Minerals Engineering 216 (2024) 108889

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Navigating the rare earth elements landscape: Challenges, innovations, and sustainability

Hongli Diao [a,b], Hang Yang [a,b,c], Tan Tan [d,*], Gui Ren [d], Minhua You [d], Longyue Wu [d], Mingxiang Yang [d], Yabin Bai [d], Shibin Xia [a,b,*], Shaoxian Song [a,b], Mildred Quintana [e], Lei Liu [f], Qiang Xue [f]

[a] Hubei Key Laboratory of Mineral Resources Processing and Environment, Wuhan University of Technology, Wuhan 430070, China
[b] School of Resources and Environmental Engineering, Wuhan University of Technology, Wuhan 430070, China
[c] State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China
[d] PowerChina Group Environmental Engineering Co., LtCd., Hangzhou 310000, China
[e] Facultad de Ciencias, Universidad Autonoma de San Luis Potosi, Av. Parque Chapultepec 1570, San Luis Potosi 78210, Mexico
[f] State Key Laboratory of Rock and Soil Mechanics and Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan 430071, China

ARTICLE INFO

Keywords:
Rare earth elements
Sustainable extraction
REE recycling
Global supply chain
Environmental impact

ABSTRACT

This review provides a comprehensive analysis of the rare earth elements (REEs) sector, encompassing their classification, properties, and global distribution, as well as their indispensable role in various high-tech, renewable energy, and defense applications. The significant environmental impact of REE mining and processing, characterized by ecological degradation and health risks, is examined alongside the economic and geopolitical challenges arising from the concentrated supply chain and market volatility. The review emphasizes the ongoing efforts and research initiatives aimed at developing sustainable extraction methods, promoting recycling from electronic waste, and exploring alternative materials. Despite these efforts, the effectiveness and scalability of recycling technologies, as well as the feasibility of substitute materials, remain limited, highlighting the need for further research. The review also delves into the impact of international and national policies on the REE industry, underlining the critical role of regulatory frameworks in shaping sustainable practices. Conclusively, this review not only provides insights into the current state of the REE sector but also identifies key areas for future research and development, crucial for the sustainable management and utilization of these vital resources in various industries.

1. Introduction

The realm of rare earth elements (REEs) has garnered significant attention in recent years, primarily due to their indispensable role in a wide array of high-tech (Dong et al., 2022; Liu et al., 2021; Zhong et al., 2023), renewable energy (Shameem et al., 2023; Zheng et al., 2021), and defense applications (Hao et al., 2023). Characterized by their unique magnetic (Oliveira et al., 2021), catalytic (Trovarelli, 1996), and luminescent properties (Binnemans, 2015), REEs have become pivotal in the advancement of modern technology (Cheisson and Schelter, 2019; Sun et al., 2020). The global distribution of these elements, however, is uneven, with certain nations holding substantial reserves, thus dominating the market (Chen et al., 2021b). Advances in extraction and processing technologies have enabled more efficient utilization of these elements (Hidayah and Abidin, 2017, 2018; Xie et al., 2014), fostering innovations in various sectors. Consequently, the demand for REEs has escalated, aligning with the global push towards sustainable and advanced technological solutions.

The rare earth elements sector, pivotal for a range of high-tech and defense applications, confronts substantial challenges that threaten its sustainability and global supply chain stability (Tukker, 2014). These challenges include significant environmental impacts from mining and processing activities, which frequently lead to ecological degradation and pose health hazards (Zaimes et al., 2015). Market volatility, compounded by a concentrated supply chain, poses additional risks to global economic stability and security. Moreover, the reliance on a limited

* Corresponding authors at: Hubei Key Laboratory of Mineral Resources Processing and Environment, Wuhan University of Technology, Wuhan 430070, China (S. Xia).
E-mail addresses: 308233334@qq.com (T. Tan), xiashibin@126.com (S. Xia).

https://doi.org/10.1016/j.mineng.2024.108889
Received 26 April 2024; Received in revised form 1 July 2024; Accepted 29 July 2024
Available online 6 August 2024
0892-6875/

number of suppliers intensifies geopolitical and supply chain vulnerabilities (Wang et al., 2024), particularly affecting nations dependent on imports for their technological and defense capabilities. Focusing on China, which controls over 70 % of the global rare earth supply, the industry is marred by critical sustainability challenges (Zhao et al., 2024a). Unregulated mining practices have led to severe environmental degradation, including substantial soil and water contamination that causes long-term ecological damage and adversely affects local communities and biodiversity (Ji et al., 2018). These issues are further aggravated by low resource utilization efficiency and minimal value addition, stemming from a lack of innovation in core technologies (He and Yang, 2022). Moreover, China's rare earth sector is hindered by incomplete industrial policies and significant regulatory enforcement challenges, which do not adequately curb illegal mining activities or ensure adherence to environmental standards (Packey and Kingsnorth, 2016).

In response to these challenges, various strategies and research initiatives have been undertaken. Efforts to develop more sustainable and less environmentally damaging extraction methods are underway (Dutta et al., 2016), with a focus on reducing the ecological footprint of mining operations. Recycling of REEs from electronic waste has emerged as a potential solution to address supply chain issues, promoting a circular economy approach (Stratiotou Efstratiadis and Michailidis, 2022; Yuksekdag et al., 2022). However, these initiatives are in nascent stages, and the effectiveness and scalability of recycling technologies remain limited. Moreover, there is a growing need for research into alternative materials that can substitute REEs in certain applications, potentially alleviating the demand pressure (Li et al., 2019; Pan et al., 2016; Riba et al., 2016).

This review aims to provide a comprehensive overview of the current state, challenges, and future outlook of the REE sector. It delves into the classification, properties, and global distribution of REEs, highlighting their critical applications in various industries. The review discusses the economic, political, and environmental aspects of REE mining and processing, including the impact of international and national policies on the industry. Furthermore, it examines the sustainability challenges, technological innovations, and potential solutions to address the issues faced by the REE sector. The significance of this review lies in its holistic analysis, which not only sheds light on the complexities of the REE industry but also identifies areas requiring further research and development, thereby contributing to the sustainable management and utilization of these vital resources.

2. Methodology

For the comprehensive review of REEs, an extensive literature search was undertaken across multiple scientific databases, including Science Direct, Scopus, China National Knowledge Infrastructure (CNKI), and Web of Science. This search strategy was meticulously designed to cover a broad array of keywords and their permutations, ensuring comprehensive coverage of the topic. The primary keyword 'Rare Earth Elements' was systematically integrated with an array of secondary keywords, as detailed in Table 1, which delineates the categorization of these keywords by thematic area.

In this stringent literature review process, a rigorous data filtration strategy was employed to ensure the relevance and quality of selected publications. Emphasis was placed on retaining literature specifically related to the properties, mining and development, economy, policy, applications, and national/international regulations of REEs. This included research focused on the critical examination of REEs in contexts such as "sustainability," "technological innovations," and "supply chain challenges." Conversely, literature solely concentrating on aspects not directly connected to these core areas, such as "unrelated technological applications" or "general geological studies," was systematically excluded. This careful selection process aimed to filter out the most relevant and impactful studies, thereby aligning with the scope and objectives of the research.

Table 1
Categorization of secondary keywords by theme.

Theme	Main secondary keywords
Overview	Classification, properties, distribution, reserves, history
Mining	Mining, purification, process, extraction, environmental impact
Applications	Applications, renewable energy, consumer electronics, defense, aerospace, environmental engineering, environmental engineering, air quality, water treatment, soil remediation, green technologies, construction, manufacturing, regulations
Economics and Geopolitics	Economy, policy, market, international trade
Challenges and Prospects	Sustainability, innovation, recycling, future trends

For an in-depth understanding of the dynamics within REEs sector, this review extends to incorporate the latest data on global production and reserve quantities as disclosed by the United States Geological Survey (USGS, https://www.usgs.gov/). This includes the comprehensive analysis of 2023 production figures and reserve estimates, offering a crucial perspective on the current state and potential future trends of the REE market.

In addition, the investigation was extended to encompass the specific trade data pertaining to rare-earth metals, scandium, and yttrium for the year 2022. Data were meticulously sourced from the Observatory of Economic Complexity (OEC) website, specifically from the dedicated profile on rare-earth metals, scandium, and yttrium (https://oec.world/en/profile/hs/rare-earth-metals-scandium-and-yttrium#latest-data).

3. Overview of rare earth elements

The realm of REEs is essential to numerous modern technologies due to their unique physical and chemical properties. This section provides a comprehensive overview of REEs, detailing their classification, properties, global distribution, reserves, and historical development. Understanding these elements' fundamental characteristics and their intricate role in technological advancements is crucial for appreciating their significance and the challenges associated with their extraction and use. This overview sets the stage for an in-depth exploration of REEs, highlighting the critical need for sustainable management practices and innovative technological solutions to ensure their availability for future applications.

3.1. Classification and properties

In the domain of REEs, classification is primarily based on atomic number and chemical properties. These elements, typically encompassing the lanthanide series from lanthanum (La) to lutetium (Lu), along with scandium (Sc) and yttrium (Y), are distinguished by their similar chemical properties. This similarity arises due to their comparable ionic radii and electronic configurations, particularly the filling of 4f orbitals. As the atomic number increases in the series, a notable contraction in ionic radii, known as lanthanide contraction, is observed. This contraction results in a subtle yet significant variation in chemical reactivity and physical properties across the series. REEs are predominantly trivalent, although a few can exhibit other valence states. This trivalency is a consequence of their electronic structure, where the removal of three outer electrons leads to a stable electronic configuration.

The physical and chemical properties of REEs are pivotal in their application in various technological domains. Table S1 depicts the classification and basic physical and chemical properties of REEs. Their magnetic (Qiao et al., 2024), catalytic (Wang et al., 2022b), and luminescent (Li et al., 2024c) properties are intrinsically tied to their unpaired 4f electrons. For instance, the unpaired electrons contribute to the unique magnetic properties observed in neodymium (Nd) (Sahanashree et al., 2017) and samarium (Sm) (Masunga et al., 2023), making them essential in the production of high-strength permanent magnets. These magnets are integral in modern technologies, from wind turbines (van Nielen et al., 2023) to electric vehicles (Bailey et al., 2021). Similarly, the luminescent properties of europium (Eu) (Deyneko et al., 2023; Zhao et al., 2024c) and terbium (Tb) (Paikaray et al., 2023) are harnessed in the manufacturing of phosphors used in lighting and display technologies. Furthermore, the catalytic properties of cerium (Ce) are exploited in automotive exhaust systems to reduce harmful emissions (Cui et al., 2020; Zhang et al., 2023a).

It is crucial to note the variability in the abundance and geochemical behavior of REEs. Despite their collective nomenclature, the abundance of REEs in the Earth's crust varies significantly. Cerium is the most abundant (Gad, 2024), whereas thulium and lutetium are among the least (Wall, 2021). This variability extends to their geochemical behavior, where certain REEs are more prone to concentration in specific mineral deposits. The extraction and separation of these elements are challenging due to their chemical similarities, necessitating complex and often costly processing techniques (Chen et al., 2022; Owusu-Fordjour and Yang, 2023). The subtle differences in ionic radii (Do-Thanh et al., 2023) and electron configurations (Liu and Chen, 2021; Mosadeghsedghi et al., 2023) play a critical role in these processes, dictating the efficacy of various separation methodologies.

3.2. Global distribution and reserves

The global distribution of REEs is characterized by a heterogeneous dispersion across various geological formations, with concentration levels varying significantly. It is observed that these elements are not typically found in their pure elemental form but are more commonly located within specific minerals such as bastnaesite (Cen et al., 2021a; Cen et al., 2021b; Wang et al., 2017b), monazite (Corbett et al., 2024; Kumari et al., 2015; Shakiba et al., 2023), and xenotime (Chelgani et al., 2015; Roy et al., 2020). The concentration of REEs in these minerals is a critical factor in determining the feasibility of their extraction and subsequent commercial viability. Globally, China holds a predominant position in the REE sector (Lin et al., 2024), not only in terms of reserves but also in processing capabilities (Nkiawete and Vander Wal, 2024). The Bayan Obo mine in Inner Mongolia is one of the world's largest known REE deposits (Hao et al., 2015). Other notable reserves are found in countries such as Australia (Guo and You, 2023), Brazil (de Freitas et al., 2023), India (Patel et al., 2023), and the United States (Dushyantha et al., 2020; Zhao et al., 2024d), with the Mountain Pass mine in California being one of the most significant in the Western Hemisphere.

The extraction of REEs from their ores is a complex and multi-stage process (Brown et al., 2023; Pereira Neves et al., 2022), often involving crushing, milling, and various forms of separation to refine the minerals into usable forms. The distribution of REEs within these ores is typically uneven, with a higher concentration of light rare earth elements (LREEs) such as lanthanum and cerium, compared to heavy rare earth elements (HREEs) like dysprosium and yttrium. This distribution pattern poses significant challenges in the separation and purification processes, as the similarity in chemical properties of LREEs and HREEs necessitates the use of intricate and precise extraction techniques (Battsengel et al., 2018; Dashti et al., 2023). Furthermore, the presence of radioactive elements such as thorium and uranium in some REE ores adds an additional layer of complexity, requiring stringent regulatory compliance and environmental management (Jun et al., 2023; Su et al., 2021).

Fig. 1 presents the global rare earth production and reserves, which underscores the significant disparities in REEs production and reserve quantities among leading countries in 2023. China dominates global

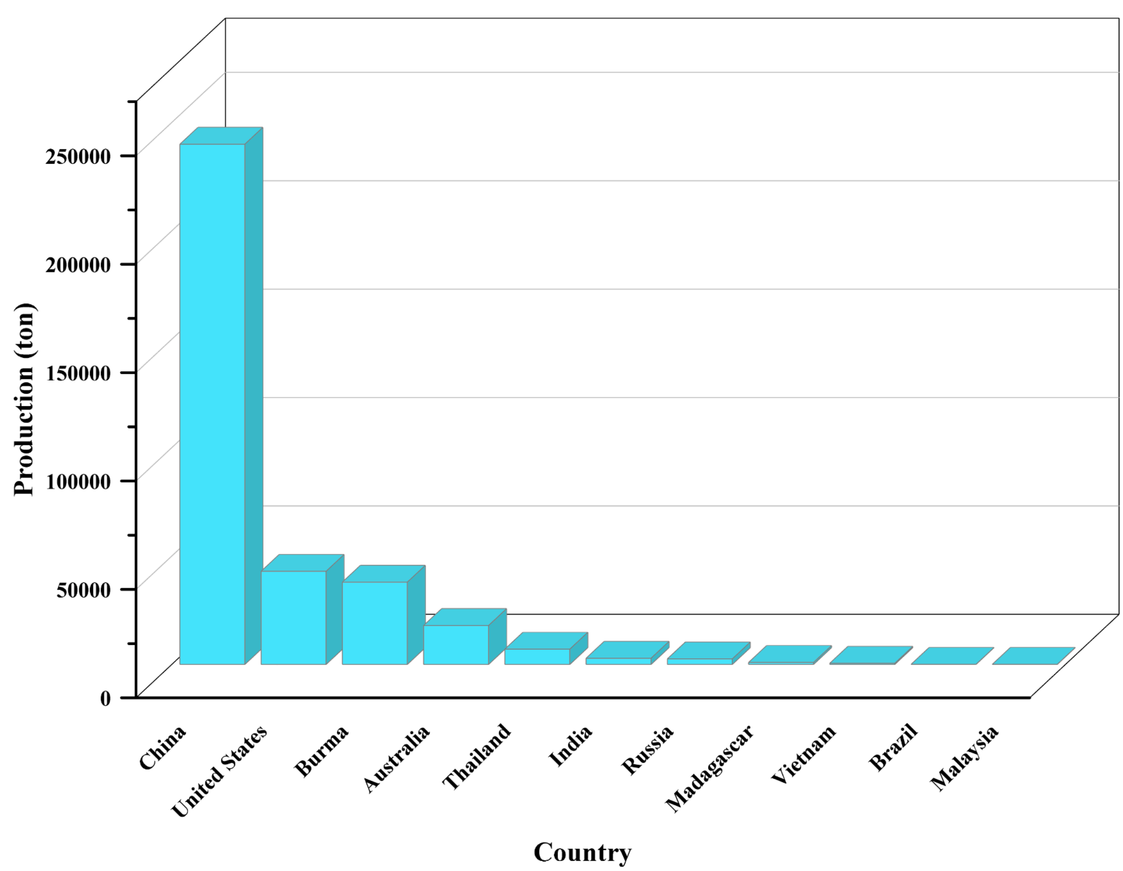

Fig. 1a. Global rare earth production overview in 2023 (U.S. Geological Survey, 2024).

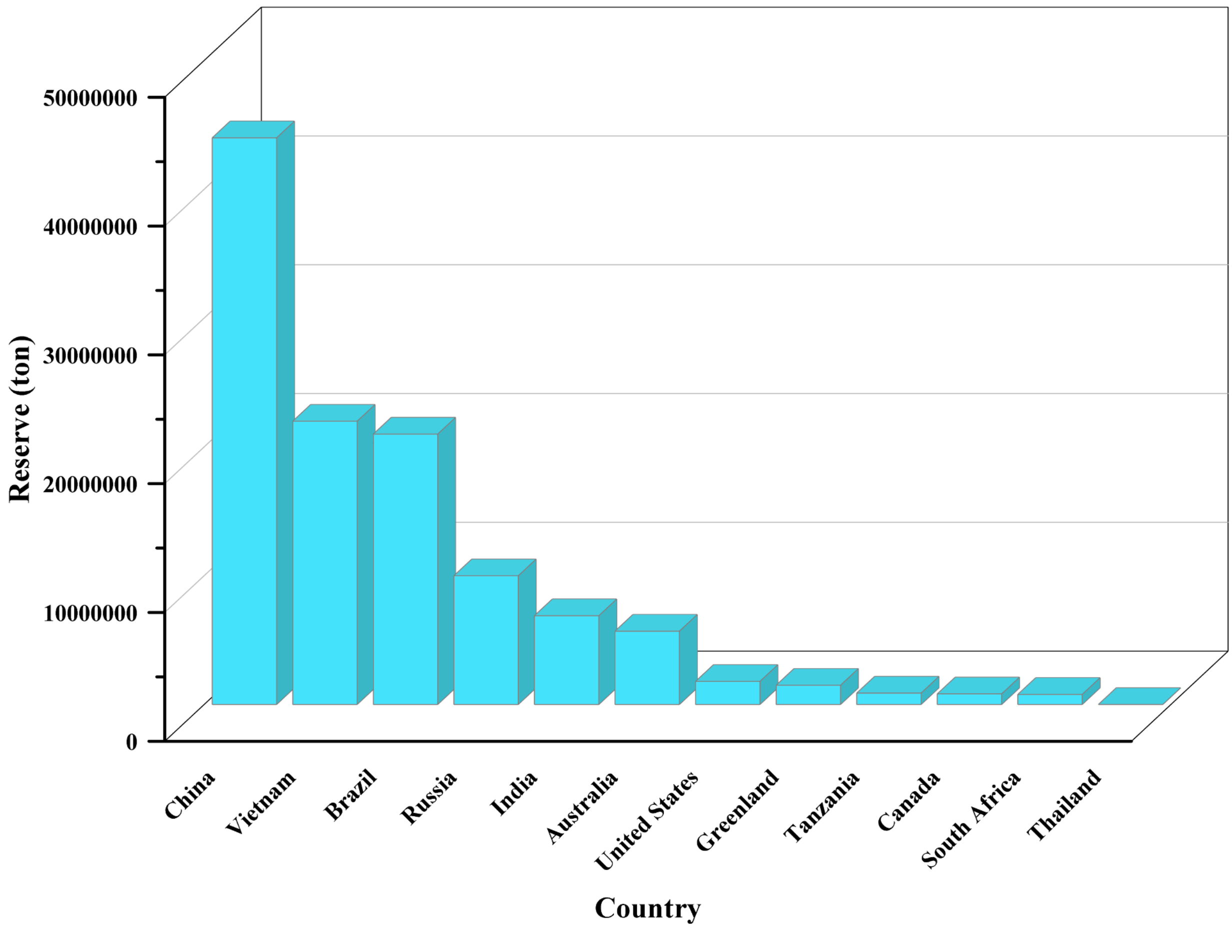

Fig. 1b. Global rare earth reserves overview in 2023 (U.S. Geological Survey, 2024).

production, contributing significantly to the world total, followed by the United States, Burma, and Australia, reflecting geopolitical and economic influences on the REE market. In contrast, reserve data reveal a broader distribution, with China, Vietnam, and Brazil holding substantial shares of global reserves.

According to the report from the Ministry of Industry and Information Technology of the People's Republic of China and the Ministry of Natural Resources (Ministry of Industry and Information Technology of the People's Republic, 2023), the 2023 quotas for rare earth mining and smelting separation in China have been set at 255,000 tons and 243,850 tons, respectively. This data underscores the significant role that China continues to play in the global rare earth industry, not only in terms of reserve holdings but also in processing capabilities.

The estimated reserves of REEs are subject to change based on ongoing exploration activities and technological advancements in extraction methods. Advances in extraction and processing technologies can potentially make previously uneconomical deposits viable, thereby altering the global landscape of REE reserves. It is pertinent to note that the future availability of REEs is not only a matter of geological abundance but also hinges on geopolitical (Chen et al., 2024d; Li et al., 2023c), economic (Charalampides et al., 2015; Pell et al., 2019), and technological factors (Leng et al., 2021).

3.3. Historical perspective

The historical development of REEs has been marked by gradual advancements in both the understanding and utilization of these elements. Table S2 displays the discovery and historical development of REEs. Initially, in the late 18th and early 19th centuries, the discovery of REEs was a byproduct of the quest for new elements and compounds. The first recognized rare earth mineral, ytterbite (later renamed gadolinite), was discovered in 1787 in a quarry near the Swedish village of Ytterby (Khalajmasoumi et al., 2017), a location that later gave its name to yttrium, terbium, erbium, and ytterbium. Over the following century, the identification and isolation of individual REEs proved to be exceptionally challenging due to their similar chemical properties and the lack of sophisticated separation techniques. It was not until the development of ion-exchange methods (Costis et al., 2021) and solvent extraction techniques (Traore et al., 2023) in the 20th century that the separation of REEs became more efficient and commercially viable.

The application of REEs remained limited until the mid-20th century when their unique magnetic, phosphorescent, and catalytic properties began to be harnessed in developing technologies. The discovery of the strong magnetic properties of some REEs, such as neodymium and samarium, led to significant advancements in the design of high-performance magnets used in various applications (Gherardini et al., 2023; Guo et al., 2023), from compact electronic devices (München and Veit, 2017) to wind turbines (Severson et al., 2022; Sherwood et al., 2022) and electric vehicles (Martínez-Hernando et al., 2023). Similarly, the distinctive luminescent properties of europium played a pivotal role in the development of color television technology (Mehare et al., 2023). The 1960 s and 1970 s witnessed a surge in demand for REEs due to their critical role in the burgeoning electronics and telecommunications industries (Blanc et al., 2023).

The geopolitical landscape has also played a significant role in the history of REEs. The latter part of the 20th century saw a shift in REE production from the United States and other countries to China (Klinger, 2015), which possesses substantial reserves and invested heavily in mining and processing infrastructure. This shift has led to China's dominance in the global REE market (Chen et al., 2018), raising concerns about supply security for other nations. As a result, there has been a renewed interest in diversifying the sources of REEs, prompting exploration and development efforts in countries like Australia (Palle Paul Mejame et al., 2022), Canada (Paulick and Machacek, 2017), and the United States (Park et al., 2023). Moreover, the environmental impact of REE mining and processing has become a subject of increasing concern (Aziman et al., 2023; Talan and Huang, 2022a; Wang et al., 2022a), driving research into more sustainable extraction methods and the recycling of these elements from electronic waste (Chen et al., 2023c; Kaim et al., 2023). The historical trajectory of REEs reflects not only the evolution of scientific understanding and technological capability but also the dynamic interplay of economic, environmental, and geopolitical factors.

4. Mining of rare earth elements

The mining of REEs is a critical component of the global supply chain, providing essential materials for a multitude of high-tech and green energy applications. This section examines the intricate processes involved in extracting REEs from their mineral ores, highlighting the advanced technologies and methodologies employed. The environmental and economic implications of REE mining are also explored, emphasizing the need for sustainable practices and regulatory compliance. Through a comprehensive analysis, this section aims to shed light on the challenges and innovations in the REE mining sector, underscoring its significance in modern industry and technology. Fig. 2 outlines the framework for discussing REE extraction and processing.

