no significant domestic production of titanium or vanadium metals. Integrated processing approaches that recover these elements as co-products from iron ore or steelmaking streams could reduce import dependence and improve supply security[9].

Graphite has gained critical status because of its use in lithium-ion battery anodes and energy storage systems. Global processing capacity is highly concentrated, increasing supply risks. Türkiye hosts natural graphite occurrences mainly in Kütahya, Aydın, and Muğla, with total resources estimated at 30–40 million tons. Current production is limited and focused on low value-added uses, leaving Türkiye dependent on imports of battery-grade graphite and anode materials. The main opportunity lies in upgrading natural graphite through purification and shaping processes to enable domestic production of battery-grade material[9].

Antimony is a strategic mineral with high supply concentration and strong relevance for defense and safety applications, including flame retardants and ammunition. Türkiye hosts antimony deposits in regions such as Kütahya, Balıkesir, and Niğde, with estimated resources of 50–60 thousand tons of Sb content. Production is limited and irregular, and Türkiye depends on imports of antimony metal and trioxide. From a preparedness perspective, the key priority is not expanding ore extraction, but establishing domestic antimony smelting and refining capacity. Even modest metallurgical upgrading would significantly improve supply security in this strategically sensitive mineral group[9].

Finally, battery metals such as lithium, cobalt, and nickel are becoming increasingly important in Türkiye's critical minerals portfolio due to their role in electric vehicles and energy storage. These metals are mainly obtained as by-products rather than from dedicated deposits. Lithium potential is linked to boron production residues and brines, particularly in the Kırka and Bigadiç areas, where studies indicate the potential for producing several thousand tons per year of LCE. Cobalt and nickel are mainly recovered from copper and lateritic nickel operations, and Türkiye remains dependent on imports of refined cobalt and nickel chemicals. Experience with cobalt recovery from copper-related processes shows how by-product recovery can reduce import dependence and strengthen supply-chain resilience. Secondary sources and recycling therefore play an important role in supporting battery metal supply[3,9].

Taken together, these examples show that Türkiye's critical and strategic minerals portfolio is defined by diversity rather than reliance on a single commodity. The common challenge across these minerals is the need to move beyond extraction toward processing, refining, and integrated value-chain development. Addressing this challenge is central to improving Türkiye's preparedness and supports the policy and technological recommendations discussed in later sections.

4. Processing, Refining and Recycling: The Real Bottleneck

Across most critical and strategic mineral value chains, the main source of vulnerability for Türkiye is not geological availability, but processing, refining, and recycling capacity. Mining alone rarely guarantees supply security. This is especially true for minerals that require complex beneficiation, chemical separation, or metallurgical upgrading, including REEs, battery metals, and specialty alloys. As conceptually illustrated in Figure 3, the principal bottleneck lies not in resource availability but in the limited conversion of domestically produced mineral concentrates into refined chemicals and high-value materials. This structural imbalance, where abundant mineral resources contrast with limited chemical separation, refining, and downstream manufacturing capacity, increases dependence on imported intermediate and refined products. In Türkiye, this bottleneck appears as a persistent gap between resource endowment and midstream capability. Although the country hosts a wide range of critical mineral resources and has strong experience in mining and mineral processing, downstream stages such as chemical refining, high-purity metal production, and advanced material manufacturing remain limited. As a result, Türkiye continues to rely on imports for refined products and