4.1. Extraction and process techniques

The extraction and process of REEs from their mineral ores involves a series of complex, multistep processes that are essential for obtaining these elements in their usable forms. Table 2 shows the main technologies and methods used in the extraction and process of REEs. Initially, the ore is subjected to physical processes such as crushing and grinding, which are followed by concentration techniques. These concentration techniques typically involve the use of gravity separation, magnetic separation, or froth flotation, methods selected based on the specific mineralogy of the ore. For instance, bastnaesite, one of the more common REE-bearing minerals, is often concentrated through froth flotation (Wang et al., 2023f; Zhou et al., 2023a), a process where the mineral particles are separated from the waste rock based on their hydrophobic properties.

Following concentration, the extracted REE minerals undergo hydrometallurgical processing, a critical step in which the REEs are leached out of the ore (Jha et al., 2016; Kim et al., 2021). This process usually involves the use of acid or alkaline solutions. For example, sulfuric acid is commonly used to leach REEs from bastnaesite (Feng et al., 2013; Yörükoğlu et al., 2003), while an alkaline process using sodium hydroxide is preferred for high grade monazite and xenotime ores (Alves et al., 2021; Demol et al., 2019). The choice of leaching agent and conditions is dependent on the specific REE mineralogy and the associated gangue materials. The leaching process not only solubilizes the REEs but also other impurities, necessitating subsequent purification steps.

The purification of this leach solution is achieved through solvent extraction and ion exchange techniques, which are designed to selectively separate REEs from each other and from other impurities. Solvent extraction involves the transfer of REEs from an aqueous phase into an organic phase using specific extractants (Xie et al., 2014). This step is repeated multiple times in a series of mixer-settler units or extraction columns to enhance the purity and separation of individual REEs (Dewulf et al., 2022; Lu et al., 1992). Ion exchange, on the other hand, employs resin beds to selectively adsorb REEs, which are then eluted using suitable solutions (He et al., 2022; Hermassi et al., 2022). These techniques are critical in obtaining high-purity REEs, which are essential for their subsequent industrial and technological applications (El Ouardi et al., 2023).

Taking ion-adsorbed clays as an example, the extraction methods employed for these deposits in Southern China, such as tank leaching, heap leaching, and in-situ leaching, each present distinct environmental challenges (Chen et al., 2024b). Tank leaching processes the ore in tanks using a dilute sulfuric acid solution to dissolve rare earth elements, offering controlled conditions but requiring significant chemical use which poses contamination risks. Heap leaching, a less costly alternative, involves stacking ore and applying the leaching solution overhead, allowing it to percolate through by gravity, which can lead to potential leachate escape and water source contamination. In-situ leaching, the

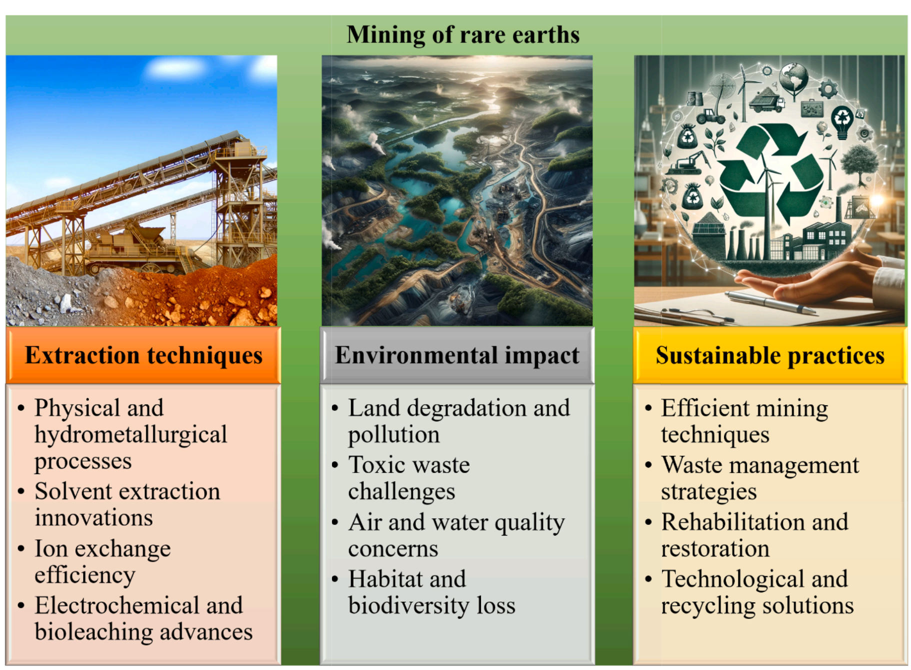

Fig. 2. Conceptual framework of REEs mining exploration.

Table 2
Main technologies and methods for extraction and process of REEs.

Technique	Description	Advantages	Challenges	References
Physical Separation	Involves crushing and grinding of the ore, followed by physical methods like gravity separation, magnetic separation, or froth flotation to concentrate REE minerals.	Simple and cost-effective for initial ore concentration.	Limited to initial concentration; not suitable for final purification.	(Alsabbagh and Mustafa, 2023; Eskanlou et al., 2022; Liu et al., 2023; Yen Chau Nguyen et al., 2021)
Hydrometallurgical Processing	Leaching process where REEs are dissolved from the ore using acid or alkaline solutions, separating them from the gangue material.	Effective for extracting REEs from different mineralogies.	Requires careful handling of chemicals and waste management.	(Ippolito et al., 2017; Tunsu et al., 2015; Wu et al., 2018)
Solvent Extraction	Uses organic solvents to selectively separate REEs from the leach solution. REEs transfer from an aqueous phase to an organic phase, enhancing purity and separation.	Highly efficient for separating individual REEs.	Complex and requires precise control of process conditions.	(Dzulqornain et al., 2024; Han et al., 2023; Hung et al., 2022; Pavón et al., 2022)
Technique	Description	Advantages	Challenges	References
Ion Exchange	Employs resins to adsorb REEs from leachates. REEs are then eluted using suitable solutions, allowing for their selective recovery.	Suitable for selective recovery and purification.	Can be slow and expensive for large-scale operations.	(Bernardo José et al., 2024; Burdzy et al., 2024; Roa et al., 2024; Zhou et al., 2023b)
Bioleaching	Utilizes microorganisms to extract REEs from ore. This method is more environmentally friendly, reducing the use of harmful chemicals.	Environmentally sustainable, with lower ecological impact.	Currently limited in scale and application.	(Cui et al., 2023; Ma et al., 2023a; Rasoulnia et al., 2021; Zhang et al., 2020a; Zhou et al., 2024a)
Electrochemical Processing	Involves the use of electrical currents to extract REEs, offering a potentially cleaner alternative to traditional chemical methods.	Reduces chemical usage, with potential for lower environmental footprint.	Still in developmental stages; not widely implemented	(Brewster et al., 2020; Sciacca et al., 2023; Zhou et al., 2020)

most environmentally invasive method, involves injecting the leaching solution directly into the ore body and extracting the solution enriched with dissolved REEs (Packey and Kingsnorth, 2016). While this method avoids the landscape disruption of traditional mining, it significantly risks groundwater contamination if not carefully managed.

The establishment of new rare earth mines and processing facilities represents a pivotal development within the global rare earth industry. This endeavor, essential for addressing the increasing demand for rare earth elements, entails considerable challenges, notably in terms of environmental compliance, technological feasibility, and economic viability. Initiating such operations requires rigorous environmental impact assessments to mitigate the ecological disruptions commonly associated with mining activities. Furthermore, the technological challenges involve the adaptation of extraction and processing techniques to the specific mineralogy of new deposits, which may differ significantly from those previously exploited. Economically, the substantial initial capital investment and the uncertainty regarding future rare earth prices add layers of complexity to the financial sustainability of new mining projects. These factors collectively necessitate a comprehensive approach, integrating advanced scientific methods and robust regulatory frameworks to ensure that new ventures in the rare earth sector are both sustainable and economically feasible.

4.2. Environmental impact

The environmental impact of REEs extraction and processing is a subject of significant concern, characterized by a range of ecological and human health implications (Dai et al., 2023a; Dai et al., 2023b; Henriques and Böhm, 2022; Migaszewski and Gałuszka, 2015; Tian et al., 2020; Xu et al., 2023c). The mining of REE-bearing minerals typically involves substantial disruption of the land (Chen et al., 2023a; Hengkai et al., 2020; Wang et al., 2017a), leading to deforestation, soil erosion, and habitat destruction. These impacts are particularly pronounced in open-pit mining operations (Yang et al., 2013), which are common for extracting REEs. Furthermore, the generation of large volumes of waste rock and tailings (Azizi et al., 2022), which often contain hazardous substances like heavy metals and radioactive elements (thorium and uranium), poses a critical environmental challenge (Phan et al., 2019). These wastes, if not managed properly, can lead to soil and water contamination, affecting local ecosystems and potentially entering human food chains.

The processing of REEs is equally impactful, notably due to the extensive use of chemicals in the extraction and refining processes. The use of strong acids and alkalis in leaching processes can lead to air and water pollution (Zhang et al., 2020c). For example, acid mine drainage, a common issue associated with sulfide mineral mining (Migaszewski et al., 2019), can lead to the release of toxic metals into nearby water bodies, adversely affecting aquatic life and water quality (Shu et al., 2023). Additionally, the release of airborne particulate matter and gaseous emissions during processing operations contributes to air pollution and poses health risks to workers and nearby communities (Jamaludin and Patunru, 2022; Zhou and Ge, 2021).

In Myanmar's Kachin State, intensive illegal mining operations for heavy REEs have led to significant environmental degradation. This region, controlled by local militias and outside the central government's regulatory reach, witnesses widespread land disruptions due to non-compliant mining practices (FX168, 2021; Irrawaddy, 2021). Techniques such as in-situ leaching, where ammonium sulfate is used to dissolve underground minerals, have resulted in substantial deforestation, soil erosion, and the destruction of habitats. The unregulated use of toxic chemicals in these processes contributes to severe water pollution, impacting aquatic life and contaminating local water sources used by surrounding communities (Naing, 2022). Additionally, the handling of waste materials laden with heavy metals and radioactive elements, primarily thorium and uranium, poses persistent environmental hazards. These activities in Kachin not only disrupt local ecosystems but also threaten human health, emphasizing the critical need for stringent environmental oversight and the implementation of sustainable mining technologies in the region.

Addressing the environmental impacts of REE extraction and processing requires the implementation of stringent regulatory frameworks and the adoption of best practices in environmental management (Ligang and Meijuan, 2020). This includes the development of more sustainable mining practices (Kalisz et al., 2022), such as the implementation of effective waste management strategies to minimize and remediate the environmental footprint (Kotte-Hewa et al., 2023). Moreover, advancements in technology play a crucial role in reducing the environmental impact (Lima and Ottosen, 2021). Innovations in extraction and processing methods aim to increase efficiency and reduce the use of harmful chemicals (Luo et al., 2024a; Zhang et al., 2023b). Additionally, the recycling of REEs from end-of-life products and industrial waste is gaining attention as a means to mitigate the environmental impacts associated with primary extraction (Gómez et al., 2023; Jyothi et al., 2020), offering a potentially less environmentally damaging source of these critical materials. These approaches are essential not only for mitigating the current ecological impacts but also for ensuring the sustainable supply of REEs in the face of growing global demand.

4.3. Sustainable practices

In the context of REEs extraction and processing, sustainable practices are increasingly being recognized as crucial for mitigating the environmental and social impacts associated with these activities. These practices are focused on reducing the ecological footprint of mining operations (Nassani et al., 2021), enhancing resource efficiency, and promoting the health and safety of local communities and ecosystems. One fundamental approach is the adoption of more efficient mining techniques that minimize land disturbance and reduce waste generation (Akinyemi et al., 2021; Kamenopoulos et al., 2016). Techniques such as in-situ leaching, where chemicals are used to dissolve REEs from ore bodies without traditional mining (Wang et al., 2023b; Zhao et al., 2024b), have been explored. Although not universally applicable, this method holds potential for reducing surface impacts and the volume of generated waste.

Another critical aspect of sustainable practices in REE extraction involves the management and disposal of mining waste and tailings (Dushyantha et al., 2022). Efforts are made to develop more effective waste management strategies, including the stabilization of tailings, to prevent leaching of hazardous substances into the environment (Chen et al., 2024a; Wang et al., 2023e). Moreover, the rehabilitation of mining sites post-extraction is essential for restoring ecosystems and preventing long-term environmental damage (Liu et al., 2017). This involves recontouring the land, replacing topsoil, and reintroducing native vegetation (Wang et al., 2023d; Zhang et al., 2020d). Such rehabilitation efforts not only address environmental concerns but also help in maintaining the social license to operate within local communities.

Advancements in extraction and processing technology are also integral to sustainable practices. Research and development efforts are focused on reducing the use of hazardous chemicals in extraction processes, thereby decreasing environmental pollution and health risks (Shin et al., 2023). For example, the development of solvent extraction methods that use more environmentally benign solvents or the optimization of process conditions to enhance efficiency and reduce waste are areas of active research (Quijada-Maldonado and Romero, 2021; Su et al., 2022). Furthermore, the recycling of REEs from electronic waste and other end-of-life products is gaining attention as a sustainable alternative to primary extraction (Patil et al., 2023; Xu et al., 2023b). This not only reduces the environmental impact associated with mining but also addresses the issue of electronic waste management. Overall, the integration of sustainable practices in the extraction and processing of REEs is imperative for balancing the growing demand for these critical elements with the need to protect and preserve the environment and ensure the well-being of communities affected by these operations.

5. Applications of rare earth elements

The applications of REEs span a wide array of industries, underpinning numerous high-tech and environmentally sustainable technologies. Their unique properties make them indispensable in enhancing performance and efficiency across various sectors. This section provides an in-depth exploration of REE applications, from renewable energy and consumer electronics to defense, aerospace, and environmental engineering. By examining these applications, the critical role of REEs in modern technology and industry is underscored, along with the challenges and opportunities presented by their utilization. Fig. 3 illustrates the conceptual framework for the applications of REEs.

5.1. In renewable energy

The incorporation of REEs in renewable energy technologies is a critical area of development, with these elements playing indispensable roles in enhancing the efficiency and functionality of various green energy solutions. In the field of wind energy, REEs such as neodymium and dysprosium are crucial components in the fabrication of high-strength permanent magnets used in wind turbine generators (Imholte et al., 2018; Weng and Mudd, 2023). These magnets are favored for their ability to maintain strong magnetic fields, which is essential for generating electricity efficiently (Fishman and Graedel, 2019; Zhdaneev et al., 2024). The use of REEs in wind turbines significantly contributes to the reduction of turbine size and weight while increasing power output, a vital factor in the economic viability and performance of wind energy systems.

In solar energy technologies, specific REEs like cerium and lanthanum are used in the production of advanced photovoltaic materials (Bellucci et al., 2020; Ostadebrahim and Dehghani, 2021; Varghese et al., 2023a; Varghese et al., 2023b). These elements are incorporated into solar cells to improve their light absorption and conversion efficiency (Li et al., 2017; Zhang et al., 2024), thereby enhancing the overall

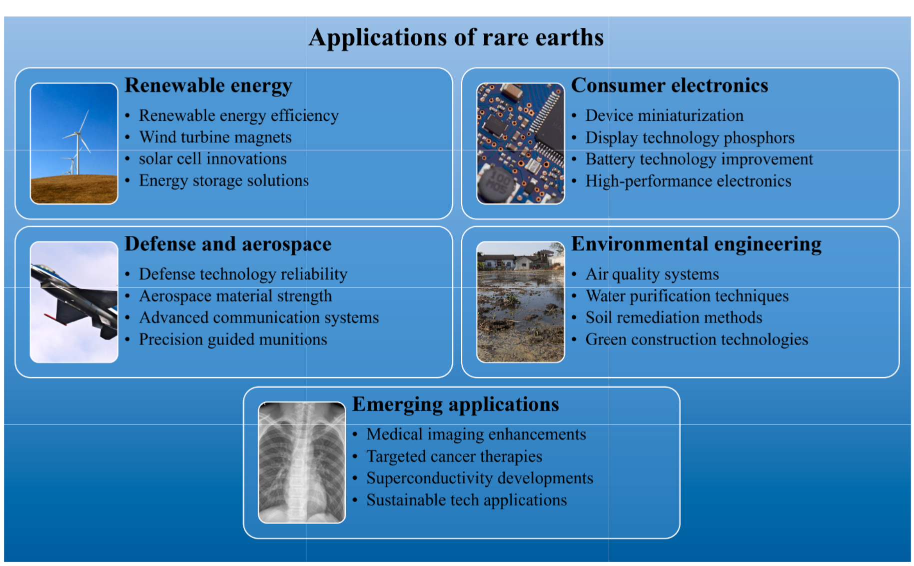

Fig. 3. Conceptual framework of REEs applications.

performance of solar panels. The application of REEs in photovoltaic cells is particularly significant in the context of the global shift towards sustainable energy sources, as it enables the development of more efficient and cost-effective solar energy solutions (Chen et al., 2021a; Sun et al., 2022). Additionally, the use of REEs in energy storage systems, including batteries and capacitors, is noteworthy (Zhao et al., 2019). For example, lanthanum and cerium are used in the production of nickel-metal hydride (NiMH) batteries (Khedimallah et al., 2022; Zhang et al., 2019), which are known for their high energy density and long cycle life. These batteries are integral in storing energy generated from renewable sources, thereby addressing one of the key challenges in the renewable energy sector – the intermittent nature of sources like wind and solar.

The role of REEs in renewable energy extends to various supporting technologies as well. For instance, yttrium and terbium are used in the manufacturing of energy-efficient lighting solutions, which are critical in reducing overall energy consumption (Varun et al., 2015; Yang et al., 2023b; Zhang et al., 2017a). The ongoing research and development in this field are continually uncovering new applications of REEs in renewable energy technologies (Toro et al., 2020), further solidifying their importance in this sector. However, the demand for REEs in renewable energy also brings forth challenges related to supply security and environmental impacts of REE mining and processing (Smith Stegen, 2015). As such, the integration of REEs in renewable energy technologies presents a complex interplay of advancing sustainable energy solutions while addressing the associated environmental and supply chain challenges.

5.2. In consumer electronics

The integration of REEs in consumer electronics has become increasingly significant, owing to their unique properties which enhance the performance and functionality of these devices (Bouri et al., 2021). In the production of smartphones, laptops, and tablets, REEs such as neodymium, praseodymium, and dysprosium are extensively utilized in the manufacture of miniature yet powerful permanent magnets (Kumari and Sahu, 2023; Tripathy et al., 2021). These magnets are essential components in miniature speakers, headphones (earphones), and vibrating motors, where they are favored for their ability to produce strong magnetic fields, crucial for high-quality sound and efficient motion (Bell, 2024; Li et al., 2016; Livingston, 1996). The compact nature of these magnets, enabled by the use of REEs, is instrumental in the ongoing trend of miniaturization in consumer electronics, allowing devices to become smaller, lighter, and more powerful.

In the realm of display technology, elements such as europium and terbium play a pivotal role. They are used as phosphors in color displays, contributing to the vivid and bright screens of modern televisions (Kottaisamy et al., 1995), computer monitors (Resende and Morais, 2015), and smartphone displays (Chancerel et al., 2015). The red and green colors in LED and LCD screens are typically produced using these phosphors (Ayoub et al., 2023; Gupta et al., 2021), which are valued for their high color saturation and stability (Lu et al., 2024). This application of REEs is particularly critical in the context of the increasing demand for high-definition and energy-efficient display technologies in consumer electronics. Additionally, cerium is used in the polishing of glass for screens and lenses (Janoš et al., 2016; Sabia et al., 1999), ensuring high clarity and scratch resistance, which are vital attributes for consumer electronic devices.

The utilization of REEs in the battery technology of consumer electronics is also noteworthy. Lanthanum and cerium are used in the production of nickel-metal hydride (NiMH) batteries, while lithium-ion batteries, which power a vast majority of portable electronic devices (Alemu et al., 2024; Ying et al., 2006), often contain lanthanum, neodymium, and other REEs to improve their performance and longevity (Al-Thyabat et al., 2013). These elements enhance the energy density and durability of batteries, a crucial factor in the usability and lifespan of consumer electronic products (Omodara et al., 2019). The extensive use of REEs in consumer electronics underscores their importance in the industry but also raises concerns about supply security and the environmental impact of their extraction and processing. As such, the role of REEs in consumer electronics represents a critical aspect of modern technology development, balancing the enhancement of device performance with the challenges associated with the sustainable and ethical sourcing of these materials.

5.3. In defense and aerospace

In the defense and aerospace sectors, the application of REEs is of paramount importance, largely due to their unique properties that are critical for various advanced technologies (Wu et al., 2021a). The use of REEs in the production of high-strength permanent magnets, primarily composed of neodymium, praseodymium, and dysprosium, is a notable example. These magnets are integral in numerous defense applications (Powell-Turner and Antill, 2015; Talan and Huang, 2022b), including precision-guided munitions, radar systems, and advanced communication equipment. Their high magnetic strength and resistance to demagnetization at elevated temperatures make them indispensable in these applications, where reliability and precision are paramount.

In aerospace, REEs are utilized in various components of aircraft and spacecraft. Samarium-cobalt (SmCo) magnets, known for their thermal stability and resistance to corrosion (Cui et al., 2022a), are used in aerospace applications (Cui et al., 2022b; Henke et al., 2018), particularly in satellite and aircraft control systems. The ability of these magnets to maintain their magnetic properties under extreme conditions is crucial for the functionality and safety of these systems. Furthermore, yttrium and other REEs are employed in the manufacturing of specialty alloys used in jet engines (Ding et al., 2007). These alloys are designed to withstand high temperatures and stress, ensuring the durability and performance of engine components (Li et al., 2024b). The addition of REEs in these alloys results in materials with superior strength-to-weight ratios, a critical factor in aerospace engineering.

Additionally, the role of REEs in the production of optical and laser systems is significant in both defense and aerospace. Elements such as erbium, ytterbium, and neodymium are used in the construction of high-powered lasers and optical fibers (Rosol et al., 2024; Wu et al., 2022). These systems are essential in various applications, ranging from communication and reconnaissance to missile defense systems (Affan Ahmed et al., 2021). The utilization of REEs in these technologies is driven by their specific optical properties, which enable the development of devices with enhanced performance, miniaturization, and reliability (Xiao et al., 2023b; Zervas, 2014). The strategic importance of REEs in defense and aerospace is underscored by their contribution to the advancement of critical technologies and systems. This reliance, however, also presents challenges in terms of supply security and the sustainability of REE extraction and processing, making the exploration of alternative materials and recycling strategies increasingly important in these sectors.

5.4. In environmental engineering

The integration of REEs in environmental engineering encapsulates a comprehensive approach to combating pollution and fostering sustainable practices. The application of REEs in air quality enhancement, water treatment and purification, soil remediation techniques, and green technologies in construction and manufacturing, collectively represents a significant advancement in environmental stewardship. Each of these domains leverages the unique properties of REEs to address specific environmental challenges, from reducing air and water pollutants to rehabilitating contaminated soils and enhancing green manufacturing processes. The continued exploration and application of REEs in these areas not only contribute to the mitigation of current environmental issues but also pave the way for more sustainable and efficient solutions for future generations. This strategic utilization of REEs underscores their vital role in the ongoing quest for environmental sustainability and technological innovation in various sectors.

5.4.1. Air quality enhancement

In the domain of air quality enhancement, REEs are increasingly recognized for their unique contributions. One of the primary applications is in the development of sophisticated air filtration systems. These systems, which often incorporate REEs like cerium and lanthanum, are capable of trapping and neutralizing a wide array of airborne pollutants (Kante et al., 2009; Tang et al., 2021), including fine particulate matter and noxious gases. The mechanism involves the interaction of these elements with pollutants, leading to the absorption and subsequent breakdown of harmful compounds (Bhatt et al., 2017; Zhan et al., 2014). This process is vital in mitigating the health risks associated with air pollution, particularly in urban and industrial settings. Additionally, the use of REEs in the fabrication of pollution sensors has gained momentum (Angadi et al., 2023; Fois et al., 2021). Sensors equipped with REE-based components exhibit enhanced sensitivity and specificity, crucial for the accurate detection of low-concentration pollutants (Hastir et al., 2017). These sensors are integral in real-time monitoring of air quality, providing essential data for environmental management and policy-making.

Another significant application of REEs in air quality management involves their role in automotive catalytic converters (Hou et al., 2020). Elements such as cerium are employed in these converters to facilitate the oxidation of hazardous exhaust gases into less harmful substances (Wang et al., 2021). The efficiency of REEs in catalyzing these reactions is instrumental in reducing vehicle emissions (Ozawa, 2006; Shinjoh, 2006), a major source of urban air pollution. This catalytic activity not only contributes to compliance with stringent environmental regulations but also plays a critical role in improving overall air quality. Furthermore, the ongoing research in this field is focused on enhancing the efficacy and durability of REE-based catalysts, ensuring their long-term performance in various environmental conditions.

In addition to these applications, REEs are also being explored for their potential in large-scale air purification projects (Ho et al., 2019; Zou et al., 2020). These projects aim to deploy REE-based technologies in industrial emissions control and urban air cleaning systems. The adaptability of REE compounds to various environmental contexts and their effectiveness in pollutant removal position them as valuable assets in combating air pollution. However, the extraction and processing of REEs for these applications necessitate a careful consideration of environmental impacts, urging a balanced approach that weighs the benefits in air quality improvement against the ecological footprint of REE production.

5.4.2. Water treatment and purification

In the field of water treatment and purification, REEs are gaining prominence due to their distinctive properties that contribute

Table 3
Application of REEs in water treatment and purification processes.

Material	Application	Usage parameters	Efficiency	Reference
Cellulose/lanthanum alginate /La (III) composite microspheres	Adsorption of phosphate	Dosage of adsorbent: 0.4 g/L Initial concentration of phosphate: 80 mg/L Reaction time: 1440 min	Adsorption efficiency for phosphate: 159.5 mg/g	(Wu et al., 2024)
Lanthanum-modified natural zeolite	Adsorption of phosphorus	Dosage of adsorbent: 0.4 g/L Initial concentration of phosphate: 10–150 mg/L Reaction time: 1440 min	Adsorption efficiency for phosphorus: 109.1 mg/g	(Luo et al., 2024b)
Lanthanum-loaded biochar	Adsorption of arsenate	Dosage of adsorbent: 1 g/L Initial concentration of arsenate: 10–100 mg/L Reaction time: 1440 min pH: 5	Adsorption efficiency for arsenate: 21.3 mg/g	(Wang et al., 2023a)
Cerium-based porous carbon microsphere	Adsorption of rhodamine B	Dosage of adsorbent: 0.2 g/L Initial concentration of rhodamine B: 100 mg/L pH: 4 Reaction time: 1440 min	Adsorption efficiency for rhodamine B: 508.2 mg/g	(Li et al., 2024a)
Material	Application	Usage parameters	Efficiency	Reference
Ru(II) and Ru(III)	Peroxymonosulfate activation for degradation of triclosan	Dosage of Ru(II)/ Ru(III): 30μM/ 10μM Initial concentration of triclosan: 10 mg/L Initial concentration of peroxymonosulfate: 0.6 mM Reaction time: 30 min pH: 7	Removal efficiency for triclosan using Ru (II)/ Ru(III): 65.2%/77.4%	(Dai et al., 2024)
Thiophene insertion and lanthanum molybdate modification of g-C_3N_4	Photocatalysis degradation of tetracycline	Dosage of photocatalyst: 0.5 g/L Initial concentration of tetracycline: 20 mg/L Light source: 300 W Xe lamp Reaction time: 90 min	Removal efficiency for tetracycline: 95.1%	(Zhang et al., 2022a)
Lanthanum-doping $BiFeO_3$	Photocatalysis degradation of phenol	Dosage of photocatalyst: 1 g/L Initial concentration of phenol: 20 mg/L Light source: 300 W Xe lamp Reaction time: 180 min	Removal efficiency for tetracycline: 96%	(Meng et al., 2016)
Boron-doped lanthanum ferrite	Photocatalysis degradation of ciprofloxacin	Dosage of photocatalyst: 0.6 g/L Initial concentration of ciprofloxacin: 40 mg/L Reaction time: 120 min pH: 6.9	Removal efficiency for ciprofloxacin: 91.2%	(Nanda et al., 2024)

significantly to the removal of contaminants (Mon et al., 2024). Table 3 exemplifies the application of REEs in water treatment and purification processes. The incorporation of REEs, such as lanthanum and cerium, into water treatment processes has been acknowledged for their efficacy in eliminating phosphate compounds (Liu et al., 2024; Wu and Lo, 2020; Wu et al., 2020; Xiao et al., 2024; Yang et al., 2023a; Zhang et al., 2021). This elimination is achieved through the formation of insoluble precipitates when REEs interact with phosphates, effectively reducing eutrophication risks in aquatic ecosystems (Lürling et al., 2014). Such applications are critical in areas where runoff from agricultural and urban sources leads to high phosphate concentrations in water bodies, posing a threat to biodiversity and water quality (Mng'ong'o et al., 2022; Zhou et al., 2024b). The use of REEs in phosphate removal not only addresses a key environmental concern but also enhances the overall efficiency of wastewater treatment facilities.

Further to their application in phosphate removal, REEs demonstrate a profound capacity for the adsorptive elimination of heavy metals, inorganic pollutants and organic pollutants from water matrices (Barreto et al., 2023; He et al., 2023b; He et al., 2019; Lv et al., 2022). The efficiency of REEs in sequestering these contaminants is pivotal for enhancing water quality and safeguarding aquatic ecosystems against the deleterious effects of pollution. Through the exploitation of their unique adsorptive properties, REEs contribute to a robust approach towards water purification, facilitating the removal of a broad spectrum of pollutants (Chen et al., 2023b). This capability is especially crucial in the context of industrial and urban wastewater treatment, where conventional methods may fall short in effectively addressing the complexity of contaminant profiles present in such effluents.

In the enhancement of water treatment methodologies, REEs are instrumental in catalyzing advanced oxidation processes (AOPs), pivotal for the generation of reactive oxygen species (ROS) that facilitate the degradation of persistent organic pollutants and neutralization of pathogens (Qin et al., 2024; Razmi et al., 2019b; Thinley et al., 2023; Wang et al., 2023c). The efficacy of REEs in promoting the formation of ROS under diverse operational conditions significantly contributes to the remediation of contaminated water (Li et al., 2021; Razmi et al., 2019a; Zhao et al., 2023a), enabling the restoration of potable water quality, the effective treatment of industrial effluents, and the purification of agricultural wastewater. The deployment of REE-based catalysts within AOPs is celebrated for its adaptability across various water treatment frameworks, providing a robust mechanism for the disinfection process and the comprehensive removal of contaminants.

Following their foundational role in AOPs, the application of REEs in the domain of photocatalysis has been notably prominent, with their capacity to activate catalytic reactions using solar energy widely recognized (Gomez et al., 2012; Ma et al., 2023b). The utilization of REEs, including the integration of cerium, lanthanum, and yttrium into various photocatalytic matrices, has been identified as enhancing the absorption efficiency of solar radiation (Abdo et al., 2022; Ghafoor et al., 2023; Martin et al., 2019; Nazir et al., 2023). Consequently, this accelerates the photocatalytic breakdown of a broad spectrum of pollutants (da Silva Júnior et al., 2024; Lin et al., 2021), thereby broadening the scope of photocatalysis in environmental management. This application, not limited to the photodegradation of complex dye molecules (Keerthana et al., 2024; Kousar et al., 2023; Sathishkumar et al., 2014) but also extends to the breakdown of pharmaceutical residues, heavy metals, and endocrine-disrupting compounds present in wastewater streams (Amirulsyafiee et al., 2022; Liu et al., 2022; Shan et al., 2023; Wu et al., 2021b; Yao et al., 2020). Positioning REEs as critical components in the drive towards sustainable water purification strategies, their inclusion in photocatalytic systems has been shown to markedly improve the degradation rates of hazardous compounds under visible light. This illustrates the profound impact of REEs on enhancing the operational efficiency of photocatalytic water treatment systems, highlighting their indispensable role in advancing sustainable environmental remediation efforts.

5.4.3. Soil remediation techniques

In the arena of soil remediation, REEs are increasingly acknowledged for their capabilities in addressing soil contamination (Elkhlifi et al., 2021), particularly heavy metal pollution. The application of REEs such as lanthanum and cerium in immobilizing heavy metals in soils is gaining attention (Bagherifam et al., 2022). This immobilization process involves the formation of stable complexes between REEs and heavy metals, thereby reducing the mobility and bioavailability of these toxic substances (Lin et al., 2020; Zhang et al., 2020b). Such stabilization is crucial in areas affected by industrial activities and mining operations, where heavy metal contamination poses significant risks to environmental health and human safety. The efficacy of REEs in soil remediation is attributed to their specific chemical properties, which enable the formation of strong bonds with heavy metals, effectively sequestering them and preventing leaching into groundwater or uptake by plants.

Additionally, the use of REEs in phytoremediation strategies is a subject of ongoing research. Certain REEs have shown potential in enhancing the growth and metal-accumulation capabilities of plants used in phytoremediation (Guo et al., 2024; Li et al., 2023b). This enhancement facilitates the extraction of contaminants from the soil, utilizing plants as natural accumulators (He et al., 2023a). The role of REEs in supporting the health of these plants, thereby increasing their efficiency in removing pollutants, represents a novel approach in remediating contaminated lands (Hu et al., 2004). Furthermore, the incorporation of REE-based compounds in soil amendments is being explored (Ayub et al., 2023; Lu et al., 2019). These compounds can improve soil quality and structure, aiding in the recovery of degraded lands. The introduction of such amendments is particularly beneficial in restoring the ecological balance of areas where soil properties have been adversely affected by contamination.

In developing these soil remediation techniques, the potential environmental impact of introducing REEs into ecosystems is carefully considered (Preetha et al., 2023; Tang et al., 2022). The sustainability of using REEs in soil treatment is evaluated in terms of their long-term effects on soil health and the surrounding environment (Zhang et al., 2017b). This consideration is paramount to ensuring that the benefits of REE-based remediation techniques do not inadvertently lead to secondary environmental issues. In summary, the application of REEs in soil remediation techniques presents promising solutions to some of the most challenging environmental issues related to soil contamination. Their unique chemical properties, coupled with innovative application methods, hold the potential to effectively restore contaminated soils, making them safe for agricultural use and habitat restoration while safeguarding environmental health.

5.4.4. Green technologies in construction and manufacturing

Within the construction and manufacturing industries, the adoption of REEs is crucial for the advancement of green technologies. These elements, when incorporated into cement and alloys (Chatterjee, 2009; Sha, 2009), bestow enhanced durability, strength, and environmental performance. Specifically, REEs in cement formulations lead to concrete with improved mechanical properties and extended service life (Li et al., 2023a), thus mitigating the need for frequent repairs and reducing both resource consumption and construction waste. This aligns perfectly with goals for sustainable development. Moreover, integrating REEs into manufacturing alloys significantly enhances corrosion resistance and mechanical integrity (Yang et al., 2021a; Zhang et al., 2023d), crucial for the development of eco-friendly industrial applications. Consequently, REEs are identified as pivotal in steering the construction and manufacturing sectors toward more sustainable and environmentally responsible practices, highlighting the necessity for their conscientious sourcing and utilization.

In the manufacturing sector, REEs are crucial in the advancement of green technologies, particularly in the production of cleaner and more efficient machinery. The implementation of REE-based components in manufacturing equipment has been shown to enhance performance while reducing energy consumption. For instance, the use of samarium-cobalt magnets in electric motors results in devices that are not only more powerful but also more energy-efficient (Bailey et al., 2021; Nordelöf et al., 2019). This improvement is significant in industries where energy consumption constitutes a major operational cost and environmental concern. Furthermore, REEs are instrumental in the development of advanced manufacturing techniques, such as additive manufacturing (Popov et al., 2018; Yan et al., 2022; Yang et al., 2021b) or 3D printing (Gultekin et al., 2023; Kumar and Kumar, 2022). The integration of REE-based alloys in these processes allows for the creation of components with enhanced properties, such as increased strength and durability, which are essential for reducing waste and enhancing the longevity of products.

5.5. Other emerging applications

The emerging applications of REEs extend beyond traditional sectors, showcasing their versatility and indispensability in various innovative technologies. One such area is in medical imaging and treatment. Gadolinium, for instance, is utilized as a contrast agent in magnetic resonance imaging (MRI) (Zhao et al., 2023b). Its paramagnetic properties enhance the contrast of images, aiding in the accurate diagnosis of medical conditions. Additionally, holmium and other REEs are being explored for use in cancer treatment (Bozkurt et al., 2016; Zhang et al., 2023c), particularly in the development of targeted radiation therapies. These applications underscore the potential of REEs in advancing healthcare technologies, offering new avenues for diagnosis and treatment.

The exploration of REEs in the field of superconductivity also represents a significant emerging application. Certain REEs, when used in the composition of superconducting materials, contribute to the achievement of superconductivity at higher temperatures (Chow et al., 2023; Pigalskiy and Trakhtenberg, 2020). This development is critical in reducing the energy and cooling requirements for superconductors, making them more practical and cost-effective for applications such as magnetic levitation, energy storage, and advanced medical equipment like MRI machines.

6. Economic and geopolitical context of rare earth elements

The economic and geopolitical landscape of REEs is shaped by their critical roles in various advanced technologies and their concentrated global supply. REEs are indispensable in numerous high-tech applications, ranging from consumer electronics to renewable energy and defense. The global demand for these elements continues to rise, driven by technological advancements and the shift towards greener energy solutions. This increasing reliance on REEs underscores their strategic importance, influencing international trade policies and geopolitical strategies. The following sections delve into the intricate market dynamics, political implications, and regulatory frameworks that govern the global REE industry, highlighting the multifaceted challenges and opportunities it presents. Fig. 4 outlines the conceptual framework of economic governance and policy structure of REEs.

6.1. Market dynamics

The market dynamics of REEs are characterized by a complex interplay of supply and demand, influenced significantly by technological advancements and geopolitical factors (Alonso et al., 2023; Wang et al., 2024). Demand for REEs has seen a consistent rise, primarily fueled by their critical applications in high-tech industries such as consumer electronics (Buechler et al., 2020), renewable energy (Madaleno et al., 2023), and defense (Riddle et al., 2021). This surge reflects the global shift towards green technology and energy sustainability. However, the market is also marked by a high degree of volatility (Song et al., 2021), attributed to the concentrated supply chain and fluctuating demand in key sectors.

Trade policies and geopolitical considerations play a crucial role in shaping the international market for REEs (Hau et al., 2022; Vivoda et al., 2024). Export restrictions (Mancheri, 2015; Seiler, 2021), tariffs (Han et al., 2015; Trujillo, 2017), and trade agreements (GU, 2011) have been instrumental in influencing the availability and pricing of these elements on the global stage (Chen et al., 2024c). The rare earth market is also subject to speculative trading, further contributing to its volatility. Supply of REEs is heavily dominated by China, accounting for a

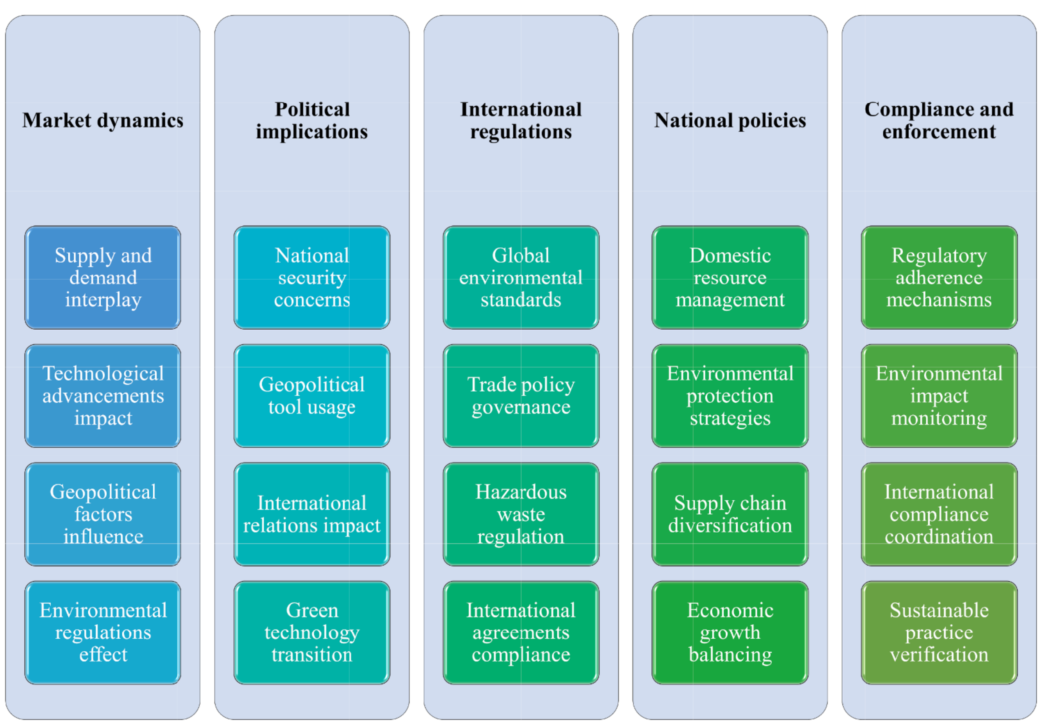

Fig. 4. Conceptual framework of economic governance and policy structure of REEs.

significant portion of both global production and processing capacity (Jowitt, 2022). Trade disputes (Proelss et al., 2018) and export quotas (Shen et al., 2020) imposed by major supplying countries can lead to significant disruptions in the supply chain, compelling importing countries to seek alternative sources or invest in domestic production capabilities. For instance, projects in countries such as Australia, the United States, and Canada have been initiated, aiming to reduce dependency on a single supplier (Lee and Dacass, 2022; Xu et al., 2023a).

Environmental and regulatory aspects significantly impact the market dynamics of REEs (Wang et al., 2017c). The mining and processing of REEs are energy-intensive and pose environmental risks (Jia et al., 2024; Shi et al., 2022), particularly in the form of radioactive waste and toxic byproducts (Weng et al., 2013). As a result, stringent environmental regulations in various countries can influence the supply chain, affecting the overall production costs and market prices of these elements (Madaka et al., 2022; Peng and Shehabi, 2023). Furthermore, the increasing awareness of sustainable practices in mining and the potential for recycling REEs from electronic waste are shaping future market trends (Sahajwalla and Hossain, 2023). These trends are expected to influence not only the supply and pricing of REEs but also the strategic investments and research focus in this sector. The market dynamics of REEs, therefore, represent a complex matrix of technological, environmental, economic, and geopolitical factors, necessitating a multi-faceted approach to ensure both the availability and sustainable utilization of these critical resources.

Fig. 5a illustrates the global exports of rare-earth metals, scandium, and yttrium for 2022, delineating the prominent roles of key exporting countries. China maintained its position as the dominant exporter, channeling goods worth \$395 million into the global market, thereby affirming its pivotal role in rare-earth processing. Vietnam, Australia, and Thailand also made substantial contributions to the exports, totaling \$197 million, \$162 million, and \$121 million respectively. These figures reflect not only the robust mining infrastructures of these nations but also their strategic geopolitical maneuvers to bolster export-driven economic frameworks. In contrast, Japan, with exports amounting to \$20.3 million, demonstrated its strategic engagement in the supply chain, albeit on a smaller scale compared to its counterparts.

Fig. 5b depicts the 2022 global imports of rare-earth metals, scandium, and yttrium, with Japan leading as the primary importer at \$628 million. This significant import volume is primarily driven by Japan's acute demand for these elements to support its advanced technological sectors, coupled with an absence of domestic reserves. Following Japan, Malaysia and Vietnam registered imports valued at \$166 million and \$56.8 million, respectively, positioning themselves as crucial hubs within the Asian technology manufacturing landscape that heavily depends on these imported materials. Additionally, Thailand and the United States were noted for their imports valued at \$18.4 million and \$14 million, respectively. These figures underscore the expanding needs of their high-tech industries for rare-earth elements, essential for developing a range of technologies from consumer electronics to renewable energy systems. This pattern of importation is influenced profoundly by the strategic imperative to secure critical resources essential for sustaining and advancing technological capabilities in a highly competitive global arena, marked by intricate supply chain interdependencies.

6.2. Political implications

The political implications of REEs are profound, stemming from their critical role in a wide array of modern technologies and their concentrated global supply (Fan et al., 2023). The geopolitical landscape surrounding REEs is marked by a complex interplay of national interests (Klinger, 2018), security concerns (Chapman, 2018; Zhang, 2022), and economic strategies (Santillán-Saldivar et al., 2021). The dominance of certain countries, particularly China, in the supply of REEs has led to significant political discourse and strategic maneuvering on an international scale (Xia et al., 2023). This dominance is not merely a matter of resource possession but extends to the capabilities in processing and refining these elements, which are equally critical in the supply chain (Salim et al., 2022). Such control over the supply has been leveraged at times as a geopolitical tool, influencing global politics and international relations.

In 2010, the notable China-Japan REEs dispute was ignited when China slashed its export quotas of rare earth elements by 40 %,

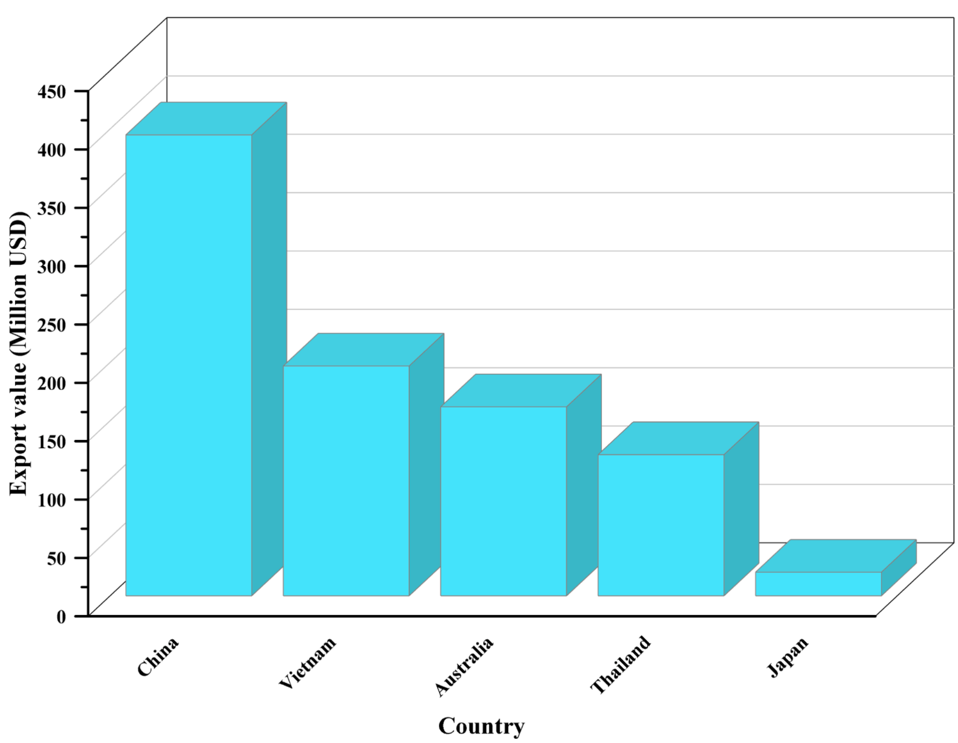

Fig. 5a. Global exports of rare-earth metals, scandium, and yttrium by country for 2022.

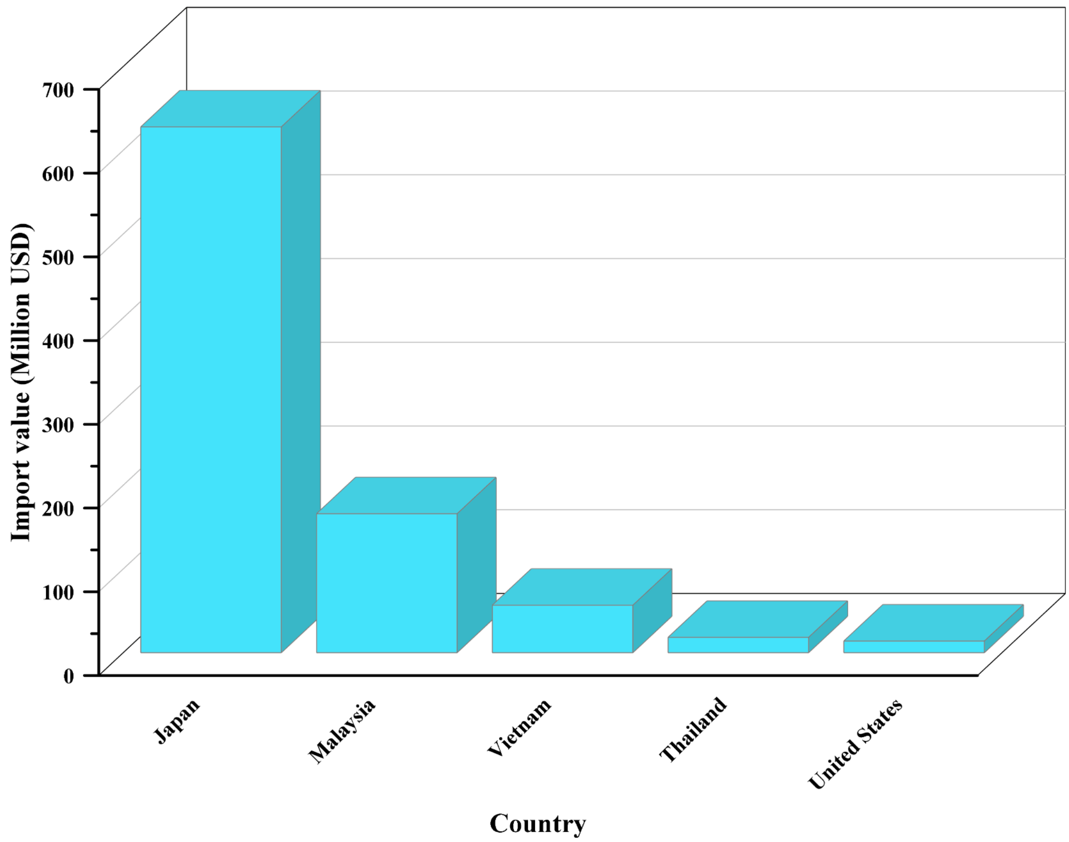

Fig. 5b. Global imports of rare-earth metals, scandium, and yttrium by country for 2022.

triggering a steep escalation in global prices. While China defended its actions on environmental grounds, international observers predominantly interpreted these measures as a tactical maneuver amid escalating diplomatic tensions with Japan (Zhou et al., 2022), following an incident near the disputed Senkaku/Diaoyu Islands involving a Chinese fishing trawler and Japanese Coast Guard vessels (Sprecher et al., 2017). This significant reduction in the export of essential materials, for which China was a primary global supplier, provoked severe international trade tensions, especially impacting Japan, whose high-tech industries were particularly dependent on these resources. Consequently, the United States, European Union, and Japan sought redress through the World Trade Organization (WTO), challenging China's export restrictions as violations of its WTO commitments (Charlier and Guillou, 2014). The WTO ultimately adjudicated against China, ruling that the export limits were unjustified under the cited environmental protections and represented a discriminatory practice against foreign importers.