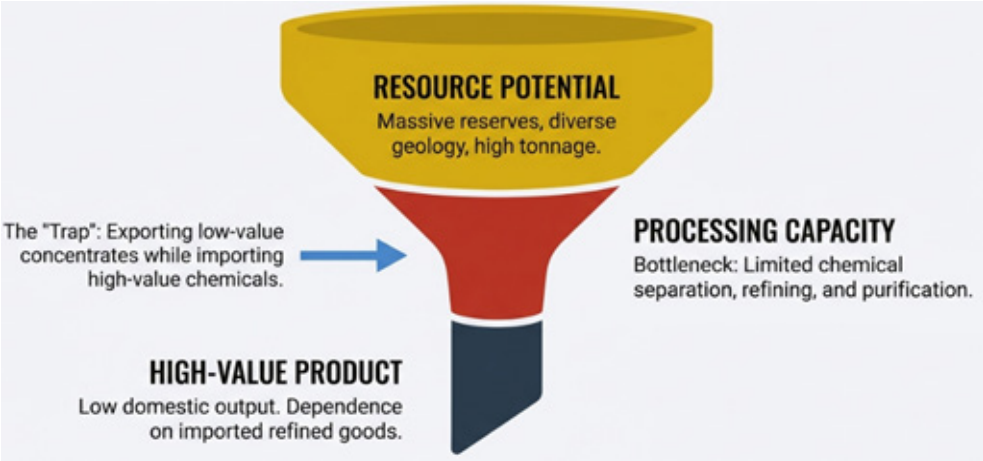


Figure 2. Conceptual illustration of Türkiye's critical mineral value-chain bottleneck, highlighting the mismatch between domestic resource availability and limited processing, refining, and downstream manufacturing capacity.

intermediate materials essential for energy, defense, and high-technology industries[3].

The challenge is not uniform across all minerals. For some commodities, physical beneficiation is relatively well developed, while chemical processing and separation remain weak. REEs illustrate this situation clearly: beneficiation can concentrate REE-bearing phases, but the main barrier lies in multi-stage chemical separation and purification. Similar constraints apply to battery metals, where refining and active material production account for most value creation and supply security.

The development of an economically viable processing route for Türkiye's REE deposits will require systematic laboratory- and pilot-scale investigations. Owing to the occurrence of REEs in multiple mineral phases, particularly in deposits such as Eskişehir-Beylikova and Malatya–Kuluncak, conventional physical beneficiation alone is unlikely to produce marketable products. Instead, detailed mineralogical characterization should first identify the distribution and association of REE-bearing minerals, followed by process development studies involving beneficiation, selective leaching, purification, and separation. At present, however, no comprehensive hydrometallurgical flowsheet or pilot-scale processing data have been reported in the open literature for these deposits. Consequently, the establishment of an optimized processing route remains one of the major technological challenges for future REE development in Türkiye. Developing such processing routes should therefore be considered a research priority for both academia and industry in Türkiye.

Recycling and secondary resources are becoming increasingly important components of processing capacity. Many critical metals are produced as by-products or recovered from industrial residues, mine wastes, and end-of-life products. In Türkiye, coal wastes, metallurgical slags, and electronic wastes remain underutilized feedstocks that could complement primary resources. Studies indicate that, under optimized processing conditions, secondary materials can yield meaningful recoveries of REEs, cobalt, and other strategic metals, while also reducing environmental impacts[3,10].

From a preparedness perspective, recycling provides both risk reduction and strategic flexibility. Unlike mining projects, secondary resources are generated continuously and domestically, reducing exposure to external supply disruptions. However, realizing this potential requires reliable access to secondary resources, investment in separation technologies, regulatory clarity, and integration with existing industrial infrastructure. Another critical

issue is technology ownership and learning. Processing and refining technologies are not easily transferred and require pilot-scale testing and operational experience. Countries that lack pilot and demonstration facilities face difficulties in scaling laboratory results to industrial production, as is currently the case for Türkiye.

Türkiye's strategic challenge is therefore not simply to expand mining output, but to build integrated midstream capacity that links resources to industrial demand. Overcoming this bottleneck will be decisive in transforming Türkiye's diverse critical mineral portfolio into more resilient and strategically valuable supply chains.

5. Preparedness Assessment: Where Does Türkiye Stand?

Preparedness in critical mineral supply chains goes beyond resource availability and is best understood as a combined capacity across geology, technology, policy, and international positioning. In this context, Türkiye shows a mixed profile: strong in resource diversity and strategic awareness, but constrained by structural gaps in processing, refining, and downstream integration (Table 3). From a geological perspective, Türkiye hosts a wide range of critical and strategic minerals, including REEs, boron, chromite, copper, graphite, antimony, and battery-related metals. This portfolio also includes significant secondary and by-product resources derived from mining, energy, and industrial activities. Such diversity reduces dependence on a single commodity and improves resilience against market or geopolitical shocks[2]. However, geological preparedness alone does not ensure supply security. As demonstrated by the REE case and other critical metals, strategic value depends on the ability to convert resources into usable and specification-compliant products.