The security implications of REEs are particularly pronounced in the defense sector, where these elements are indispensable in the production of advanced military equipment and technologies (Xiao et al., 2023a). The reliance on external sources for these critical materials has been recognized as a vulnerability by several nations, prompting initiatives to develop alternative supply chains and enhance domestic production capacities (Andersen et al., 2024; Schmid, 2019). This aspect of REEs has become a strategic focus in national defense policies, with implications for international diplomacy and military preparedness (Wübbeke, 2013; Zhang et al., 2015). Additionally, the strategic importance of REEs in the transition to green energy technologies has placed them at the center of international environmental policies and agreements (Depraiter and Goutte, 2023). As nations strive to reduce carbon emissions and invest in renewable energy, the demand for REEs in technologies such as wind turbines and electric vehicles heightens, further entangling the political dynamics associated with their supply.

6.3. International regulations

The international regulations governing the extraction, trade, and use of REEs are multifaceted and play a crucial role in shaping the global REE industry. These regulations are primarily designed to address the environmental impacts of REEs, ensure fair trade practices, and mitigate geopolitical risks associated with the concentrated supply of these elements. The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, for instance, is instrumental in regulating the international movement of hazardous waste (Rummel-Bulska, 2004). This convention aims to protect human health and the environment against the adverse effects of hazardous waste (Zeng et al., 2022).

Another significant aspect of international regulations is related to trade policies. WTO plays a pivotal role in overseeing the trade of REEs, ensuring that member countries adhere to fair trade practices (Barteková and Kemp, 2016). Disputes related to export quotas, tariffs, and other trade barriers in the REE sector have been addressed under the WTO framework, seeking to maintain an equitable and non-discriminatory trading environment (GU, 2011). This is particularly important given the strategic nature of REEs and their critical role in various high-tech and green industries. For example, the WTO has been involved in resolving disputes related to export restrictions imposed by major REE-producing countries, which have significant implications for global supply and pricing (Mancheri, 2015).

Moreover, the Rare Earth Industry Association (REIA), headquartered in Belgium, plays a crucial role in uniting stakeholders across the global REE industry. Established in 2019 under the European Union's EIT RawMaterials initiative, REIA aims to foster sustainability and ensure best practices within the REE sector. As the only industry association outside of China, REIA's efforts are pivotal in promoting international collaboration, advocating for regulatory coherence, and facilitating the adoption of environmental and ethical standards across the rare earth supply chain

Environmental regulations at both international and national levels also significantly impact the REE industry (Dallas et al., 2021). Agreements like the Paris Agreement on climate change indirectly influence the REE market, as the transition to green technologies, heavily reliant on REEs, is a key component of global climate change mitigation strategies (Li et al., 2024d). These regulations drive the demand for REEs in clean energy technologies, such as wind turbines and electric vehicles, while also imposing strict environmental standards on mining practices. The adherence to these international environmental agreements and standards ensures that the extraction and processing of REEs are conducted in a manner that minimizes environmental degradation and promotes sustainable practices.

6.4. National policies

National policies pertaining to REEs are crucial in shaping the exploration, extraction, processing, and utilization of these resources within individual countries. Table 4 summarizes the national policies and laws regarding REEs industry.

These policies are often driven by the need to balance economic interests, environmental protection, and national security concerns. In countries with significant REE reserves, such as China, national policies have historically focused on the development and control of the REE industry (Shen et al., 2020). These policies encompass regulations on mining practices, export quotas, and environmental standards (Liu and Ge, 2023). For example, China's approach to regulating its REE industry has included measures to consolidate mining activities, impose export restrictions, and enforce environmental regulations to mitigate the ecological impact of mining (Mancheri, 2016; Zhü et al., 2016). These actions, influenced by both economic and environmental considerations, have had far-reaching implications on the global supply of REEs (Zhang et al., 2022b).

Table 4
National policies and laws regarding REEs industry.

Country	Key Policies/Laws	Focus Areas	Recent Developments
China	Resource Tax Law, Environmental Protection Law, Regulations on the Management of REEs	Resource control, environmental protection, export quotas	Consolidation of domestic REE industry, crackdown on illegal mining, increased investment in REE recycling
United States	National Defense Authorization Act, Critical Minerals Policy Act	Supply security, defense sector reliance, domestic production enhancement	Investment in domestic REE mining and processing capabilities, partnerships with other countries
Australia	Environmental Protection and Biodiversity Conservation Act, Critical Minerals Facilitation Office	Environmental conservation, development of critical mineral resources	Strategic partnerships for REE exploration and processing, focus on environmental sustainability
India	National Mineral Policy, Atomic Energy Act	Resource management, nuclear materials regulation, self-reliance	Enhanced exploration activities, emphasis on self-sufficiency in critical minerals
Japan	Act on the Promotion of Recycling and Related Activities for the Treatment of Cyclical Food Resources	Resource recycling, technological innovation, supply chain diversification	Collaboration in international REE supply chains, focus on recycling and secondary production
European Union	Raw Materials Initiative, European Green Deal	Sustainable resource use, green technology promotion, supply chain resilience	Funding for research in REE alternatives, establishment of secure and sustainable supply chains

In other countries, particularly those dependent on REE imports, national policies often emphasize the diversification of supply sources and the development of domestic production capabilities (Zuo et al., 2022). The United States and the European Union, for instance, have implemented strategies aimed at reducing dependence on imported REEs (Charalampides et al., 2015; Eheliyagoda et al., 2023). These strategies include funding for research and development in REE exploration, mining, and recycling technologies, as well as initiatives to establish partnerships with other countries to secure stable and sustainable REE supplies (Golev et al., 2014; Machacek et al., 2015; Rabe et al., 2017). Such policies are not only motivated by supply security concerns but also by the desire to develop a competitive domestic REE industry.

Environmental policies at the national level also significantly impact the REE sector. Countries with REE mining activities are increasingly implementing stringent environmental regulations to address the negative impacts of mining, such as land degradation, water contamination, and radioactive waste management (Chai et al., 2020; Zapp et al., 2022). These regulations often require mining companies to adhere to specific standards for environmental protection, waste management, and rehabilitation of mining sites. Additionally, some countries are actively promoting the recycling of REEs from electronic waste as part of their national policy frameworks (Ramprasad et al., 2022). This approach not only helps in reducing the environmental impact associated with REE mining but also contributes to the creation of a circular economy for these critical materials.

6.5. Compliance and enforcement

Compliance and enforcement in the context of REEs involve a multifaceted approach to ensure adherence to various international and national regulations and policies governing the REE sector. Compliance is critical in maintaining a sustainable and ethically responsible REE industry, particularly given the environmental and geopolitical sensitivities associated with these elements. Enforcement mechanisms are often instituted at both international and national levels to ensure that stakeholders in the REE industry, including miners, processors, and traders, adhere to established guidelines and standards.

At the international level, compliance is monitored through various treaties and agreements, such as the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes (Zhang, 2021). Countries party to these agreements are required to implement domestic legislation that aligns with international standards. Enforcement is carried out through mechanisms such as reporting requirements, inspections, and audits. Non-compliance can lead to penalties, including trade restrictions or sanctions. These international frameworks are crucial in managing the transboundary environmental impacts of REE mining and processing (Yakovleva et al., 2023), ensuring that hazardous waste is handled in an environmentally sound manner.

National enforcement of REE-related regulations often involves government agencies responsible for mining, environmental protection, and trade. These agencies implement a range of enforcement actions, including permitting and licensing for mining operations (Barakos and Mischo, 2021; Riesgo García et al., 2019), regular inspections, and monitoring of environmental impacts. In countries with significant REE reserves, such as China, the government has established strict regulations on REE mining to control environmental damage and illegal mining activities (Packey and Kingsnorth, 2016; Zheng et al., 2023). Enforcement of these regulations is critical to mitigate the extensive ecological disruption often associated with REE mining.

Furthermore, compliance with environmental standards is enforced through various mechanisms, including environmental impact assessments (EIAs) before the initiation of mining projects, ongoing monitoring of mining sites, and rehabilitation requirements after mining activities have ceased (Pereira et al., 2023; Wang et al., 2020). Non-compliance with environmental regulations can result in legal actions, fines, and revocation of licenses. Additionally, some countries have introduced initiatives to encourage responsible sourcing of REEs, including certification schemes that verify the ethical and sustainable extraction of these elements (Chadly et al., 2023). These measures aim to promote compliance throughout the REE supply chain, from extraction to end-use.

7. Challenges and prospects

REEs sector is at the intersection of technological innovation, environmental stewardship, and geopolitical strategy. As the demand for REEs intensifies due to their indispensable role in high-tech and green energy applications, the sector faces significant challenges and opportunities. This section delves into the multifaceted sustainability challenges, explores the latest technological innovations aimed at mitigating these issues, and provides an outlook on the future prospects of the REE industry. By addressing the environmental, economic, and social dimensions of REE production and utilization, a comprehensive understanding of the path forward for sustainable and resilient REE supply chains is offered.

7.1. Sustainability challenges

The sustainability challenges in the context of REEs are multifaceted, encompassing environmental, economic, and social dimensions. One of the primary environmental challenges is the significant ecological impact associated with REE mining and processing. These activities often lead to substantial land disruption, soil and water contamination, and biodiversity loss. The release of toxic substances, including radioactive materials inherent in some REE ores, poses serious environmental risks. Addressing these impacts necessitates the implementation of more sustainable mining practices, effective waste management strategies, and the rehabilitation of mining sites. The adoption of such practices is crucial to mitigate the adverse environmental effects and ensure the long-term viability of REE resources.

Economically, the sustainability of the REE sector is challenged by the volatility of the market and the concentrated nature of the supply chain. The majority of the world's REEs are sourced from a limited number of countries, with China being the dominant player. This concentration raises concerns about supply security, particularly for countries dependent on these imports for their high-tech industries. The fluctuating prices and supply uncertainties pose significant risks for businesses and economies reliant on these critical elements. Diversifying the supply sources, developing new extraction and processing technologies, and enhancing recycling and recovery of REEs from electronic waste are essential to overcome these economic challenges and ensure a stable and sustainable REE market.

Social challenges related to REE mining and processing include health and safety concerns for workers and surrounding communities. Exposure to hazardous chemicals and radioactive materials in mining and processing sites can have detrimental health effects. Ensuring the safety and well-being of workers and residents in these areas is imperative. Furthermore, the socio-economic impacts on local communities, such as displacement and disruption of livelihoods due to mining activities, necessitate the incorporation of social responsibility in the REE sector. Engaging with local communities, ensuring fair compensation, and providing opportunities for sustainable development are key to addressing these social challenges. In summary, tackling the sustainability challenges in the REE sector requires a comprehensive approach that balances environmental protection, economic stability, and social responsibility. This approach is vital for the responsible management and utilization of rare earth resources in a way that is equitable and sustainable for current and future generations.

7.2. Technological innovations

The field of REEs is witnessing significant technological innovations aimed at addressing sustainability challenges and optimizing their utilization. One key area of innovation is the development of more efficient and environmentally friendly extraction techniques. Traditional methods of REE extraction, often involving intensive use of chemicals and significant energy consumption, are being reevaluated. Emerging techniques, such as bioleaching, where microorganisms extract REEs from ore, offer a more sustainable alternative by minimizing harmful chemicals and lowering energy requirements. These advancements in extraction are essential for reducing the environmental footprint and ensuring the sustainable management of REEs.

Advancements in recycling technologies represent another critical innovation area, driven by the increasing use of REEs in various high-tech applications. Innovative methods for recovering REEs from discarded products are being developed, aiming to reduce reliance on primary sources and mitigate mining's environmental impacts. These methods include hydrometallurgical processes that dissolve REEs from electronic waste and electrochemical processes that use electrical currents to separate REEs from other components. Efficient and cost-effective recycling technologies are crucial in establishing a circular economy for REEs, contributing significantly to the industry's sustainability. Nonetheless, the environmental impact of the chemicals used in hydrometallurgical processes and the energy consumption of electrochemical methods must be minimized to achieve true sustainability.

Research into alternative materials that can substitute for REEs in certain applications is also ongoing, with the goal of finding materials with similar properties but less environmental impact or supply risk. This research is particularly important in high-demand sectors like renewable energy and electronics. These innovations help reduce the demand pressure on REEs and contribute to diversifying materials used in various industries, enhancing overall sustainability. While promising, the development and production of alternative materials must be evaluated for their own environmental footprints and resource requirements to ensure they offer a genuinely sustainable option. Continuous advancements in extraction, recycling, and material substitution are vital for the sustainable management and use of REEs, ensuring their availability for future technological applications while minimizing ecological and social impacts.

7.3. Future outlook

The future outlook for the REEs sector is shaped by a convergence of technological, environmental, and geopolitical factors, indicating a trajectory towards more sustainable and diversified practices. Anticipated advancements in extraction and processing technologies, such as solvent extraction techniques with lower environmental footprints and more effective separation processes, are expected to reduce environmental impacts and increase efficiency. These advancements will not only address current ecological concerns but also enable more cost-effective recovery of REEs, crucial for meeting the growing global demand and ensuring the sector's sustainability.

Efforts are being made to reduce dependence on a limited number of sources, contributing to a more geographically dispersed supply chain. Exploration projects in various parts of the world are likely to result in the discovery of new REE deposits. Additionally, the development of secondary sources from recycling electronic waste is expected to gain momentum, alleviating pressure on primary sources and contributing to a circular economy. This shift towards recycling reduces waste and mitigates the environmental impact associated with the disposal of electronic products, enhancing overall sustainability in the REE sector.

The role of REEs in emerging and future technologies, particularly in the green energy sector, is expected to expand significantly. With the global push towards renewable energy and sustainable technologies, the demand for REEs in wind turbines, electric vehicles, and advanced battery technologies is projected to rise. This increase in demand underscores the need for continued innovation in the REE sector, focusing on material efficiency and the development of alternative materials with similar properties but lower environmental and geopolitical risks. Balancing the growing demand with sustainable practices, ensuring supply security, and navigating geopolitical landscapes will be essential for shaping a sustainable and resilient future for the REE industry, critical for advancing modern technologies and the transition towards a more environmentally conscious global economy.

Declaration of Generative AI and AI-assisted technologies in the writing process

Statement: During the preparation of this work the authors used ChatGPT-4.0 in order to improve readability and language. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Hongli Diao: Writing – review & editing. **Hang Yang:** Writing – original draft. **Tan Tan:** Methodology. **Gui Ren:** Software. **Minhua You:** Resources. **Longyue Wu:** Conceptualization. **Mingxiang Yang:** Visualization. **Yabin Bai:** Writing – original draft. **Shibin Xia:** Writing – review & editing. **Shaoxian Song:** Conceptualization. **Mildred Quintana:** Writing – review & editing. **Lei Liu:** Writing – review & editing. **Qiang Xue:** Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors sincerely thank the grant funded by Fuling Shale Gas Environmental Exploration Technology of National Science and Technology Special Project (No. 2016ZX05060).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mineng.2024.108889.

References

Abdo, M.A., Mansour, S.F., Al-Bassami, N.S., Abu-Elsaad, N.I., 2022. Yttrium substituted Co–Cu–Zn nanoferrite: A synergetic impact of Y^{3+} on enhanced physical properties and photocatalysis. Ceram. Int. 48 (11), 15314–15326. https://doi.org/10.1016/j.ceramint.2022.02.065.

Affan Ahmed, S., Mohsin, M., Zubair Ali, S.M., 2021. Survey and technological analysis of laser and its defense applications. Defence Technol. 17 (2), 583–592. https://doi.org/10.1016/j.dt.2020.02.012.

Akinyemi, S.A., Nyakuma, B.B., Jauro, A., Olanipekun, T.A., Mudzielwana, R., Gitari, M. W., Saikia, B.K., Dotto, G.L., Hower, J.C., Silva, L.F.O., 2021. Rare earth elements study of Cretaceous coals from Benue Trough basin, Nigeria: Modes of occurrence for greater sustainability of mining. Fuel 304, 121468. https://doi.org/10.1016/j.fuel.2021.121468.

Alemu, M.A., Worku, A.K., Getie, M.Z., 2024. Recent advances in electrically rechargeable transition metal-based-air batteries for electric mobility. Inorg. Chem. Commun. 159, 111742 https://doi.org/10.1016/j.inoche.2023.111742.

Alonso, E., Pineault, D.G., Gambogi, J., Nassar, N.T., 2023. Mapping first to final uses for rare earth elements, globally and in the United States. J. Ind. Ecol. 27 (1), 312–322. https://doi.org/10.1111/jiec.13354.

Alsabbagh, A.H., Mustafa, R.M., 2023. Wet gravity separation and froth floatation techniques for rare earth elements beneficiation from monazite ore in Jordan. Heliyon 9 (9), e19597.

Al-Thyabat, S., Nakamura, T., Shibata, E., Iizuka, A., 2013. Adaptation of minerals processing operations for lithium-ion (LiBs) and nickel metal hydride (NiMH) batteries recycling: Critical review. Miner. Eng. 45, 4–17. https://doi.org/10.1016/j.mineng.2012.12.005.

Alves, R.C., Nascimento, M., Paulino, J.F., Afonso, J.C., 2021. Selection of a hydrometallurgical process for rare earths extraction from a Brazilian monazite. Hydrometall. 200, 105556 https://doi.org/10.1016/j.hydromet.2021.105556.

Amirulsyafiee, A., Khan, M.M., Khan, M.Y., Khan, A., Harunsani, M.H., 2022. Visible light active La-doped Ag_3PO_4 for photocatalytic degradation of dyes and reduction of Cr(VI). Solid State Sci. 131, 106950 https://doi.org/10.1016/j.solidstatesciences.2022.106950.

Andersen, E.V., Shan, Y., Bruckner, B., Černý, M., Hidiroglu, K., Hubacek, K., 2024. The vulnerability of shifting towards a greener world: The impact of the EU's green transition on material demand. Sustainable Horizons 10, 100087. https://doi.org/10.1016/j.horiz.2023.100087.

Angadi, V.J., Pasha, A., Ubaidullah, M., Gupta, M., Pandit, B., Manjunatha, S.O., Sehgal, S.S., 2023. Rare earth(Sm^{3+}) doped $CoCr_2O_4$ ceramics sensor towards room temperature detection of greenhouse methane gas. Ceram. Int. 49 (10), 16174–16181. https://doi.org/10.1016/j.ceramint.2023.01.215.

Ayoub, I., Mushtaq, U., Yagoub, M.Y.A., Som, S., Swart, H.C., Kumar, V., 2023. Structural and optical characteristics of green-emitting $BaGd_2ZnO_5$:Tb^{3+} phosphor for LED applications. Phys. B Condens. Matter 669, 415299. https://doi.org/10.1016/j.physb.2023.415299.

Ayub, M.A., Ahmad, H.R., Zia ur Rehman, M., Waraich, E.A., 2023. Cerium oxide nanoparticles alleviates stress in wheat grown on Cd contaminated alkaline soil. Chemosphere 338, 139561. https://doi.org/10.1016/j.chemosphere.2023.139561.

Aziman, E.S., Ismail, A.F., Rahmat, M.A., 2023. Balancing economic growth and environmental protection: A sustainable approach to Malaysia's rare-earth industry. Resour. Policy 83, 103753. https://doi.org/10.1016/j.resourpol.2023.103753.

Azizi, M., Faz, A., Zornoza, R., Martínez-Martínez, S., Shahrokh, V., Acosta, J.A., 2022. Environmental pollution and depth distribution of metal(loid)s and rare earth elements in mine tailing. J. Environ. Chem. Eng. 10 (3), 107526 https://doi.org/10.1016/j.jece.2022.107526.

Bagherifam, S., Brown, T.C., Fellows, C.M., Naidu, R., Komarneni, S., 2022. *In situ* stabilization of arsenic in soil with organoclay, organozeolite, birnessite, goethite and lanthanum-doped magnetic biochar. Pedosphere 32 (5), 764–776. https://doi.org/10.1016/j.pedsph.2022.06.008.

Bailey, G., Orefice, M., Sprecher, B., Önal, M.A.R., Herraiz, E., Dewulf, W., Van Acker, K., 2021. Life cycle inventory of samarium-cobalt permanent magnets, compared to neodymium-iron-boron as used in electric vehicles. J. Clean. Prod. 286, 125294 https://doi.org/10.1016/j.jclepro.2020.125294.

Barakos, G., Mischo, H., 2021. Insertion of the social license to operate into the early evaluation of technical and economic aspects of mining projects: Experiences from the Norra Kärr and Bokan Dotson rare earth element projects. Extractive Industr. Soc. 8 (2), 100814 https://doi.org/10.1016/j.exis.2020.09.008.

Barreto, A.S., Moura, K.O., da Conceição Silva Barreto, M., Júnior, S.A., 2023. Luminescence of rare earth 3D hydroxide framework Eu^{3+}-doped and its application in dye adsorption tests. Appl. Clay Sci. 245, 107128 https://doi.org/10.1016/j.clay.2023.107128.

Barteková, E., Kemp, R., 2016. National strategies for securing a stable supply of rare earths in different world regions. Resour. Policy 49, 153–164. https://doi.org/10.1016/j.resourpol.2016.05.003.

Battsengel, A., Batnasan, A., Narankhuu, A., Haga, K., Watanabe, Y., Shibayama, A., 2018. Recovery of light and heavy rare earth elements from apatite ore using sulphuric acid leaching, solvent extraction and precipitation. Hydrometall. 179, 100–109. https://doi.org/10.1016/j.hydromet.2018.05.024.

Bell, J., 2024. Rare Earth Magnets: Manufacturing and Applications. In: Murty, Y.V., Alvin, M.A., Lifton, J.P. (Eds.), Rare Earth Metals and Minerals Industries: Status and Prospects. Springer International Publishing, Cham, pp. 295–317.

Bellucci, A., Mastellone, M., Girolami, M., Serpente, V., Generosi, A., Paci, B., Mezzi, A., Kaciulis, S., Carducci, R., Polini, R., Orlando, S., Santagata, A., De Bonis, A., Meucci, M., Mercatelli, L., Sani, E., Trucchi, D.M., 2020. Nanocrystalline lanthanum boride thin films by femtosecond pulsed laser deposition as efficient emitters in hybrid thermionic-photovoltaic energy converters. Appl. Surf. Sci. 513, 145829 https://doi.org/10.1016/j.apsusc.2020.145829.

Bernardo José, L., Cordeiro Silva, G., Cláudia Queiroz Ladeira, A., 2024. Pre-concentration and partial fractionation of rare earth elements by ion exchange. Miner. Eng. 205, 108477 https://doi.org/10.1016/j.mineng.2023.108477.

Bhatt, P.M., Belmabkhout, Y., Assen, A.H., Weseliński, Ł.J., Jiang, H., Cadiau, A., Xue, D.-X., Eddaoudi, M., 2017. Isoreticular rare earth fcu-MOFs for the selective removal of H_2S from CO_2 containing gases. Chem. Eng. J. 324, 392–396. https://doi.org/10.1016/j.cej.2017.05.008.

Binnemans, K., 2015. Interpretation of europium(III) spectra. Coord. Chem. Rev. 295, 1–45. https://doi.org/10.1016/j.ccr.2015.02.015.