Processing and refining remain the most significant weaknesses in Türkiye's preparedness profile. While physical beneficiation capabilities are relatively well developed for several minerals, advanced chemical separation, refining, and high-purity metal production remain limited. This gap leads to continued reliance on imports of refined products and intermediate materials, even where domestic mining capacity exists. The lack of pilot-scale and demonstration facilities further limits technological learning and scale-up, making it difficult to move from laboratory research to industrial application[3].

Türkiye shows increasing awareness of the strategic role of recycling and secondary resources, but implementation remains uneven. Coal wastes,

Table 3. Preparedness dimensions and priority actions in Türkiye

Dimension	Current Status	Main Gap	Priority Action	Implementation Timeline
Resource Base	Strong and diversified	Need for deeper exploration and regular data updates	Systematic resource mapping and periodic criticality review	Short-term (1–3 years)
Processing and Refining	Limited midstream capacity	Insufficient chemical separation and refining facilities	Investment in pilot and industrial-scale processing plants	Short- to Medium-term (2–7 years)
Recycling and Secondary Resources	Emerging but fragmented	Limited industrial-scale recovery	Regulatory clarity and integration into industrial infrastructure	Medium-term (3–7 years)
Policy and Governance	Improving strategic recognition	Fragmented implementation across institutions	Integrated national critical minerals roadmap	Short-term (1–3 years)
International Positioning	Strong geopolitical location	Weak midstream leverage in partnerships	Co-investment in processing and technology transfer	Continuous / Long-term

metallurgical slags, and electronic wastes offer substantial potential for recovering critical metals, yet industrial-scale deployment is still limited. Preparedness in this area depends not only on technology, but also on regulatory clarity, economic incentives, and integration with existing industrial infrastructure. At present, the use of secondary resources remains more a strategic opportunity than a fully established component of supply security.

Recent policy initiatives have strengthened Türkiye's strategic preparedness. The formal recognition of critical and strategic minerals, the adoption of data-driven assessment approaches, and coordinated permitting mechanisms reflect growing institutional attention to mineral supply security as a national priority[2]. Nevertheless, implementation remains fragmented across exploration, mining, processing, recycling, and industrial development. Stronger coordination among ministries, regulatory authorities, academia, and industry is still required to translate strategic intent into operational outcomes.

Türkiye's geopolitical position and diversified foreign relations add another dimension to preparedness. The country maintains links with both resource-rich and technology-intensive economies, enabling flexible partnership models. This positioning allows Türkiye to act as a supplier, processor, or transit hub within regional and global critical mineral value chains. However, international positioning alone cannot offset weak midstream capacity. Without reliable processing and refining capability, supply-chain vulnerabilities will continue.

Taken together, Türkiye's preparedness can be described as moderate to high in potential, but limited in execution. Resource diversity, strategic awareness, and recent policy momentum provide a solid foundation. The main challenge lies in converting this foundation into resilient supply chains through sustained investment in processing, refining, recycling, and technological capability. From a broader perspective, Türkiye's experience reinforces a clear lesson: preparedness is not defined by what lies underground, but by what a country can reliably deliver to industry.

6. Actionable Lessons from Türkiye for the Rest of the World

Türkiye's experience with critical and strategic minerals offers several lessons that are relevant beyond the national context. Located between resource-rich regions and technology-intensive markets, Türkiye illustrates how countries with diverse but unevenly developed mineral portfolios can improve preparedness through integrated approaches rather than focusing on individual commodities.

For countries with limited domestic resources, Türkiye's case highlights the importance of technological capability and system integration. Preparedness can be strengthened through the development of processing technologies, recycling capacity, and capabilities in logistics, trading, and supply-chain management. Strategic partnerships with resource-rich countries are most effective when they extend beyond raw material procurement and include co-investment in processing and refining, allowing risks and benefits to be shared.