Blanc, W., Gyu Choi, Y., Zhang, X., Nalin, M., Richardson, K.A., Righini, G.C., Ferrari, M., Jha, A., Massera, J., Jiang, S., Ballato, J., Petit, L., 2023. The past, present and future of photonic glasses: A review in homage to the United Nations International Year of glass 2022. Prog. Mater Sci. 134, 101084 https://doi.org/10.1016/j.pmatsci.2023.101084.

Bouri, E., Kanjilal, K., Ghosh, S., Roubaud, D., Saeed, T., Rare earth and allied sectors in stock markets: extreme dependence of return and volatility. Appl. Econ., 2021, 53, 1-21.10.1080/00036846.2021.1927971.

Bozkurt, M.F., Salanci, B.V., Uğur, Ö., 2016. Intra-Arterial Radionuclide Therapies for Liver Tumors. Semin. Nucl. Med. 46 (4), 324–339. https://doi.org/10.1053/j.semnuclmed.2016.01.008.
Brewster, E.T., Freguia, S., Edraki, M., Berry, L., Ledezma, P., 2020. Staged electrochemical treatment guided by modelling allows for targeted recovery of metals and rare earth elements from acid mine drainage. J. Environ. Manage. 275, 111266 https://doi.org/10.1016/j.jenvman.2020.111266.
Brown, R.M., Mirkouei, A., Reed, D., Thompson, V., 2023. Current nature-based biological practices for rare earth elements extraction and recovery: Bioleaching and biosorption. Renew. Sustain. Energy Rev. 173, 113099 https://doi.org/10.1016/j.rser.2022.113099.
Buechler, D.T., Zyaykina, N.N., Spencer, C.A., Lawson, E., Ploss, N.M., Hua, I., 2020. Comprehensive elemental analysis of consumer electronic devices: Rare earth, precious, and critical elements. Waste Manag. 103, 67–75. https://doi.org/10.1016/j.wasman.2019.12.014.
Burdzy, K., Jastrząb, R., Kołodyńska, D., 2024. GLDA and ion exchangers: Unlocking sustainable solutions for recovery of rare earth elements. Chem. Eng. J. 479, 147632 https://doi.org/10.1016/j.cej.2023.147632.
Cen, P., Bian, X., Liu, Z., Gu, M., Wu, W., Li, B., 2021a. Extraction of rare earths from bastnaesite concentrates: A critical review and perspective for the future. Miner. Eng. 171, 107081 https://doi.org/10.1016/j.mineng.2021.107081.
Cen, P., Bian, X., Wu, W., Li, B., 2021b. A sustainable green technology for separation and simultaneous recovery of rare earth elements and fluorine in bastnaesite concentrates. Sep. Purif. Technol. 274, 118380 https://doi.org/10.1016/j.seppur.2021.118380.
Chadly, A., Hasan, H.R., Moawad, K., Salah, K., Omar, M., Mayyas, A., 2023. A blockchain-based solution for the traceability of rare earth metals used in thin-film photovoltaics. J. Clean. Prod. 428, 139399 https://doi.org/10.1016/j.jclepro.2023.139399.
Chai, S., Zhang, Z., Ge, J., 2020. Evolution of environmental policy for China's rare earths: Comparing central and local government policies. Resour. Policy 68, 101786. https://doi.org/10.1016/j.resourpol.2020.101786.
Chancerel, P., Marwede, M., Nissen, N.F., Lang, K.-D., 2015. Estimating the quantities of critical metals embedded in ICT and consumer equipment. Resour. Conserv. Recycl. 98, 9–18. https://doi.org/10.1016/j.resconrec.2015.03.003.
Chapman, B., 2018. The geopolitics of rare earth elements: Emerging challenge for U.S. national security and economics. Journal of Self-Governance and Management. Economics 6 (2), 50–91.
Charalampides, G., Vatalis, K.I., Apostoplos, B., Ploutarch-Nikolas, B., 2015. Rare earth elements: industrial applications and economic dependency of Europe. Procedia Econ. Finance 24, 126–135. https://doi.org/10.1016/S2212-5671(15)00630-9.
Charlier, C., Guillou, S., 2014. Distortion effects of export quota policy: an analysis of the *China-Raw Materials* dispute. China Econ. Rev. 31, 320–338. https://doi.org/10.1016/j.chieco.2014.10.004.
Chatterjee, A.K., 2009. Re-examining the prospects of aluminous cements based on alkali-earth and rare-earth oxides. Cem. Concr. Res. 39 (11), 981–988. https://doi.org/10.1016/j.cemconres.2009.07.027.
Cheisson, T., Schelter, E.J., 2019. Rare earth elements: Mendeleev's bane, modern marvels. Science 363 (6426), 489–493. https://doi.org/10.1126/science.aau7628.
Chelgani, S.C., Rudolph, M., Leistner, T., Gutzmer, J., Peuker, U.A., 2015. A review of rare earth minerals flotation: Monazite and xenotime. Int. J. Min. Sci. Technol. 25 (6), 877–883. https://doi.org/10.1016/j.ijmst.2015.09.002.
Chen, H., Chen, H., Kardos, L., Szabó, V., 2023a. Application of Biochar for Ion-Adsorption of Rare Earth Contaminated Soil Remediation: A Review. Sustainability 15 (10), 7934.
Chen, L., Chen, S., Xing, T., Long, Y., Wang, Z., Kong, X., Xu, A., Wu, Q., Sun, Y., 2024a. Phytoremediation with application of anaerobic fermentation residues regulate the assembly of ecological clusters within co-occurrence network in ionic rare earth tailings soil: A pot experiment. Environ. Pollut. 340, 122790 https://doi.org/10.1016/j.envpol.2023.122790.
Chen, W.-Q., Eckelman, M.J., Sprecher, B., Chen, W., Wang, P., 2024c. Interdependence in rare earth element supply between China and the United States helps stabilize global supply chains. One Earth. https://doi.org/10.1016/j.oneear.2024.01.011.
Chen, J., Zhu, X., Liu, G., Chen, W., Yang, D., 2018. China's rare earth dominance: The myths and the truths from an industrial ecology perspective. Resour. Conserv. Recycl. 132, 139–140. https://doi.org/10.1016/j.resconrec.2018.01.011.
Chen, J., Gao, H., Tao, Z., Wang, L., Li, R., Wang, G., 2023b. Recent progress in mixed rare earth metal-organic frameworks: From synthesis to application. Coord. Chem. Rev. 485, 215121 https://doi.org/10.1016/j.ccr.2023.215121.
Chen, Q., Hong, J., Lai, G., Yang, X., Chen, G., Xu, N., Li, X., Hu, K., Chen, T., Song, Y., Wan, Y., 2024b. What are exposure biomarkers of rare earth elements for the ionic rare earth occupational population? Environ. Pollut. 345, 123499 https://doi.org/10.1016/j.envpol.2024.123499.
Chen, Z., Hu, Z., Li, K., 2021b. The spillover effect of trade policy along the value Chain: Evidence from China's rare earth-related sectors. World Economy 44 (12), 3550–3582.
Chen, Z., Li, Z., Chen, J., Kallem, P., Banat, F., Qiu, H., 2022. Recent advances in selective separation technologies of rare earth elements: a review. J. Environ. Chem. Eng. 10 (1), 107104 https://doi.org/10.1016/j.jece.2021.107104.
Chen, Y., Liu, S., Zhou, N., Li, N., Zhou, H., Sun, L.-D., Yan, C.-H., 2021a. An overview of rare earth coupled lead halide perovskite and its application in photovoltaics and light emitting devices. Prog. Mater Sci. 120, 100737 https://doi.org/10.1016/j.pmatsci.2020.100737.
Chen, J., Sun, S., Tu, G., Xiao, F., 2023c. Review of efficient recycling and resource utilization for rare earth molten salt electrolytic slag. Miner. Eng. 204, 108425 https://doi.org/10.1016/j.mineng.2023.108425.
Chen, W., Wang, P., Meng, F., Pehlken, A., Wang, Q.-C., Chen, W.-Q., 2024d. Reshaping heavy rare earth supply chains amidst China's stringent environmental regulations. Fundamental Res. https://doi.org/10.1016/j.fmre.2023.11.019.
Chow, C.C.T., Ainslie, M.D., Chau, K.T., 2023. High temperature superconducting rotating electrical machines: An overview. Energy Rep. 9, 1124–1156. https://doi.org/10.1016/j.egyr.2022.11.173.
Corbett, M.K., Gifford, A., Fimognari, N., Watkin, E.L.J., 2024. Analysis of element yield, bacterial community structure and the impact of carbon sources for bioleaching rare earth elements from high grade monazite. Res. Microbiol. 175 (1), 104133 https://doi.org/10.1016/j.resmic.2023.104133.
Costis, S., Mueller, K.K., Coudert, L., Neculita, C.M., Reynier, N., Blais, J.-F., 2021. Recovery potential of rare earth elements from mining and industrial residues: A review and cases studies. J. Geochem. Explor. 221, 106699 https://doi.org/10.1016/j.gexplo.2020.106699.
Cui, S., Li, R., Zhu, C., Pei, J., Wen, Y., 2020. Cerium-bismuth solid solution material prepared and application in automobile exhaust purification. Sep. Purif. Technol. 239, 116520 https://doi.org/10.1016/j.seppur.2020.116520.
Cui, B., Liu, X., Nlebedim, C.I., Cui, J., 2022a. Mechanically strengthened heterogeneous Sm-Co sintered magnets. J. Alloys Compd. 904, 163937 https://doi.org/10.1016/j.jallcom.2022.163937.
Cui, B., Liu, X., Nlebedim, I.C., Cui, J., 2022b. Mechanically robust high magnetic-performance Sm-Co sintered magnets through microstructure engineering. J. Alloys Compd. 926, 166869 https://doi.org/10.1016/j.jallcom.2022.166869.
Cui, H., Zhang, X., Chen, J., Qian, X., Zhong, Y., Ma, C., Zhang, H., Liu, K., 2023. The Construction of a Microbial Synthesis System for Rare Earth Enrichment and Material Applications. Adv. Mater. 35 (33), 2303457. https://doi.org/10.1002/adma.202303457.
da Silva Júnior, J.F., Nascimento, E.d.S.d., Santos, A.S., Feitosa, R.P., Dávila, Y.G., da Luz Júnior, G.E., Furtini, J.A.O., Gusmão, G.O.d.M., Viana, B.C., Samarium doped cerium oxide nanoparticles under extreme temperatures and its photocatalysis activity on tetracycline. Solid State Commun., 2024, **378**, 115412.doi: 10.1016/j.ssc.2023.115412.
Dai, L., Deng, L., Wang, W., Li, Y., Wang, L., Liang, T., Liao, X., Cho, J., Sonne, C., Shiung Lam, S., Rinklebe, J., 2023a. Potentially toxic elements in human scalp hair around China's largest polymetallic rare earth ore mining and smelting area. Environ. Int. 172, 107775 https://doi.org/10.1016/j.envint.2023.107775.
Dai, L., Ge, J., Wang, L., Wan, X., Guo, G., Liang, T., Bolan, N., Rennert, T., Rinklebe, J., 2023b. Hair-biomonitoring assessment of rare-earth-element exposure in residents of the largest rare-earth mining and smelting area of China. Environ. Int. 179, 108177 https://doi.org/10.1016/j.envint.2023.108177.
Dai, C., Huang, X., Liu, Q., You, X., Duan, Y., Li, J., Hu, J., Zhang, Y., Liu, S., Fu, R., 2024. Peroxymonosulfate activation by ruthenium in homogeneous systems for degradation of triclosan: Comparison between Ru(II) and Ru(III). Sep. Purif. Technol. 332, 125820 https://doi.org/10.1016/j.seppur.2023.125820.
Dallas, J.A., Raval, S., Saydam, S., Dempster, A.G., 2021. Investigating extraterrestrial bodies as a source of critical minerals for renewable energy technology. Acta Astronaut. 186, 74–86. https://doi.org/10.1016/j.actaastro.2021.05.021.
Dashti, S., Shakibania, S., Rashchi, F., Ghahreman, A., 2023. Synergistic, extractive, and selective separation of light, medium, and heavy rare earth elements using Cyanex 572 and Alamine 336 from a chloride medium. Miner. Eng. 204, 108447 https://doi.org/10.1016/j.mineng.2023.108447.
de Freitas, A.d.S., Pompermayer, L.L.d.O., Santos, A.D.d.O., do Nascimento, M.T.L., Saint'Pierre, T.D., Hauser-Davis, R.A., Baptista Neto, J.A., da Fonseca, E.M., Rare earth elements as sediment contamination tracers in a coastal lagoon in the state of Rio de Janeiro, Brazil. J. Trace Elements Miner., 2023, **4**, 100068.doi: 10.1016/j.jtemin.2023.100068.
Demol, J., Ho, E., Soldenhoff, K., Senanayake, G., 2019. The sulfuric acid bake and leach route for processing of rare earth ores and concentrates: A review. Hydrometall. 188, 123–139. https://doi.org/10.1016/j.hydromet.2019.05.015.
Depraiter, L., Goutte, S., 2023. The role and challenges of rare earths in the energy transition. Resour. Policy 86, 104137. https://doi.org/10.1016/j.resourpol.2023.104137.
Dewulf, B., Riaño, S., Binnemans, K., 2022. Separation of heavy rare-earth elements by non-aqueous solvent extraction: Flowsheet development and mixer-settler tests. Sep. Purif. Technol. 290, 120882 https://doi.org/10.1016/j.seppur.2022.120882.
Deyneko, D.V., Spassky, D.A., Antropov, A.V., Ril', A.I., Baryshnikova, O.V., Pavlova, E.T., Lazoryak, B.I., 2023. Anomalous oxidation state of europium in the $Sr_3(PO_4)_2$-type phosphors doped with alkaline cations. Mater. Res. Bull. 165, 112296 https://doi.org/10.1016/j.materresbull.2023.112296.
Ding, R.G., Ojo, O.A., Chaturvedi, M.C., 2007. Laser beam weld-metal microstructure in a yttrium modified directionally solidified Ni_3Al-base alloy. Intermetallics 15 (12), 1504–1510. https://doi.org/10.1016/j.intermet.2007.05.008.
Dong, J., Ni, X., Meng, R., Kong, W., Liang, S., Zhou, J., 2022. A rare-earth spectral traceability anti-counterfeiting detection technology. Optoelectron. Lett. 18 (9), 535–540. https://doi.org/10.1007/s11801-022-2048-z.
Do-Thanh, C.-L., Luo, H., Dai, S., 2023. A perspective on task-specific ionic liquids for the separation of rare earth elements. RSC Sustainability 1 (5), 1168–1176. https://doi.org/10.1039/d3su00007a.
Dushyantha, N., Batapola, N., Ilankoon, I.M.S.K., Rohitha, S., Premasiri, R., Abeysinghe, B., Ratnayake, N., Dissanayake, K., 2020. The story of rare earth elements (REEs): Occurrences, global distribution, genesis, geology, mineralogy and global production. Ore Geol. Rev. 122, 103521 https://doi.org/10.1016/j.oregeorev.2020.103521.
Dushyantha, N., Ilankoon, I.M.S.K., Ratnayake, N.P., Premasiri, H.M.R., Dharmaratne, P.G.R., Abeysinghe, A.M.K.B., Rohitha, L.P.S., Chandrajith, R., Ratnayake, A.S., Dissanayake, D.M.D.O.K., Batapola, N.M., 2022. Recovery potential of rare earth

elements (REEs) from the gem mining waste of Sri Lanka: a case study for mine waste management. Minerals 12 (11), 1411.
Dutta, T., Kim, K.-H., Uchimiya, M., Kwon, E.E., Jeon, B.-H., Deep, A., Yun, S.-T., 2016. Global demand for rare earth resources and strategies for green mining. Environ. Res. 150, 182–190. https://doi.org/10.1016/j.envres.2016.05.052.
Dzulqornain, A.M., Cueva-Sola, A.B., Chung, K.W., Lee, J.-Y., Jyothi, R.K., 2024. Strategy for possible separation of light rare earth elements (La, Ce, Pr, Nd) from synthetic chloride solutions by oxidative precipitation, solvent extraction and stripping. Hydrometall. 224, 106242 https://doi.org/10.1016/j.hydromet.2023.106242.
Eheliyagoda, D., Ramanujan, D., Veluri, B., Liu, Q., Liu, G., 2023. Tracing the multiregional evolution of the global dysprosium demand-supply chain. Resour. Conserv. Recycl. 199, 107245 https://doi.org/10.1016/j.resconrec.2023.107245.
El Ouardi, Y., Virolainen, S., Massima Mouele, E.S., Laatikainen, M., Repo, E., Laatikainen, K., 2023. The recent progress of ion exchange for the separation of rare earths from secondary resources – A review. Hydrometall. 218, 106047 https://doi.org/10.1016/j.hydromet.2023.106047.
Elkhlifi, Z., Kamran, M., Maqbool, A., El-Naggar, A., Ifthikar, J., Parveen, A., Bashir, S., Rizwan, M., Mustafa, A., Irshad, S., Ali, S., Chen, Z., 2021. Phosphate-lanthanum coated sewage sludge biochar improved the soil properties and growth of ryegrass in an alkaline soil. Ecotoxicol. Environ. Saf. 216, 112173 https://doi.org/10.1016/j.ecoenv.2021.112173.
Eskanlou, A., Huang, Q., Zhang, P., 2022. De-sliming followed by froth flotation for the recovery of phosphorus and enrichment of rare earth elements from Florida waste clay. Resour. Conserv. Recycl. 178, 106049 https://doi.org/10.1016/j.resconrec.2021.106049.
Fan, J.H., Omura, A., Roca, E., 2023. Geopolitics and rare earth metals. Eur. J. Polit. Econ. 78, 102356 https://doi.org/10.1016/j.ejpoleco.2022.102356.
Feng, X.-L., Long, Z.-Q., Cui, D.-L., Wang, L.-S., Huang, X.-W., Zhang, G.-C., 2013. Kinetics of rare earth leaching from roasted ore of bastnaesite with sulfuric acid. Trans. Nonferrous Met. Soc. Chin. 23 (3), 849–854. https://doi.org/10.1016/S1003-6326(13)62538-8.
Fishman, T., Graedel, T.E., 2019. Impact of the establishment of US offshore wind power on neodymium flows. Nat. Sustainability 2 (4), 332–338. https://doi.org/10.1038/s41893-019-0252-z.
Fois, M., Cox, T., Ratcliffe, N., de Lacy Costello, B., 2021. Rare earth doped metal oxide sensor for the multimodal detection of volatile organic compounds (VOCs). Sens. Actuators B 330, 129264. https://doi.org/10.1016/j.snb.2020.129264.
FX168, 【Rare Earth Spotlight】Shocking Revelation of China-Myanmar Collusion! Environmental Groups Report: Chinese Workers Flooding into Myanmar's Mining Areas for Illegal Rare Earth Extraction to Supply China. Sina finance, 2021.
Gad, S.C., 2024. Cerium. In: Wexler, P. (Ed.), Encyclopedia of Toxicology (Fourth Edition), Academic Press, Oxford, pp. 711-714.
Ghafoor, A., Bibi, I., Majid, F., Ata, S., Nouren, S., Raza, Q., Mansoor, S., Alqahtani, F.O., Elqahtani, Z.M., Mehr un, M., Iqbal, M., 2023. Yttrium and cobalt doped $LaNiO_3$ nanoparticles synthesis and solar light driven photocatalytic removal of Rhodamine B. Mater. Res. Bull. 159, 112112 https://doi.org/10.1016/j.materresbull.2022.112112.
Gherardini, M., Masiero, F., Ianniciello, V., Cipriani, C., 2023. The myokinetic interface: Implanting permanent magnets to restore the sensory-motor control loop in amputees. Curr. Opin. Biomed. Eng. 27, 100460 https://doi.org/10.1016/j.cobme.2023.100460.
Golev, A., Scott, M., Erskine, P.D., Ali, S.H., Ballantyne, G.R., 2014. Rare earths supply chains: Current status, constraints and opportunities. Resour. Policy 41, 52–59. https://doi.org/10.1016/j.resourpol.2014.03.004.
Gomez, V., Balu, A.M., Serrano-Ruiz, J.C., Irusta, S., Dionysiou, D.D., Luque, R., Santamaría, J., 2012. Microwave-assisted mild-temperature preparation of neodymium-doped titania for the improved photodegradation of water contaminants. Appl. Catal. A 441–442, 47–53. https://doi.org/10.1016/j.apcata.2012.07.003.
Gómez, M., Grimes, S., Bin-Jamaludin, D., Fowler, G., 2023. Novel closed-loop recovery of light rare earth elements, as their oxides, from end-of-life mobile phone speakers using [Hbet][Tf_2N]. J. Environ. Chem. Eng. 11 (5), 111001 https://doi.org/10.1016/j.jece.2023.111001.
Gu, B., 2011. Mineral export restraints and sustainable development—are rare earths testing the WTO's loopholes? J. Int. Econ. Law 14 (4), 765–805. https://doi.org/10.1093/jiel/jgr034.
Gultekin, B., Bulut, F., Yildiz, H., Us, H., Ogul, H., 2023. Production and investigation of 3D printer ABS filaments filled with some rare-earth elements for gamma-ray shielding. Nucl. Eng. Technol. 55 (12), 4664–4670. https://doi.org/10.1016/j.net.2023.09.009.
Guo, T., He, D., Liu, Y., Li, J., Wang, F., 2024. Lanthanum promotes *Solanum nigrum* L. growth and phytoremediation of cadmium and lead through endocytosis: Physiological and biochemical response, heavy metal uptake and visualization. Sci. Total Environ. 912, 168915 https://doi.org/10.1016/j.scitotenv.2023.168915.
Guo, D., Li, J., Yue, G., Li, M., Hu, W., Shi, Y., Ma, F., 2023. Effects of magnetization with neodymium magnets treatment on blueberry wine ageing. Food Biosci. 51, 102332 https://doi.org/10.1016/j.fbio.2022.102332.
Guo, Q., You, W., 2023. A comprehensive evaluation of the international competitiveness of strategic minerals in China, Australia, Russia and India: The case of rare earths. Resour. Policy 85, 103821. https://doi.org/10.1016/j.resourpol.2023.103821.
Gupta, I., Singh, S., Bhagwan, S., Singh, D., 2021. Rare earth (RE) doped phosphors and their emerging applications: A review. Ceram. Int. 47 (14), 19282–19303. https://doi.org/10.1016/j.ceramint.2021.03.308.
Han, A., Ge, J., Lei, Y., 2015. An adjustment in regulation policies and its effects on market supply: Game analysis for China's rare earths. Resour. Policy 46, 30–42. https://doi.org/10.1016/j.resourpol.2015.07.007.
Han, J., Wu, G., Li, Y., Li, S., Liao, W., 2023. Efficient separation of high-abundance rare earth element yttrium and lanthanides by solvent extraction using 2-(bis((2-ethylhexyl)oxy)phosphoryl)-2-hydroxyacetic acid. Sep. Purif. Technol. 306, 122683 https://doi.org/10.1016/j.seppur.2022.122683.
Hao, Z., Li, Y., Li, H., Wei, B., Liao, X., Liang, T., Yu, J., 2015. Levels of rare earth elements, heavy metals and uranium in a population living in Baiyun Obo, Inner Mongolia, China: A pilot study. Chemosphere 128, 161–170. https://doi.org/10.1016/j.chemosphere.2015.01.057.
Hao, C.-L., Yang, C.-Y., Liu, P., Luan, Y.-K., Sang, B.-G., 2023. Effects of rare earth elements on inclusions, microstructure and impact toughness of spring steel. J. Iron Steel Res. Int. https://doi.org/10.1007/s42243-023-01055-8.
Hastir, A., Kohli, N., Singh, R.C., 2017. Comparative study on gas sensing properties of rare earth (Tb, Dy and Er) doped ZnO sensor. J. Phys. Chem. Solids 105, 23–34. https://doi.org/10.1016/j.jpcs.2017.02.004.
Hau, L., Zhu, H., Yu, Y., Yu, D., 2022. Time-frequency coherence and quantile causality between trade policy uncertainty and rare earth prices: Evidence from China and the US. Resour. Policy 75, 102529. https://doi.org/10.1016/j.resourpol.2021.102529.
He, D., Guo, T., Peng, C., Li, J., Wang, F., 2023a. Foliar application of lanthanum promotes growth and phytoremediation potential Solanum nigrum L. J. Environ. Manage. 334, 117259 https://doi.org/10.1016/j.jenvman.2023.117259.
He, Q., Qiu, J., Chen, J., Zan, M., Xiao, Y., 2022. Progress in green and efficient enrichment of rare earth from leaching liquor of ion adsorption type rare earth ores. J. Rare Earths 40 (3), 353–364. https://doi.org/10.1016/j.jre.2021.09.011.
He, Y., Sun, R., Zhang, D., Wang, Y., Zhou, S., Deng, X., Wang, B., Hu, G., 2023b. Separable alginate gel spheres encapsulated with La-Fe modified biochar for efficient adsorption of Sb(III) with high capacity. J. Hazard. Mater. 460, 132322 https://doi.org/10.1016/j.jhazmat.2023.132322.
He, H., Yang, W., 2022. REE Mineral Resources in China: Review and Perspective. Geotecton. Metallog. 46 (05), 829–841. https://doi.org/10.16539/j.ddgzyckx.2022.05.001.
He, Y., Zhang, L., An, X., Wan, G., Zhu, W., Luo, Y., 2019. Enhanced fluoride removal from water by rare earth (La and Ce) modified alumina: Adsorption isotherms, kinetics, thermodynamics and mechanism. Sci. Total Environ. 688, 184–198. https://doi.org/10.1016/j.scitotenv.2019.06.175.
Hengkai, L., Feng, X., Qin, L., 2020. Remote sensing monitoring of land damage and restoration in rare earth mining areas in 6 counties in southern Jiangxi based on multisource sequential images. J. Environ. Manage. 267, 110653 https://doi.org/10.1016/j.jenvman.2020.110653.
Henke, M., Narjes, G., Hoffmann, J., Wohlers, C., Urbanek, S., Heister, C., Steinbrink, J., Canders, W.-R., Ponick, B., 2018. Challenges and opportunities of very light high-performance electric drives for aviation. Energies 11 (2), 344.
Henriques, I., Böhm, S., 2022. The perils of ecologically unequal exchange: Contesting rare-earth mining in Greenland. J. Clean. Prod. 349, 131378 https://doi.org/10.1016/j.jclepro.2022.131378.
Hermassi, M., Granados, M., Valderrama, C., Skoglund, N., Ayora, C., Cortina, J.L., 2022. Impact of functional group types in ion exchange resins on rare earth element recovery from treated acid mine waters. J. Clean. Prod. 379, 134742 https://doi.org/10.1016/j.jclepro.2022.134742.
Hidayah, N.N., Abidin, S.Z., 2017. The evolution of mineral processing in extraction of rare earth elements using solid-liquid extraction over liquid-liquid extraction: A review. Miner. Eng. 112, 103–113. https://doi.org/10.1016/j.mineng.2017.07.014.
Hidayah, N.N., Abidin, S.Z., 2018. The evolution of mineral processing in extraction of rare earth elements using liquid-liquid extraction: A review. Miner. Eng. 121, 146–157. https://doi.org/10.1016/j.mineng.2018.03.018.
Ho, C.-C., Kang, F., Chang, G.-M., You, S.-J., Wang, Y.-F., 2019. Application of recycled lanthanum-doped TiO_2 immobilized on commercial air filter for visible-light photocatalytic degradation of acetone and NO. Appl. Surf. Sci. 465, 31–40. https://doi.org/10.1016/j.apsusc.2018.09.136.
Hou, Z., Pei, W., Zhang, X., Zhang, K., Liu, Y., Deng, J., Jing, L., Dai, H., 2020. Rare earth oxides and their supported noble metals in application of environmental catalysis. J. Rare Earths 38 (8), 819–839. https://doi.org/10.1016/j.jre.2020.01.011.
Hu, Z.Y., Richter, H., Sparovek, G., Schnug, E., 2004. Physiological and biochemical effects of rare earth elements on plants and their agricultural significance: A review. J. Plant Nutr. 27 (1), 183–220. https://doi.org/10.1081/PLN-120027555.
Hung, N.T., Thuan, L.B., Thanh, T.C., Thuy, N.T., Tra, D.T.T., Do Van, K., Watanabe, M., Minh, P.Q., Than, H.S., Vuong, N.D., Van Phuc, D., Lee, J.-Y., Jeon, J.H., Jyothi, R.K., 2022. Selective recovery of thorium and uranium from leach solutions of rare earth concentrates in continuous solvent extraction mode with primary amine N1923. Hydrometall. 213, 105933 https://doi.org/10.1016/j.hydromet.2022.105933.
Imholte, D.D., Nguyen, R.T., Vedantam, A., Brown, M., Iyer, A., Smith, B.J., Collins, J.W., Anderson, C.G., O'Kelley, B., 2018. An assessment of U.S. rare earth availability for supporting U.S. wind energy growth targets. Energy Policy 113, 294–305. https://doi.org/10.1016/j.enpol.2017.11.001.
Ippolito, N.M., Innocenzi, V., De Michelis, I., Medici, F., Vegliò, F., 2017. Rare earth elements recovery from fluorescent lamps: A new thermal pretreatment to improve the efficiency of the hydrometallurgical process. J. Clean. Prod. 153, 287–298. https://doi.org/10.1016/j.jclepro.2017.03.195.
Irrawaddy, T., Illegal Rare Earth Mines on China Border Multiply Since Myanmar's Coup. The Irrawaddy, 2021. https://www.irrawaddy.com/news/burma/illegal-rare-earth-mines-china-border-multiply-since-myanmars-coup.html.
Jamaludin, H., Patunru, A., 2022. The impact of objective and subjective valuations on behaviours: A case study of a rare earth processing plant. Extract. Industr. Soc. 12, 101185 https://doi.org/10.1016/j.exis.2022.101185.
Janoš, P., Ederer, J., Pilařová, V., Henych, J., Tolasz, J., Milde, D., Opletal, T., 2016. Chemical mechanical glass polishing with cerium oxide: Effect of selected physico-

chemical characteristics on polishing efficiency. Wear 362–363, 114–120. https://doi.org/10.1016/j.wear.2016.05.020.
Jha, M.K., Kumari, A., Panda, R., Rajesh Kumar, J., Yoo, K., Lee, J.Y., 2016. Review on hydrometallurgical recovery of rare earth metals. Hydrometall. 165, 2–26. https://doi.org/10.1016/j.hydromet.2016.01.035.
Ji, G., Zhang, H., Li, Q., Xia, H., 2018. Current status of rare earth resources in China and strategies for its sustainable development. China Mining Magazine 27 (08), 9–16.
Jia, Y.G., Yan, Z., Shang, L., Chen, J., 2024. Environmental risk of ion-absorbed rare earth ores: concentration of leaching agent and fractionation of Pb. Environ. Sci. Pollut. Res. 31 (4), 6425–6436. https://doi.org/10.1007/s11356-023-31516-2.
Jowitt, S.M., 2022. Mineral economics of the rare-earth elements. MRS Bull. 47 (3), 276–282. https://doi.org/10.1557/s43577-022-00289-3.
Jun, B.-M., Kim, H.-H., Rho, H., Seo, J., Jeon, J.-W., Nam, S.-N., Min Park, C., Yoon, Y., 2023. Recovery of rare-earth and radioactive elements from contaminated water through precipitation: A review. Chem. Eng. J. 475, 146222 https://doi.org/10.1016/j.cej.2023.146222.
Jyothi, R.K., Thenepalli, T., Ahn, J.W., Parhi, P.K., Chung, K.W., Lee, J.-Y., 2020. Review of rare earth elements recovery from secondary resources for clean energy technologies: Grand opportunities to create wealth from waste. J. Clean. Prod. 267, 122048 https://doi.org/10.1016/j.jclepro.2020.122048.
Kaim, V., Rintala, J., He, C., 2023. Selective recovery of rare earth elements from e-waste via ionic liquid extraction: A review. Sep. Purif. Technol. 306, 122699 https://doi.org/10.1016/j.seppur.2022.122699.
Kalisz, S., Kibort, K., Mioduska, J., Lieder, M., Małachowska, A., 2022. Waste management in the mining industry of metals ores, coal, oil and natural gas - A review. J. Environ. Manage. 304, 114239 https://doi.org/10.1016/j.jenvman.2021.114239.
Kamenopoulos, S.N., Shields, D., Agioutantis, Z., 2016. Chapter 6 - Sustainable Development Criteria and Indicators for the Assessment of Rare Earth Element Mining Projects. In: Borges De Lima, I., Leal Filho, W. (Eds.), Rare Earths Industry. Elsevier, Boston, pp. 87–109.
Kante, K., Deliyanni, E., Bandosz, T.J., 2009. Interactions of NO_2 with activated carbons modified with cerium, lanthanum and sodium chlorides. J. Hazard. Mater. 165 (1), 704–713. https://doi.org/10.1016/j.jhazmat.2008.10.092.
Keerthana, S.P., Yuvakkumar, R., Ravi, G., Arunmetha, S., Thambidurai, M., Velauthapillai, D., 2024. Magnetically separable rare earth metal incorporated $CdFe_2O_4$ photocatalyst for degradation of cationic and azo dyes. J. Mol. Struct. 1302, 137479 https://doi.org/10.1016/j.molstruc.2024.137479.
Khalajmasoumi, M., Sadeghi, B., Carranza, E.J.M., Sadeghi, M., 2017. Geochemical anomaly recognition of rare earth elements using multi-fractal modeling correlated with geological features. Central Iran. J. Geochem. Explor. 181, 318–332. https://doi.org/10.1016/j.gexplo.2016.12.011.
Khedimallah, A., Dabaki, Y., Kaabi, A., Khaldi, C., Molière, M., ElKedim, O., Fenineche, N., Lamloumi, J., 2022. Electrochemical study of the $LaFe_{0.8}Ni_{0.2}O_3$ perovskite-type oxide used as anode in nickel-metal hydride batteries. Ceram. Int. 48 (21), 31157–31171. https://doi.org/10.1016/j.ceramint.2022.06.191.
Kim, K., Candeago, R., Rim, G., Raymond, D., Park, A.-H.-A., Su, X., 2021. Electrochemical approaches for selective recovery of critical elements in hydrometallurgical processes of complex feedstocks. iScience 24 (5), 102374. https://doi.org/10.1016/j.isci.2021.102374.
Klinger, J.M., 2015. A historical geography of rare earth elements: From discovery to the atomic age. Extract. Industr. Soc. 2 (3), 572–580. https://doi.org/10.1016/j.exis.2015.05.006.
Klinger, J.M., 2018. Rare earth elements: Development, sustainability and policy issues. Extract. Industr. Soc. 5 (1), 1–7. https://doi.org/10.1016/j.exis.2017.12.016.
Kottaisamy, M., Jagannathan, R., Rao, R.P., Avudaithai, M., Srinivasan, L.K., Sundaram, V., 1995. On the Formation of Flux Grown $Y_2O_2S : Eu^{3+}$ Red Phosphor. J. Electrochem. Soc. 142 (9), 3205. https://doi.org/10.1149/1.2048714.
Kotte-Hewa, D.J., Durce, D., Salah, S., Ruiz Cánovas, C., Smolders, E., 2023. Remediation of acid mine drainage and immobilization of rare earth elements: Comparison between natural and residual alkaline materials. Appl. Geochem. 158, 105800 https://doi.org/10.1016/j.apgeochem.2023.105800.
Kousar, T., Aadil, M., Zulfiqar, S., Ibrahim, S.M., Mubeen, S., Hassan, W., Shafiq, K., Mahmood, F., 2023. Facile synthesis of graphene anchored rare earth doped mixed metal ferrite nanorods: A potential candidate for azo dye mineralization. J. Rare Earths. https://doi.org/10.1016/j.jre.2023.07.002.
Kumar, P., Kumar, R., 2022. Investigations on rare earth activated ZnO nanoparticles reinforcement in polymer matrix for 3D printing application. In: Hashmi M.S.J. (Ed.), Encyclopedia of Materials: Plastics and Polymers, Elsevier, Oxford, pp. 204-211.
Kumari, A., Panda, R., Jha, M.K., Kumar, J.R., Lee, J.Y., 2015. Process development to recover rare earth metals from monazite mineral: A review. Miner. Eng. 79, 102–115. https://doi.org/10.1016/j.mineng.2015.05.003.
Kumari, A., Sahu, S.K., 2023. A comprehensive review on recycling of critical raw materials from spent neodymium iron boron (NdFeB) magnet. Sep. Purif. Technol. 317, 123527 https://doi.org/10.1016/j.seppur.2023.123527.
Lee, Y., Dacass, T., 2022. Reducing the United States' risks of dependency on China in the rare earth market. Resour. Policy 77, 102702. https://doi.org/10.1016/j.resourpol.2022.102702.
Leng, Z., Sun, H., Cheng, J., Wang, H., Yao, Z., 2021. China's rare earth industry technological innovation structure and driving factors: A social network analysis based on patents. Resour. Policy 73, 102233. https://doi.org/10.1016/j.resourpol.2021.102233.
Li, D., Li, Y., Pan, D., Zhang, Z., Choi, C.-J., 2019. Prospect and status of iron-based rare-earth-free permanent magnetic materials. J. Magn. Magn. Mater. 469, 535–544. https://doi.org/10.1016/j.jmmm.2018.09.032.
Li, C., Li, A., Tang, J., Yang, X., Li, J., Jiang, J., 2023a. Preparation and properties of Portland cement from secondary recycle waste of rare earth tailing. Constr. Build. Mater. 406, 133337 https://doi.org/10.1016/j.conbuildmat.2023.133337.
Li, J., Li, T., Xue, G., Liu, J., Ma, P., Wang, L., 2024a. One step synthesis of cerium-based porous carbon microsphere by ultrasonic spray pyrolysis and its adsorption of rhodamine B. Sep. Purif. Technol. 346, 127524 https://doi.org/10.1016/j.seppur.2024.127524.
Li, Y., Liu, L., Wang, Z., Zhou, L., Lan, Y., Chen, C., 2021. Simultaneous oxidation of 4-aminophenylarsonic acid and adsorption of the produced inorganic arsenic by a combination of Co_3O_4-La_2CO_5@RSBC with peroxymonosulfate. Chem. Eng. J. 413, 127417 https://doi.org/10.1016/j.cej.2020.127417.
Li, Z.-Z., Meng, Q., Zhang, L., Lobont, O.-R., Shen, Y., 2023c. How do rare earth prices respond to economic and geopolitical factors? Resour. Policy 85, 103853. https://doi.org/10.1016/j.resourpol.2023.103853.
Li, J.G., Wang, N., Liu, J.D., Xu, W., 2024b. Influence of rare earth elements (Y, La and Ce) on the mechanical properties and oxidation resistance of nickel-based superalloys: A critical review. J. Mater. Sci. Technol. https://doi.org/10.1016/j.jmst.2023.11.077.
Li, L., Wang, Y., Gao, Z., Mao, X., Zhang, X., Xing, W., Jia, C., Huang, L., Tang, J., 2024c. Research progress on electrospinning fluorescent nanofibers based on rare earth complex. Dyes Pigm. 224, 111977 https://doi.org/10.1016/j.dyepig.2024.111977.
Li, Y., Xu, R., Ma, C., Yu, J., Lei, S., Han, Q., Wang, H., 2023b. Potential functions of engineered nanomaterials in cadmium remediation in soil-plant system: A review. Environ. Pollut. 336, 122340 https://doi.org/10.1016/j.envpol.2023.122340.
Li, T., Yue, X.-G., Qin, M., Norena-Chavez, D., 2024d. Towards Paris Climate Agreement goals: The essential role of green finance and green technology. Energy Econ. 129, 107273 https://doi.org/10.1016/j.eneco.2023.107273.
Li, Z.-B., Zhang, M., Shen, B.-G., Hu, F.-X., Sun, J.-R., 2016. Variations of phase constitution and magnetic properties with Ce content in Ce-Fe-B permanent magnets. Mater. Lett. 172, 102–104. https://doi.org/10.1016/j.matlet.2016.02.149.
Li, H., Zheng, B., Xue, Y., Liu, S., Gao, C., Liu, X., 2017. Spray deposited lanthanum doped TiO_2 compact layers as electron selective contact for perovskite solar cells. Sol. Energy Mater. Sol. Cells 168, 85–90. https://doi.org/10.1016/j.solmat.2017.04.027.
Ligang, X., Meijuan, X., 2020. Research on the Negative Externalities Evaluation for the Development of Weathered Crust Elution-Deposited Rare Earth Ores. Adv. Mater. Sci. Eng. 2020, 8130196. https://doi.org/10.1155/2020/8130196.
Lima, A.T., Ottosen, L., 2021. Recovering rare earth elements from contaminated soils: Critical overview of current remediation technologies. Chemosphere 265, 129163. https://doi.org/10.1016/j.chemosphere.2020.129163.
Lin, L., Gao, M., Song, Z., Mu, H., 2020. Mitigating arsenic accumulation in rice (*Oryza sativa* L.) using Fe-Mn-La-impregnated biochar composites in arsenic-contaminated paddy soil. Environ. Sci. Pollut. Res. 27 (33), 41446–41457. https://doi.org/10.1007/s11356-020-10083-w.
Lin, H., Tang, X., Wang, J., Zeng, Q., Chen, H., Ren, W., Sun, J., Zhang, H., 2021. Enhanced visible-light photocatalysis of clofibric acid using graphitic carbon nitride modified by cerium oxide nanoparticles. J. Hazard. Mater. 405, 124204 https://doi.org/10.1016/j.jhazmat.2020.124204.
Lin, Z., Zhang, Y., Liang, X., Huang, G., Fan, F., Yin, X., Chen, Z., 2024. Spatial distribution of rare earth elements and their impact factors in an area with a high abundance of regolith-hosted deposits. Chemosphere 141374. https://doi.org/10.1016/j.chemosphere.2024.141374.
Liu, T., Chen, J., 2021. Extraction and separation of heavy rare earth elements: A review. Sep. Purif. Technol. 276, 119263 https://doi.org/10.1016/j.seppur.2021.119263.
Liu, Y., Ge, J., 2023. What kind of environmental fiscal and taxation policies can support green production of ionic rare earths? A computable general equilibrium analysis. Extract. Industr. Soc. 13, 101201 https://doi.org/10.1016/j.exis.2022.101201.
Liu, Z., He, J., Ramanujan, R.V., 2021. Significant progress of grain boundary diffusion process for cost-effective rare earth permanent magnets: A review. Mater. Des. 209, 110004 https://doi.org/10.1016/j.matdes.2021.110004.
Liu, W., Li, X., Chu, X., Zuo, S., Gao, B., Yao, C., Li, Z., Chen, Y., 2022. Boosting photocatalytic reduction of nitrate to ammonia enabled by perovskite/biochar nanocomposites with oxygen defects and O-containing functional groups. Chemosphere 294, 133763. https://doi.org/10.1016/j.chemosphere.2022.133763.
Liu, L., Wang, X., Wen, Q., Jia, Q., Liu, Q., 2017. Interspecific associations of plant populations in rare earth mining wasteland in southern China. Int. Biodeterior. Biodegrad. 118, 82–88. https://doi.org/10.1016/j.ibiod.2017.01.011.
Liu, C., Xu, L., Deng, J., Tian, J., Wang, D., Xue, K., Zhang, X., Wang, Y., Fang, J., Liu, J., 2023. A review of flotation reagents for bastnäsite-(Ce) rare earth ore. Adv. Colloid Interface Sci. 321, 103029 https://doi.org/10.1016/j.cis.2023.103029.
Liu, Y., Zhong, D., Xu, Y., Dong, L., Han, Z., 2024. Performance study of phosphate removal from water using synergistic interaction between lanthanum-magnesium bimetallic organic frameworks and polyethyleneimine. J. Mol. Liq. 396, 124065 https://doi.org/10.1016/j.molliq.2024.124065.
Livingston, J.D., 1996. Links of Science & Technology. MRS Bull. 21 (4), 55–59. https://doi.org/10.1557/S0883769400035351.
Lu, H., Feng, Y., Feng, Y., Dong, Y., Sun, H., Xing, J., Shao, H., Xue, L., Yang, L., 2019. Cerium-modified biochar: A recycling biomaterial for regulating phosphorus availability in paddy ecosystem from coastal mudflat reclamation. Geoderma 346, 43–51. https://doi.org/10.1016/j.geoderma.2019.03.025.
Lu, Z., Liu, S., Tang, Z., Zhang, H., Li, W., Zhuang, J., Hu, C., Liu, Y., Lei, B., Zhang, X., 2024. In situ precipitation of high efficiency and high thermostability CsPbBr 3 quantum dots in borosilicate glass for wide color gamut display. Ceram. Int. 50 (5), 8390–8396. https://doi.org/10.1016/j.ceramint.2023.12.174.

Lu, L., Zhao, B., Lin, P., Zhang, J., 1992. Rare earth elements separation in double mixing chamber mixer-settler systems. Sep. Technol. 2 (3), 136–140. https://doi.org/10.1016/0956-9618(92)80016-7.

Luo, B., Ni, S., Liu, C., Sun, X., 2024a. The sustainable recovery of rare earth in the leaching solution of Baotou minerals with extraction-precipitation strategy based on fatty acids. Sustain. Chem. Pharm. 37, 101381 https://doi.org/10.1016/j.scp.2023.101381.

Luo, Q., Wei, J., Guo, Z., Song, Y., 2024b. Adsorption and immobilization of phosphorus from water and sediments using a lanthanum-modified natural zeolite: Performance, mechanism and effect. Sep. Purif. Technol. 329, 125187 https://doi.org/10.1016/j.seppur.2023.125187.

Lürling, M., Waajen, G., van Oosterhout, F., 2014. Humic substances interfere with phosphate removal by lanthanum modified clay in controlling eutrophication. Water Res. 54, 78–88. https://doi.org/10.1016/j.watres.2014.01.059.

Lv, T.-T., Ma, W., Zhang, D., Zhang, T., Tang, J.-H., Zeng, X., Feng, M.-L., Huang, X.-Y., 2022. Rapid and highly selective Sr^{2+} uptake by 3D microporous rare earth oxalates with the facile synthesis, high water stability and radiation resistance. Chem. Eng. J. 435, 134906 https://doi.org/10.1016/j.cej.2022.134906.

Ma, J., Li, S., Wang, J., Jiang, S., Panchal, B., Sun, Y., 2023a. Bioleaching rare earth elements from coal fly ash by *Aspergillus niger*. Fuel 354, 129387. https://doi.org/10.1016/j.fuel.2023.129387.

Ma, X., Yang, T., Ouyang, J., Zhang, X., 2023b. Research progress in photocatalysis of rare earth metal-organic frameworks: From environmental restoration, resource utilization to photodynamic therapy. Inorg. Chem. Commun. 156, 111210 https://doi.org/10.1016/j.inoche.2023.111210.

Machacek, E., Richter, J.L., Habib, K., Klossek, P., 2015. Recycling of rare earths from fluorescent lamps: Value analysis of closing-the-loop under demand and supply uncertainties. Resour. Conserv. Recycl. 104, 76–93. https://doi.org/10.1016/j.resconrec.2015.09.005.

Madaka, H., Babbitt, C.W., Ryen, E.G., 2022. Opportunities for reducing the supply chain water footprint of metals used in consumer electronics. Resour. Conserv. Recycl. 176, 105926 https://doi.org/10.1016/j.resconrec.2021.105926.

Madaleno, M., Taskin, D., Dogan, E., Tzeremes, P., 2023. A dynamic connectedness analysis between rare earth prices and renewable energy. Resour. Policy 85, 103888. https://doi.org/10.1016/j.resourpol.2023.103888.

Mancheri, N.A., 2015. World trade in rare earths, Chinese export restrictions, and implications. Resour. Policy 46, 262–271. https://doi.org/10.1016/j.resourpol.2015.10.009.

Mancheri, N.A., 2016. Chapter 2 - An Overview of Chinese Rare Earth Export Restrictions and Implications. In: Borges De Lima, I., Leal Filho, W. (Eds.), Rare Earths Industry. Elsevier, Boston, pp. 21–36.

Martin, M.V., Alfano, O.M., Satuf, M.L., 2019. Cerium-doped TiO_2 thin films: Assessment of radiation absorption properties and photocatalytic reaction efficiencies in a microreactor. J. Environ. Chem. Eng. 7 (6), 103478 https://doi.org/10.1016/j.jece.2019.103478.

Martínez-Hernando, M.-P., Bolonio, D., Ortega, M.F., Llamas, J.F., García-Martínez, M.-J., 2023. Material flow analysis and regional greenhouse gas emissions associated to permanent magnets and batteries used in electric vehicles. Sci. Total Environ. 904, 166368 https://doi.org/10.1016/j.scitotenv.2023.166368.

Masunga, N., Mamba, B.B., Kefeni, K.K., 2023. Improved magnetic, optical, electrochemical, and structural properties of copper ferrite through the optimized addition of samarium dopant using the co-precipitation method. Mater. Sci. Eng. B 296, 116662. https://doi.org/10.1016/j.mseb.2023.116662.

Mehare, M.D., Mehare, C.M., Swart, H.C., Dhoble, S.J., 2023. Recent development in color tunable phosphors: A review. Prog. Mater Sci. 133, 101067 https://doi.org/10.1016/j.pmatsci.2022.101067.