Another transferable lesson is the strategic importance of recycling and secondary resources. Coal-related wastes, metallurgical residues, and end-of-life products provide domestically controlled and continuously generated material streams that can partially reduce dependence on primary supply. Treating recycling as a core element of supply strategy, rather than as a secondary environmental measure, supports both supply security and sustainability goals.

Türkiye's evolving policy framework also highlights the need for coordinated and adaptive governance. Critical mineral strategies must respond to changes in technology, markets, and geopolitical conditions. Static lists and fixed classifications can quickly lose relevance in dynamic supply environments. While formal recognition of critical and strategic minerals is an important starting point, lasting impact depends on clear implementation mechanisms and effective coordination among ministries, regulatory authorities, research institutions, and industry.

Finally, Türkiye's experience demonstrates the value of shifting from a mineral-focused perspective

toward value-chain preparedness. The key issue is not which minerals are considered critical at a given time, but whether a country can reliably supply processed materials and components to industry under changing conditions. This perspective supports more resilient strategies that remain applicable as priorities evolve. Türkiye's diverse mineral base, together with increasing awareness of processing and recycling constraints, shows how such an approach can contribute to long-term preparedness.

From an implementation perspective, strengthening Türkiye's critical mineral preparedness can be considered as a phased process. In the short term (1–3 years), priorities should include expanding geological data, supporting laboratory-scale process development, improving recycling infrastructure, and establishing pilot-scale processing facilities. The medium term (3–7 years) should focus on demonstration-scale refining technologies, stronger integration between mining and downstream industries, and commercialization of selected recycling technologies. Over the longer term (beyond 7 years), the objective should be the development of fully integrated value chains linking mining, processing, refining, advanced materials manufacturing, and recycling. The timing and scale of these developments will ultimately depend on market conditions, technological progress, and national industrial priorities.

7. Conclusions

Critical minerals have become central to global economic competitiveness, energy transition, and geopolitical stability. In this context, Türkiye occupies a distinct position, characterized by a diverse portfolio of critical and strategic minerals, increasing policy attention, and growing awareness of supply-chain vulnerabilities.

The main challenge for Türkiye is not the availability of mineral resources, but the gap between resource potential and value-chain integration. Processing, refining, and recycling capabilities, rather than mining alone, determine preparedness and strategic relevance. The REE case illustrates these structural challenges, while the broader critical minerals portfolio highlights the importance of diversity instead of reliance on a single commodity.

Translating mineral potential into supply security and strategic advantage requires a coordinated policy–industry approach. Fragmented, mineral-specific initiatives need to be replaced by an integrated national critical minerals roadmap that links exploration, processing, refining, recycling, and downstream manufacturing. Particular emphasis should be placed on addressing the midstream bottleneck through targeted investment in processing, refining, and pilot-scale facilities, which are essential for technological learning, scale-up, and industrial deployment.

Recycling and secondary resources should be treated as core components of critical mineral strategies rather than supporting activities. Clear regulatory frameworks and appropriate economic incentives are necessary to enable industrial-scale recovery from wastes, residues, and end-of-life products. Effective implementation also depends on coordination between government, industry, and academia. Joint pilot projects, shared facilities, and data exchange can support innovation while lowering investment risk.

Finally, Türkiye can strengthen its preparedness by using its geopolitical position to develop international partnerships focused on co-investment in processing technologies and value-chain integration, while also building domestic expertise in mineral processing and recycling. More broadly, Türkiye's experience underlines a general lesson: preparedness is a system-level capability shaped by technological capacity, institutional coordination, and the integration of primary and secondary resources. Countries that focus mainly on extraction remain vulnerable to external disruptions, regardless of resource endowment.

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Author Contribution

F.B.: Conceptualization, methodology, literature review, data curation, writing—original draft preparation, visualization, writing—review and editing. **A.E.Y.:** Conceptualization, literature review, writing—review and editing, validation. **C.Z.:** Literature review, writing—review and editing, validation. All authors have read and agreed to the published version of the manuscript.