Meng, W., Hu, R., Yang, J., Du, Y., Li, J., Wang, H., 2016. Influence of lanthanum-doping on photocatalytic properties of $BiFeO_3$ for phenol degradation. Chin. J. Catal. 37 (8), 1283–1292. https://doi.org/10.1016/S1872-2067(16)62449-X.

Migaszewski, Z.M., Gałuszka, A., The Characteristics, Occurrence, and Geochemical Behavior of Rare Earth Elements in the Environment: A Review. Crit. Rev. Environ. Sci. Technol., 2015, **45(5)**, 429-471.10.1080/10643389.2013.866622.

Migaszewski, Z.M., Gałuszka, A., Dołęgowska, S., 2019. Extreme enrichment of arsenic and rare earth elements in acid mine drainage: Case study of Wiśniówka mining area (south-central Poland). Environ. Pollut. 244, 898–906. https://doi.org/10.1016/j.envpol.2018.10.106.

Ministry of Industry and Information Technology of the People's Republic, 2023. Notice on Issuing the Third Batch of Total Control Indicators for Rare Earth Mining and Smelting Separation in 2023 by the Ministry of Industry and Information Technology and the Ministry of Natural Resources. https://www.miit.gov.cn/jgsj/ycls/xt/art/2023/art_cefb6f10710b4d08926ee13da618a2b4.html.

Mng'ong'o, M., Munishi, L.K., Blake, W., Comber, S., Hutchinson, T.H., Ndakidemi, P.A., 2022. Towards sustainability: Threat of water quality degradation and eutrophication in Usangu agro-ecosystem Tanzania. Mar. Pollut. Bull. 181, 113909 https://doi.org/10.1016/j.marpolbul.2022.113909.

Mon, P.P., Cho, P.P., Vidyasagar, D., Ghosal, P., Madras, G., Challapalli, S., 2024. Synergistic sorption: Enhancing arsenic (V) removal using biochar decorated with cerium oxide composite. Mater. Today Sustain. 25, 100675 https://doi.org/10.1016/j.mtsust.2024.100675.

Mosadeghsedghi, S., Sauber, M.E., Baghbanzadeh, M., Kenari, S.L.D., Volchek, K., Issa, S., Mortazavi, S., 2023. Separation of rare earth elements using chelation-assisted electrodialysis. J. Environ. Chem. Eng. 11 (6), 111313 https://doi.org/10.1016/j.jece.2023.111313.

München, D.D., Veit, H.M., 2017. Neodymium as the main feature of permanent magnets from hard disk drives (HDDs). Waste Manag. 61, 372–376. https://doi.org/10.1016/j.wasman.2017.01.032.

Naing, Y., 2022. China-Backed Illegal Rare Earth Mining Surging in Northern Myanmar. The Irrawaddy.

Nanda, B., Behera, S.A., Subhadarshini, A., Mishra, P.M., Achary, P.G.R., 2024. Sunlight assisted photocatalytic degradation of antibiotics by boron-doped lanthanum ferrite. J. Mol. Struct. 1306, 137921 https://doi.org/10.1016/j.molstruc.2024.137921.

Nassani, A.A., Aldakhil, A.M., Zaman, K., 2021. Ecological footprints jeopardy for mineral resource extraction: Efficient use of energy, financial development and insurance services to conserve natural resources. Resour. Policy 74, 102271. https://doi.org/10.1016/j.resourpol.2021.102271.

Nazir, A., Imran, M., Kanwal, F., Latif, S., Javaid, A., Kim, T.H., Boczkaj, G., Shami, A., Iqbal, H., 2023. Degradation of cefadroxil drug by newly designed solar light responsive alcoholic template-based lanthanum ferrite nanoparticles. Environ. Res. 231, 116241 https://doi.org/10.1016/j.envres.2023.116241.

Nkiawete, M.M., Vander Wal, R.L., 2024. Rare earth elements: Sector allocations and supply chain considerations. J. Rare Earths. https://doi.org/10.1016/j.jre.2024.01.020.

Nordelöf, A., Grunditz, E., Lundmark, S., Tillman, A.-M., Alatalo, M., Thiringer, T., 2019. Life cycle assessment of permanent magnet electric traction motors. Transp. Res. Part D: Transp. Environ. 67, 263–274. https://doi.org/10.1016/j.trd.2018.11.004.

Oliveira, L.L., Cortés, J.A., Caldeira, B.S., Strusch, T., Wiedwald, U., Simoes, A.Z., 2021. Structural, electronic paramagnetic resonance and magnetic properties of praseodymium-doped rare earth CeO_2 semiconductors. Ceram. Int. 47 (15), 20768–20780. https://doi.org/10.1016/j.ceramint.2021.04.133.

Omodara, L., Pitkäaho, S., Turpeinen, E.-M., Saavalainen, P., Oravisjärvi, K., Keiski, R.L., 2019. Recycling and substitution of light rare earth elements, cerium, lanthanum, neodymium, and praseodymium from end-of-life applications - A review. J. Clean. Prod. 236, 117573 https://doi.org/10.1016/j.jclepro.2019.07.048.

Ostadebrahim, M., Dehghani, H., 2021. The study of the treatment of cerium-zinc sulfide passivation layer on photovoltaic performance of $CdSe_{0.2}S_{0.8}$ ternary quantum dot sensitized solar cells. J. Power Sources 507, 230266. https://doi.org/10.1016/j.jpowsour.2021.230266.

Owusu-Fordjour, E.Y., Yang, X., 2023. Bioleaching of rare earth elements challenges and opportunities: A critical review. J. Environ. Chem. Eng. 11 (5), 110413 https://doi.org/10.1016/j.jece.2023.110413.

Ozawa, M., 2006. Thermal stabilization of catalytic compositions for automobile exhaust treatment through rare earth modification of alumina nanoparticle support. J. Alloys Compd. 408–412, 1090–1095. https://doi.org/10.1016/j.jallcom.2004.12.111.

Packey, D.J., Kingsnorth, D., 2016. The impact of unregulated ionic clay rare earth mining in China. Resour. Policy 48, 112–116. https://doi.org/10.1016/j.resourpol.2016.03.003.

Paikaray, R., Badapanda, T., Mohapatra, H., Richhariya, T., Tiwari, K., Brahme, N., Tripathy, S.N., 2023. Exploration of crystal structure, and luminescence behaviors of Terbium-activated $CaWO_4$ phosphor. J. Mol. Struct. 1290, 135902 https://doi.org/10.1016/j.molstruc.2023.135902.

Palle Paul Mejame, M., King, D., Banhalmi-zakar, Z., He, Y., 2022. Circular economy: A sustainable management strategy for rare earth elements consumption in Australia. Curr. Res. Environ. Sustain. 4, 100157 https://doi.org/10.1016/j.crsust.2022.100157.

Pan, H., Ren, Y., Fu, H., Zhao, H., Wang, L., Meng, X., Qin, G., 2016. Recent developments in rare-earth free wrought magnesium alloys having high strength: A review. J. Alloys Compd. 663, 321–331. https://doi.org/10.1016/j.jallcom.2015.12.057.

Park, S., Tracy, C.L., Ewing, R.C., 2023. Reimagining US rare earth production: Domestic failures and the decline of US rare earth production dominance – Lessons learned and recommendations. Resour. Policy 85, 104022. https://doi.org/10.1016/j.resourpol.2023.104022.

Patel, A.K., Upadhyay, D., Mishra, B., Pruseth, K.L., 2023. Magmatic rare earth element mineralization and secondary fluid-assisted redistribution in the Kamthai carbonatite complex. NW India. Lithos 456–457, 107294. https://doi.org/10.1016/j.lithos.2023.107294.

Patil, A.B., Thalmann, N., Torrent, L., Tarik, M., Struis, R.P.W.J., Ludwig, C., 2023. Surfactant-based enrichment of rare earth elements from NdFeB magnet e-waste: Optimisation of cloud formation and rare earths extraction. J. Mol. Liq. 382, 121905 https://doi.org/10.1016/j.molliq.2023.121905.

Paulick, H., Machacek, E., 2017. The global rare earth element exploration boom: An analysis of resources outside of China and discussion of development perspectives. Resour. Policy 52, 134–153. https://doi.org/10.1016/j.resourpol.2017.02.002.

Pavón, S., Haneklaus, N., Meerbach, K., Bertau, M., 2022. Iron(III) removal and rare earth element recovery from a synthetic wet phosphoric acid solution using solvent extraction. Miner. Eng. 182, 107569 https://doi.org/10.1016/j.mineng.2022.107569.

Pell, R.S., Wall, F., Yan, X., Bailey, G., 2019. Applying and advancing the economic resource scarcity potential (ESP) method for rare earth elements. Resour. Policy 62, 472–481. https://doi.org/10.1016/j.resourpol.2018.10.003.

Peng, P., Shehabi, A., 2023. Regional economic potential for recycling consumer waste electronics in the United States. Nat. Sustainability 6 (1), 93–102. https://doi.org/10.1038/s41893-022-00983-9.

Pereira, W.V.d.S., Ramos, S.J., Melo, L.C.A., Dias, Y.N., Martins, G.C., Ferreira, L.C.G., Fernandes, A.R., Human and environmental exposure to rare earth elements in gold mining areas in the northeastern Amazon. Chemosphere, 2023, **340**, 139824.doi: 10.1016/j.chemosphere.2023.139824.

Pereira Neves, H., Max Dias Ferreira, G., Max Dias Ferreira, G., Rodrigues de Lemos, L., Dias Rodrigues, G., Albis Leão, V., Barbosa Mageste, A., Liquid-liquid extraction of rare earth elements using systems that are more environmentally friendly: Advances, challenges and perspectives. Sep. Purif. Technol., 2022, **282**, 120064.doi: 10.1016/j.seppur.2021.120064.

Phan, Q.V., Dao, T.T., Nguyen, P., Trinh, D.H., Heinig, T., 2019. An Assessment of Natural Radioactivity in the Namxe Rare Earth Deposit, Laichau Province. Vietnam. Minerals 9 (10), 602.
Pigalskiy, K.S., Trakhtenberg, L.I., 2020. Enhancement of intrinsic pinning in the high-temperature superconductor $TmBa_2Cu_3O_y$: Manifestation of the interaction between vortices and a magnetic rare-earth ion. J. Magn. Magn. Mater. 497, 165916 https://doi.org/10.1016/j.jmmm.2019.165916.
Popov, V., Koptyug, A., Radulov, I., Maccari, F., Muller, G., 2018. Prospects of additive manufacturing of rare-earth and non-rare-earth permanent magnets. Procedia Manuf. 21, 100–108. https://doi.org/10.1016/j.promfg.2018.02.199.
Powell-Turner, J., Antill, P.D., 2015. Will future resource demand cause significant and unpredictable dislocations for the UK Ministry of Defence? Resour. Policy 45, 217–226. https://doi.org/10.1016/j.resourpol.2015.05.002.
Preetha, J.S.Y., Sriram, D., Premasudha, P., Pudake, R.N., Arun, M., 2023. Cerium oxide as a nanozyme for plant abiotic stress tolerance: An overview of the mechanisms. Plant Nano Biology 6, 100049. https://doi.org/10.1016/j.plana.2023.100049.
Proelss, J., Schweizer, D., Seiler, V., 2018. Do announcements of WTO dispute resolution cases matter? Evidence from the rare earth elements market. Energy Econ. 73, 1–23. https://doi.org/10.1016/j.eneco.2018.05.004.
Qiao, J., Li, L., Liu, J., Wu, N., Liu, W., Wu, F., Zeng, Z., 2024. The vital application of rare earth for future high-performance electromagnetic wave absorption materials: A review. J. Mater. Sci. Technol. 176, 188–203. https://doi.org/10.1016/j.jmst.2023.09.003.
Qin, H., Guo, M., Zhou, C., Li, J., Jing, X., Wan, Y., Song, W., Yu, H., Peng, G., Yao, Z., Liu, J., Hu, K., 2024. Enhancing singlet oxygen production of dioxygen activation on the carbon-supported rare-earth oxide nanocluster and rare-earth single atom catalyst to remove antibiotics. Water Res., 121184 https://doi.org/10.1016/j.watres.2024.121184.
Quijada-Maldonado, E., Romero, J., 2021. Solvent extraction of rare-earth elements with ionic liquids: Toward a selective and sustainable extraction of these valuable elements. Curr. Opin. Green Sustainable Chem. 27, 100428 https://doi.org/10.1016/j.cogsc.2020.100428.
Rabe, W., Kostka, G., Smith Stegen, K., 2017. China's supply of critical raw materials: Risks for Europe's solar and wind industries? Energy Policy 101, 692–699. https://doi.org/10.1016/j.enpol.2016.09.019.
Ramprasad, C., Gwenzi, W., Chaukura, N., Izyan Wan Azelee, N., Upamali Rajapaksha, A., Naushad, M., Rangabhashiyam, S., Strategies and options for the sustainable recovery of rare earth elements from electrical and electronic waste. Chem. Eng. J., 2022, **442**, 135992.doi: 10.1016/j.cej.2022.135992.
Rasoulnia, P., Barthen, R., Lakaniemi, A.-M., A critical review of bioleaching of rare earth elements: The mechanisms and effect of process parameters. Crit. Rev. Environ. Sci. Technol., 2021, **51(4)**, 378-427.10.1080/10643389.2020.1727718.
Razmi, R., Ardjmand, M., Ramavandi, B., Heydarinasab, A., 2019a. Optimization of phenol removal from wastewater by activation of persulfate and ultrasonic waves in the presence of biochar catalyst modified by lanthanum chloride. Water Environ. J. 33 (4), 499–507. https://doi.org/10.1111/wej.12420.
Razmi, R., Ramavandi, B., Ardjmand, M., Heydarinasab, A., Efficient phenol removal from petrochemical wastewater using biochar-La/ultrasonic/persulphate system: characteristics, reusability, and kinetic study. Environ. Technol., 2019b, **40(7)**, 822-834.10.1080/09593330.2017.1408694.
Resende, L.V., Morais, C.A., 2015. Process development for the recovery of europium and yttrium from computer monitor screens. Miner. Eng. 70, 217–221. https://doi.org/10.1016/j.mineng.2014.09.016.
Riba, J.-R., López-Torres, C., Romeral, L., Garcia, A., 2016. Rare-earth-free propulsion motors for electric vehicles: A technology review. Renew. Sustain. Energy Rev. 57, 367–379. https://doi.org/10.1016/j.rser.2015.12.121.
Riddle, M.E., Tatara, E., Olson, C., Smith, B.J., Bennett Irion, A., Harker, B., Pineault, D., Alonso, E., Graziano, D.J., 2021. Agent-based modeling of supply disruptions in the global rare earths market. Resour. Conserv. Recycl. 164, 105193 https://doi.org/10.1016/j.resconrec.2020.105193.
Riesgo García, M.V., Krzemień, A., Sáiz Bárcena, L.C., Diego Álvarez, I., Castañón Fernández, C., 2019. Scoping studies of rare earth mining investments: Deciding on further project developments. Resour. Policy 64, 101525. https://doi.org/10.1016/j.resourpol.2019.101525.
Roa, A., López, J., Cortina, J.L., 2024. Recovery of Rare Earth Elements from Acidic Mine Waters: A circular treatment scheme utilizing selective precipitation and ion exchange. Sep. Purif. Technol. 338, 126525 https://doi.org/10.1016/j.seppur.2024.126525.
Rosol, A.H.A., Hamzah, A., Zulkipli, N.F., Harun, S.W., 2024. Short pulsed (1088.5 nm) neodymium-doped fiber laser via $Ti_3C_2T_x$PVA film-based SA. Optik 296, 171552. https://doi.org/10.1016/j.ijleo.2023.171552.
Roy, S., Wu, L., Goverapet Srinivasan, S., Stack, A.G., Navrotsky, A., Bryantsev, V.S., 2020. Hydration structure and water exchange kinetics at xenotime–water interfaces: implications for rare earth minerals separation. Phys. Chem. Chem. Phys. 22 (15), 7719–7727. https://doi.org/10.1039/D0CP00087F.
Rummel-Bulska, I., 2004. Chapter II.2 - The Basel Convention and its implementation. In: Twardowska, I. (Ed.), Waste Management Series, Elsevier, pp. 133-169.
Sabia, R., Stevens, H.J., Varner, J.R., 1999. Pitting of a glass-ceramic during polishing with cerium oxide. J. Non-Cryst. Solids 249 (2), 123–130. https://doi.org/10.1016/S0022-3093(99)00316-6.
Sahajwalla, V., Hossain, R., 2023. Rethinking circular economy for electronics, energy storage, and solar photovoltaics with long product life cycles. MRS Bull. 48 (4), 375–385. https://doi.org/10.1557/s43577-023-00519-2.
Sahanashree, B.M., Melagiriyappa, E., Veena, M., Shankaramurthy, G.J., Somashekarappa, A., Jayanna, H.S., Somashekarappa, H.M., 2017. Dielectric and complex impedance properties of γ-rays irradiated Neodymium substituted Co-Zn nanoferrites. Radiat. Phys. Chem. 139, 55–65. https://doi.org/10.1016/j.radphyschem.2017.05.020.
Salim, H., Sahin, O., Elsawah, S., Turan, H., Stewart, R.A., 2022. A critical review on tackling complex rare earth supply security problem. Resour. Policy 77, 102697. https://doi.org/10.1016/j.resourpol.2022.102697.
Santillán-Saldivar, J., Cimprich, A., Shaikh, N., Laratte, B., Young, S.B., Sonnemann, G., 2021. How recycling mitigates supply risks of critical raw materials: Extension of the geopolitical supply risk methodology applied to information and communication technologies in the European Union. Resour. Conserv. Recycl. 164, 105108 https://doi.org/10.1016/j.resconrec.2020.105108.
Sathishkumar, P., Mangalaraja, R.V., Rozas, O., Mansilla, H.D., Gracia-Pinilla, M.A., Meléndrez, M.F., Anandan, S., 2014. Sonophotocatalytic degradation of Acid Blue 113 in the presence of rare earth nanoclusters loaded TiO_2 nanophotocatalysts. Sep. Purif. Technol. 133, 407–414. https://doi.org/10.1016/j.seppur.2014.06.063.
Schmid, M., 2019. Mitigating supply risks through involvement in rare earth projects: Japan's strategies and what the US can learn. Resour. Policy 63, 101457. https://doi.org/10.1016/j.resourpol.2019.101457.
Sciacca, R., Berrettoni, M., Conti, P., Giorgetti, M., 2023. Comparative electrochemical behavior of Prussian blue analogues as a host electrode for rare earth element recovery. J. Electroanal. Chem. 947, 117791 https://doi.org/10.1016/j.jelechem.2023.117791.
Seiler, V., 2021. China-to-FOB price transmission in the rare earth elements market and the end of Chinese export restrictions. Energy Econ. 102, 105485 https://doi.org/10.1016/j.eneco.2021.105485.
Severson, M.H., Nguyen, R.T., Ormerod, J., Palasyuk, A., Cui, J., 2022. A preliminary feasibility study of potential market applications for non-commercial technology magnets. Heliyon 8 (12), e11773.
Sha, L., 2009. Study on rare-earth doped cemented carbides in China. Int. J. Refract Metal Hard Mater. 27 (3), 528–534. https://doi.org/10.1016/j.ijrmhm.2008.10.002.
Shakiba, G., Saneie, R., Abdollahi, H., Ebrahimi, E., Rezaei, A., Mohammadkhani, M., 2023. Application of deep eutectic solvents (DESs) as a green lixiviant for extraction of rare earth elements from caustic-treated monazite concentrate. J. Environ. Chem. Eng. 11 (5), 110777 https://doi.org/10.1016/j.jece.2023.110777.
Shameem, A., Devendran, P., Murugan, A., Siva, V., Ramadoss, G., Shamima, H., Asath Bahadur, S., 2023. Microwave-assisted design and fabrication of rare earth doped $NiMoO_4$: An admirable electrode material in redox electrolytes with excellent power density for high-end energy storage systems. Sustain. Mater. Technol. 37, e00661.
Shan, Z., Ma, F., You, S., Shan, L., Kong, D., Guo, H., Cui, C., 2023. Enhanced visible light photo-Fenton catalysis by lanthanum-doping $BiFeO_3$ for norfloxacin degradation. Environ. Res. 216, 114588 https://doi.org/10.1016/j.envres.2022.114588.
Shen, Y., Moomy, R., Eggert, R.G., 2020. China's public policies toward rare earths, 1975–2018. Miner. Econ. 33 (1), 127–151. https://doi.org/10.1007/s13563-019-00214-2.
Sherwood, J., Gongora, G.T., Velenturf, A.P.M., 2022. A circular economy metric to determine sustainable resource use illustrated with neodymium for wind turbines. J. Clean. Prod. 376, 134305 https://doi.org/10.1016/j.jclepro.2022.134305.
Shi, Z., Yong, L., Liu, Z., Wang, Y., Sui, H., Mao, W., Zhang, L., Li, Y., Liu, J., Wei, S., Song, Y., 2022. Risk assessment of rare earth elements in fruits and vegetables from mining areas in China. Environ. Sci. Pollut. Res. 29 (32), 48694–48703. https://doi.org/10.1007/s11356-022-19080-7.
Shin, W.-R., Ahn, G., Lee, J.-P., Oh, I.-H., Ahn, J.-Y., Kim, Y.-H., Chae, S., 2023. Recent advances in engineering aptamer-based sensing and recovery of heavy metals and rare earth elements for environmental sustainability. Chem. Eng. J. 472, 144742 https://doi.org/10.1016/j.cej.2023.144742.
Shinjoh, H., 2006. Rare earth metals for automotive exhaust catalysts. J. Alloys Compd. 408–412, 1061–1064. https://doi.org/10.1016/j.jallcom.2004.12.151.
Shu, W., Li, F., Zhang, Q., Li, Z., Qiao, Y., Audet, J., Chen, G., 2023. Pollution caused by mining reshaped the structure and function of bacterial communities in China's largest ion-adsorption rare earth mine watershed. J. Hazard. Mater. 451, 131221 https://doi.org/10.1016/j.jhazmat.2023.131221.
Smith Stegen, K., 2015. Heavy rare earths, permanent magnets, and renewable energies: An imminent crisis. Energy Policy 79, 1–8. https://doi.org/10.1016/j.enpol.2014.12.015.
Song, Y., Bouri, E., Ghosh, S., Kanjilal, K., 2021. Rare earth and financial markets: Dynamics of return and volatility connectedness around the COVID-19 outbreak. Resour. Policy 74, 102379. https://doi.org/10.1016/j.resourpol.2021.102379.
Sprecher, B., Daigo, I., Spekkink, W., Vos, M., Kleijn, R., Murakami, S., Kramer, G.J., 2017. Novel Indicators for the Quantification of Resilience in Critical Material Supply Chains, with a 2010 Rare Earth Crisis Case Study. Environ. Sci. Technol. 51 (7), 3860–3870. https://doi.org/10.1021/acs.est.6b05751.
Stratiotou Efstratiadis, V., Michailidis, N., 2022. Sustainable recovery, recycle of critical metals and rare earth elements from waste electric and electronic equipment (Circuits, Solar, Wind) and their reusability in additive manufacturing applications: a review. Metals 12 (5), 794.
Su, J., Gao, Y., Ni, S., Xu, R., Sun, X., 2021. A safer and cleaner process for recovering thorium and rare earth elements from radioactive waste residue. J. Hazard. Mater. 406, 124654 https://doi.org/10.1016/j.jhazmat.2020.124654.
Su, H., Ni, S., Bie, C., Wu, S., Sun, X., 2022. Efficient and sustainable separation of yttrium from heavy rare earth using functionalized ionic liquid $[N_{1888}]$[NDA]. Sep. Purif. Technol. 285, 120302 https://doi.org/10.1016/j.seppur.2021.120302.
Sun, J., Yang, X., Sun, S., Zhao, L., Wang, S., Li, Y., 2022. Recent progress of rare earth conversion material in perovskite solar cells: A mini review. Inorg. Chem. Commun. 143, 109731 https://doi.org/10.1016/j.inoche.2022.109731.
Sun, X., Yuan, K., Zhang, Y., 2020. Advances and prospects of rare earth metal-organic frameworks in catalytic applications. J. Rare Earths 38 (8), 801–818. https://doi.org/10.1016/j.jre.2020.01.012.

Talan, D., Huang, Q., 2022a. A review of environmental aspect of rare earth element extraction processes and solution purification techniques. Miner. Eng. 179, 107430 https://doi.org/10.1016/j.mineng.2022.107430.
Talan, D., Huang, Q., 2022b. A review study of rare Earth, Cobalt, Lithium, and Manganese in Coal-based sources and process development for their recovery. Miner. Eng. 189, 107897 https://doi.org/10.1016/j.mineng.2022.107897.
Tang, X., Dong, Y., Wei, J., Kong, Z., Yu, L., Zhang, H., Ji, Y., 2021. Polypropylene nonwoven loaded with cerium-doped manganese oxides submicron particles for ozone decomposition and air filtration. Sep. Purif. Technol. 262, 118332 https://doi.org/10.1016/j.seppur.2021.118332.
Tang, W., Wang, G., Zhang, S., Li, T., Xu, X., Deng, O., Luo, L., He, Y., Zhou, W., 2022. Physiochemical responses of earthworms (*Eisenia fetida*) under exposure to lanthanum and cerium alone or in combination in artificial and contaminated soils. Environ. Pollut. 296, 118766 https://doi.org/10.1016/j.envpol.2021.118766.
Thinley, T., Prabagar, J.S., Yadav, S., Anusha, H.S., Anilkumar, K.M., Kitirote, W., Shahmoradi, B., Shivaraju, H.P., 2023. $LaNiO_3$-rGO perovskite interface for sustainable decontaminants of emerging concerns under visible light photocatalysis. J. Mol. Struct. 1285, 135413 https://doi.org/10.1016/j.molstruc.2023.135413.
Tian, S., Li, K., Møller, P., Ying, S.C., Wang, L., Li, Z., Roursgaard, M., Liang, T., 2020. Assessment of reactive oxygen species production and genotoxicity of rare earth mining dust: Implications for public health and mining management. Sci. Total Environ. 740, 139759 https://doi.org/10.1016/j.scitotenv.2020.139759.
Toro, N., Robles, P., Jeldres, R.I., 2020. Seabed mineral resources, an alternative for the future of renewable energy: A critical review. Ore Geol. Rev. 126, 103699 https://doi.org/10.1016/j.oregeorev.2020.103699.
Traore, M., Gong, A., Wang, Y., Qiu, L., Bai, Y., Zhao, W., Liu, Y., Chen, Y., Liu, Y., Wu, H., Li, S., You, Y., 2023. Research progress of rare earth separation methods and technologies. J. Rare Earths 41 (2), 182–189. https://doi.org/10.1016/j.jre.2022.04.009.
Tripathy, P.K., Mondal, K., Khanolkar, A.R., 2021. One-step manufacturing process for neodymium-iron (magnet-grade) master alloy. Mater. Sci. Energy Technol. 4, 249–255. https://doi.org/10.1016/j.mset.2021.07.001.
Trovarelli, A., 1996. Catalytic properties of Ceria and CeO_2-containing materials. Catal. Rev. 38 (4), 439–520. https://doi.org/10.1080/01614949608006464.
Trujillo, E., 2017. China measures related to the exportation of rare earths, tungsten, and molybdenum. Am. J. Int. Law 109 (3), 616–623. https://doi.org/10.5305/amerjintelaw.109.3.0616.
Tukker, A., 2014. Rare earth elements supply restrictions: market failures, not scarcity, hamper their current use in high-tech applications. Environ. Sci. Technol. 48 (17), 9973–9974. https://doi.org/10.1021/es503548f.
Tunsu, C., Petranikova, M., Gergorić, M., Ekberg, C., Retegan, T., 2015. Reclaiming rare earth elements from end-of-life products: A review of the perspectives for urban mining using hydrometallurgical unit operations. Hydrometall. 156, 239–258. https://doi.org/10.1016/j.hydromet.2015.06.007.
U.S. Geological Survey, Mineral Commodity Summaries, 2024, 212.10.3133/mcs2024.
van Nielen, S.S., Sprecher, B., Verhagen, T.J., Kleijn, R., 2023. Towards neodymium recycling: Analysis of the availability and recyclability of European waste flows. J. Clean. Prod. 394, 136252 https://doi.org/10.1016/j.jclepro.2023.136252.
Varghese, R., Jose, S.M., Lakshmi, J.S., Thomas, J.K., 2023a. Investigation of the structural, optical, electrical, and photovoltaic characteristics of nanostructured Ce-doped $BaTiO_3$ by a modified combustion method. Opt. Quant. Electron. 56 (1), 118. https://doi.org/10.1007/s11082-023-05686-9.
Varghese, R., Sreekala, C.O., Kurian, S., Thomas, J.K., 2023b. Insight into structural, optical, electrical, dielectric, and photovoltaic behaviour of cerium-doped strontium titanate by a modified combustion method. J. Mater. Sci.: Mater. Electron. 34 (11), 957. https://doi.org/10.1007/s10854-023-10325-w.
Varun, S., Kalra, M., Gandhi, M., 2015. White Light Emission Through Downconversion of Terbium and Europium Doped CeF_3 Nanophosphors. J. Fluoresc. 25 (5), 1501–1505. https://doi.org/10.1007/s10895-015-1641-y.
Vivoda, V., Matthews, R., McGregor, N., 2024. A critical minerals perspective on the emergence of geopolitical trade blocs. Resour. Policy 89, 104587. https://doi.org/10.1016/j.resourpol.2023.104587.
Wall, F., 2021. Rare Earth Elements. In: Alderton, D., Elias, S.A. (Eds.), Encyclopedia of Geology (second Edition). Academic Press, Oxford, pp. 680–693.
Wang, X., Ge, J., Li, J., Han, A., 2017c. Market impacts of environmental regulations on the production of rare earths: A computable general equilibrium analysis for China. J. Clean. Prod. 154, 614–620. https://doi.org/10.1016/j.jclepro.2017.03.200.
Wang, L., Huang, X., Yu, Y., Zhao, L., Wang, C., Feng, Z., Cui, D., Long, Z., 2017b. Towards cleaner production of rare earth elements from bastnaesite in China. J. Clean. Prod. 165, 231–242. https://doi.org/10.1016/j.jclepro.2017.07.107.
Wang, H.-Y., Kumar, A., Li, J., Chen, P., Yu, Z.-G., Sun, G.-X., 2023a. The adsorption behavior and mechanism for arsenate by lanthanum-loaded biochar with different modification methods. Environ. Technol. Innov. 32, 103344 https://doi.org/10.1016/j.eti.2023.103344.
Wang, A., Li, Y., Li, R., Feng, X., 2017a. Environmental cost analysis of the development and utilization of the Bayan Obo rare earth resources, Inner Mongolia. Acta Geoscientica Sinica 38 (1), 94–100. https://doi.org/10.3975/cagsb.2017.01.14.
Wang, X., Tang, Y., Lee, J.-M., Fu, G., 2022b. Recent advances in rare-earth-based materials for electrocatalysis. Chem Catalysis 2 (5), 967–1008. https://doi.org/10.1016/j.checat.2022.02.007.
Wang, L., Wang, P., Chen, W.-Q., Wang, Q.-Q., Lu, H.-S., 2020. Environmental impacts of scandium oxide production from rare earths tailings of Bayan Obo Mine. J. Clean. Prod. 270, 122464 https://doi.org/10.1016/j.jclepro.2020.122464.
Wang, J., Wang, G., Luo, S., Liang, Y., Sun, Z., Hu, S., Yang, Y., 2023b. The influence of low-permeability geological inclusions on the seepage behavior of ionic rare earth leaching mining: A study using visual microfluidic technology. Miner. Eng. 204, 108440 https://doi.org/10.1016/j.mineng.2023.108440.
Wang, W.-D., Wang, T., Sun, Z.-B., Bo, Y.-X., Zou, C.-X., Wang, Z., Zheng, C.-L., 2023e. Solidification treatment of rare earth tailings by a renewable biological cementation method. Process Saf. Environ. Prot. 179, 585–592. https://doi.org/10.1016/j.psep.2023.09.023.
Wang, Y., Wang, D., Xu, L., Xue, K., Zhang, X., Shi, X., Liu, C., Meng, J., 2023f. Synthesis and utilization of a novel oleate hydroxamic acid collector for the flotation separation of bastnaesite from barite. Miner. Eng. 204, 108405 https://doi.org/10.1016/j.mineng.2023.108405.
Wang, K., Xing, X., Liu, W., Jiang, Y., Li, H., Lu, Y., Chen, H., Ren, H., 2023c. Fabrication of a novel PbO_2 electrode with rare earth elements doping for p-nitrophenol degradation. J. Environ. Chem. Eng. 11 (2), 109513 https://doi.org/10.1016/j.jece.2023.109513.
Wang, S., Xiong, Z., Wang, L., Yang, X., Yan, X., Li, Y., Zhang, C., Liang, T., 2022a. Potential hot spots contaminated with exogenous, rare earth elements originating from e-waste dismantling and recycling. Environ. Pollut. 309, 119717 https://doi.org/10.1016/j.envpol.2022.119717.
Wang, M., Yang, M., Fan, T., Wang, D., He, J., Wu, H., Si, D., Wang, M., Wu, S., Zhou, D., 2023d. Activating soil nitrification by co-application of peanut straw biochar and organic fertilizer in a rare earth mining soil. Sci. Total Environ. 866, 161506 https://doi.org/10.1016/j.scitotenv.2023.161506.
Wang, P., Yang, Y.-Y., Heidrich, O., Chen, L.-Y., Chen, L.-H., Fishman, T., Chen, W.-Q., 2024. Regional rare-earth element supply and demand balanced with circular economy strategies. Nat. Geosci. 17 (1), 94–102. https://doi.org/10.1038/s41561-023-01350-9.
Wang, L., Yu, X., Wei, Y., Liu, J., Zhao, Z., 2021. Research advances of rare earth catalysts for catalytic purification of vehicle exhausts – Commemorating the 100th anniversary of the birth of Academician Guangxian Xu. J. Rare Earths 39 (10), 1151–1180. https://doi.org/10.1016/j.jre.2021.05.001.
Weng, Z.H., Jowitt, S.M., Mudd, G.M., Haque, N., 2013. Assessing rare earth element mineral deposit types and links to environmental impacts. Appl. Earth Sci. 122 (2), 83–96. https://doi.org/10.1179/1743275813Y.0000000036.
Weng, Z., Mudd, G.M., 2023. Chapter 32 - Global rare earth supply, life cycle assessment, and wind energy. In: Letcher, T.M. (Ed.), Wind Energy Engineering (second Edition). Academic Press, pp. 475–487.
Wu, H., Liu, X., Wen, J., Liu, Y., Zheng, X., 2021b. Rare-earth oxides modified Mg-Al layered double oxides for the enhanced adsorption-photocatalytic activity. Colloids Surf. A Physicochem. Eng. Asp. 610, 125933 https://doi.org/10.1016/j.colsurfa.2020.125933.
Wu, B., Lo, I.M.C., 2020. Surface Functional Group Engineering of CeO_2 Particles for Enhanced Phosphate Adsorption. Environ. Sci. Technol. 54 (7), 4601–4608. https://doi.org/10.1021/acs.est.9b06812.
Wu, D., Tian, S., Zhang, X., Yu, B., Ma, J., Xie, K., Cheng, S., Zhang, J., Hu, Z., 2022. Temperature controllable optical switch for erbium-doped random fiber laser. Opt. Laser Technol. 148, 107772 https://doi.org/10.1016/j.optlastec.2021.107772.
Wu, B., Wan, J., Zhang, Y., Pan, B., Lo, I.M.C., 2020. Selective Phosphate Removal from Water and Wastewater using Sorption: Process Fundamentals and Removal Mechanisms. Environ. Sci. Technol. 54 (1), 50–66. https://doi.org/10.1021/acs.est.9b05569.
Wu, S., Wang, L., Zhao, L., Zhang, P., El-Shall, H., Moudgil, B., Huang, X., Zhang, L., 2018. Recovery of rare earth elements from phosphate rock by hydrometallurgical processes – A critical review. Chem. Eng. J. 335, 774–800. https://doi.org/10.1016/j.cej.2017.10.143.
Wu, G., Wang, C., Sun, M., Ding, W., 2021a. Recent developments and applications on high-performance cast magnesium rare-earth alloys. J. Magnesium Alloys 9 (1), 1–20. https://doi.org/10.1016/j.jma.2020.06.021.
Wu, J., Zhong, Y., Hao, C., Chen, J., Gao, H., Han, S., Shen, Y., Wang, X., 2024. Emulsion synthesis of cellulose/lanthanum alginate /La (III) composite microspheres for efficient and selective adsorption of phosphate. Chem. Eng. J. 488, 150949 https://doi.org/10.1016/j.cej.2024.150949.
Wübbeke, J., 2013. Rare earth elements in China: Policies and narratives of reinventing an industry. Resour. Policy 38 (3), 384–394. https://doi.org/10.1016/j.resourpol.2013.05.005.
Xia, Q., Du, D., Cao, W., Li, X., 2023. Who is the core? Reveal the heterogeneity of global rare earth trade structure from the perspective of industrial chain. Resour. Policy 82, 103532. https://doi.org/10.1016/j.resourpol.2023.103532.
Xiao, Y.-F., Zhang, Y., Wang, D.-C., Su, Y.-M., Wu, J., Liu, J.-Q., Yang, L.-L., Jin, Z., 2024. Hydrothermal synthesis of lanthanum oxide nanoparticles modified pumice: High lanthanum oxide loading ratio and efficiency phosphate removal. J. Environ. Chem. Eng. 12 (1), 111587 https://doi.org/10.1016/j.jece.2023.111587.
Xiao, W., Zhou, L., Yang, P., Yan, N., Wei, C., 2023a. An international comparative study of rare earth research from the perspective of bibliometrics. Heliyon 9 (5), e16075.
Xiao, Y., Zhu, J., Kuang, L., Ji, Y., Zhao, Q., Yang, C., Wang, W., 2023b. High-gain fluoro-sulfo-phosphate-based active fiber for compact low-threshold kilohertz-linewidth single-frequency fiber laser. Opt. Commun. 546, 129750 https://doi.org/10.1016/j.optcom.2023.129750.
Xie, F., Zhang, T.A., Dreisinger, D., Doyle, F., 2014. A critical review on solvent extraction of rare earths from aqueous solutions. Miner. Eng. 56, 10–28. https://doi.org/10.1016/j.mineng.2013.10.021.
Xu, J., Li, J., Charles, V., Zhao, X., 2023a. Evolution of the rare earth trade network: A perspective of dependency and competition. Geosci. Front. 101653 https://doi.org/10.1016/j.gsf.2023.101653.
Xu, Q., Wu, D., Hu, W., Zhang, Z., Liu, X., Yang, F., Wang, Z., 2023b. Recycling NdFeB magnets and rare earth fluorescent materials from electronic waste. JOM. https://doi.org/10.1007/s11837-023-06235-1.

Xu, Z., Yang, J.-L., Zhao, Y., Hao, R., Zhang, G.-L., 2023c. Soil acidification in a tailing area of ionic rare earth in Southeast China. Sci. Total Environ. 884, 163834 https://doi.org/10.1016/j.scitotenv.2023.163834.

Yakovleva, N., Gavrilyeva, T.N., Makarov, A.I., Krasilnikova, N.A., 2023. Free prior informed consent in the extractive industry: Approaches to involving Indigenous peoples in decision-making in Russia. J. Environ. Manage. 344, 118341 https://doi.org/10.1016/j.jenvman.2023.118341.

Yan, W.-G., Wang, H.-M., Tang, H.-B., Cheng, X., Zhu, Y.-Y., 2022. Effect of Nd addition on microstructure and tensile properties of laser additive manufactured TC11 titanium alloy. Trans. Nonferrous Met. Soc. Chin. 32 (5), 1501–1512. https://doi.org/10.1016/S1003-6326(22)65889-8.

Yang, B., Han, F., Bai, Y., Xie, Z., Shi, T., Wang, J., Li, Y., 2023a. Phosphate removal performance and mechanism of magnesium–lanthanum-modified coal gasification coarse slag. Mater. Today Sustain. 22, 100357 https://doi.org/10.1016/j.mtsust.2023.100357.

Yang, X.J., Lin, A., Li, X.-L., Wu, Y., Zhou, W., Chen, Z., 2013. China's ion-adsorption rare earth resources, mining consequences and preservation. Environ. Devel. 8, 131–136. https://doi.org/10.1016/j.envdev.2013.03.006.

Yang, Y., Luo, L.M., Zan, X., Zhu, X.Y., Zhu, L., Wu, Y.C., 2021a. Study on preparation and properties of WC-8Co cemented carbide doped with rare earth oxide. Int. J. Refract Metal Hard Mater. 98, 105536 https://doi.org/10.1016/j.ijrmhm.2021.105536.

Yang, S., Sun, W., Xu, Q., Yang, C., Zhang, S., Jiao, M., 2023b. Synthesis, structure, and luminescence properties of Europium/Cerium/Terbium doped strontium-anorthite-type green phosphor for solid state lighting. Spectrochim. Acta A Mol. Biomol. Spectrosc. 292, 122402 https://doi.org/10.1016/j.saa.2023.122402.

Yang, Y., Yang, M., He, C., Qi, F., Wang, D., Peng, S., Shuai, C., 2021b. Rare earth improves strength and creep resistance of additively manufactured Zn implants. Compos. B Eng. 216, 108882 https://doi.org/10.1016/j.compositesb.2021.108882.

Yao, L., Chen, Z., Li, J., Shi, C., 2020. Creation of oxygen vacancies to activate lanthanum-doped bismuth titanate nanosheets for efficient synchronous photocatalytic removal of Cr(VI) and methyl orange. J. Mol. Liq. 314, 113613 https://doi.org/10.1016/j.molliq.2020.113613.

Yen Chau Nguyen, T., Tran, L.-H., Mueller, K.K., Coudert, L., Mercier, G., Blais, J.-F., 2021. Pre-concentration of fluorite from a rare earth element carbonatite deposit through the combination of magnetic separation and leaching. Miner. Eng. 174, 106998 https://doi.org/10.1016/j.mineng.2021.106998.

Ying, T.K., Gao, X.P., Hu, W.K., Wu, F., Noréus, D., 2006. Studies on rechargeable NiMH batteries. Int. J. Hydrogen Energy 31 (4), 525–530. https://doi.org/10.1016/j.ijhydene.2005.04.018.

Yörükoğlu, A., Obut, A., Girgin, İ., 2003. Effect of thiourea on sulphuric acid leaching of bastnaesite. Hydrometall. 68 (1), 195–202. https://doi.org/10.1016/S0304-386X(02)00199-8.

Yuksekdag, A., Kose-Mutlu, B., Siddiqui, A.F., Wiesner, M.R., Koyuncu, I., 2022. A holistic approach for the recovery of rare earth elements and scandium from secondary sources under a circular economy framework – A review. Chemosphere 293, 133620. https://doi.org/10.1016/j.chemosphere.2022.133620.

Zaimes, G.G., Hubler, B.J., Wang, S., Khanna, V., 2015. Environmental Life Cycle Perspective on Rare Earth Oxide Production. ACS Sustain. Chem. Eng. 3 (2), 237–244. https://doi.org/10.1021/sc500573b.

Zapp, P., Schreiber, A., Marx, J., Kuckshinrichs, W., 2022. Environmental impacts of rare earth production. MRS Bull. 47 (3), 267–275. https://doi.org/10.1557/s43577-022-00286-6.

Zeng, X., Ogunseitan, O.A., Nakamura, S., Suh, S., Kral, U., Li, J., Geng, Y., 2022. Reshaping global policies for circular economy. Circular Economy 1 (1), 100003. https://doi.org/10.1016/j.cec.2022.100003.

Zervas, M.N., 2014. High power ytterbium-doped fiber lasers — fundamentals and applications. Int. J. Mod Phys B 28 (12), 1442009. https://doi.org/10.1142/s0217979214420090.

Zhan, W., Guo, Y., Gong, X., Guo, Y., Wang, Y., Lu, G., 2014. Current status and perspectives of rare earth catalytic materials and catalysis. Chin. J. Catal. 35 (8), 1238–1250. https://doi.org/10.1016/S1872-2067(14)60189-3.

Zhang, Q., 2021. China's policy and finding ways to prevent collapse in WEEE processing in the context of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal. Int. Environ. Agreements: Politics, Law Econ. 21 (4), 693–710. https://doi.org/10.1007/s10784-021-09540-9.

Zhang, S., 2022. Study on economic significance of rare earth mineral resources development based on goal programming and few-shot learning. Comput. Intell. Neurosci. 2022, 7002249. https://doi.org/10.1155/2022/7002249.

Zhang, D.-R., Chen, H.-R., Nie, Z.-Y., Xia, J.-L., Li, E.-P., Fan, X.-L., Zheng, L., 2020a. Extraction of Al and rare earths (Ce, Gd, Sc, Y) from red mud by aerobic and anaerobic bi-stage bioleaching. Chem. Eng. J. 401, 125914 https://doi.org/10.1016/j.cej.2020.125914.

Zhang, C., Gao, S., Yu, D., Zhou, S., Wang, L., Yu, X., Zhao, Z., 2023a. Research progress on preparation of cerium-based oxide catalysts with specific morphology and their application for purification of diesel engine exhaust. J. Rare Earths. https://doi.org/10.1016/j.jre.2023.12.001.

Zhang, L., Guo, Q., Zhang, J., Huang, Y., Xiong, T., 2015. Did China's rare earth export policies work? — Empirical evidence from USA and Japan. Resour. Policy 43, 82–90. https://doi.org/10.1016/j.resourpol.2014.11.007.

Zhang, L., Jia, Z., Wang, W., Rodríguez-Pérez, I.A., Zhao, Y., Li, Y., Zhao, X., Wang, L., Han, S., 2019. A new choice for the anode of nickel metal hydride batteries with long cycling life: A Ce_2Ni_7-type single-phase $Nd_{0.80}Mg_{0.20}Ni_{3.58}$ hydrogen storage alloy. J. Power Sources 433, 126687. https://doi.org/10.1016/j.jpowsour.2019.05.093.

Zhang, K., Kleit, A.N., Nieto, A., 2017a. An economics strategy for criticality – Application to rare earth element Yttrium in new lighting technology and its sustainable availability. Renew. Sustain. Energy Rev. 77, 899–915. https://doi.org/10.1016/j.rser.2016.12.127.

Zhang, G., Liu, X., Gao, M., Song, Z., 2020b. Effect of Fe–Mn–Ce modified biochar composite on microbial diversity and properties of arsenic-contaminated paddy soils. Chemosphere 250, 126249. https://doi.org/10.1016/j.chemosphere.2020.126249.

Zhang, R., Liu, M., Liu, S., Liang, X., Lu, R., Shuai, X., Wu, D., Cao, Z., 2023c. Holmium (III)-doped multifunctional nanotheranostic agent for ultra-high-field magnetic resonance imaging-guided chemo-photothermal tumor therapy. Acta Biomater. 172, 454–465. https://doi.org/10.1016/j.actbio.2023.10.017.

Zhang, W., Musante, C., White, J.C., Schwab, P., Wang, Q., Ebbs, S.D., Ma, X., 2017b. Bioavailability of cerium oxide nanoparticles to *Raphanus sativus* L. in two soils. Plant Physiol. Biochem. 110, 185–193. https://doi.org/10.1016/j.plaphy.2015.12.013.

Zhang, Q., Ren, F., Li, F., Chen, G., Yang, G., Wang, J., Du, K., Liu, S., Li, Z., 2020c. Ammonia nitrogen sources and pollution along soil profiles in an in-situ leaching rare earth ore. Environ. Pollut. 267, 115449 https://doi.org/10.1016/j.envpol.2020.115449.

Zhang, Q., Wan, G., Zhou, C., Luo, J., Lin, J., Zhao, X., 2020d. Rehabilitation effect of the combined application of bamboo biochar and coal ash on ion-adsorption-type rare earth tailings. J. Soils Sediments 20 (9), 3351–3357. https://doi.org/10.1007/s11368-020-02670-8.

Zhang, Y., Wang, M., Gao, X., Qian, J., Pan, B., 2021. Structural Evolution of Lanthanum Hydroxides during Long-Term Phosphate Mitigation: Effect of Nanoconfinement. Environ. Sci. Technol. 55 (1), 665–676. https://doi.org/10.1021/acs.est.0c05577.

Zhang, L., Xiao, W., Li, G., Wang, D., Wu, J., Du, H., Lin, Y., Ye, C., Qi, T., Wang, Z., 2023b. A cleaner and sustainable method for recovering rare earth and cobalt from NdFeB leaching residues. J. Clean. Prod. 422, 138576 https://doi.org/10.1016/j.jclepro.2023.138576.

Zhang, J., Zhang, W., Yue, L., Hu, X., Lin, H., Zhao, L., He, Y., 2022a. Thiophene insertion and lanthanum molybdate modification of g-C_3N_4 for enhanced visible-light-driven photoactivity in tetracycline degradation. Appl. Surf. Sci. 592, 153337 https://doi.org/10.1016/j.apsusc.2022.153337.

Zhang, J., Yang, Q., Gao, C., Wang, X., Gao, C., Liu, X., 2024. Copper doped lanthanum hydroxide nanorods as a low temperature processable hole transport material for perovskite solar cells. J. Power Sources 590, 233797. https://doi.org/10.1016/j.jpowsour.2023.233797.

Zhang, X., Yue, Y., Xu, D., Qin, J., Zhang, X., Liu, R., 2023d. Effect of rare-earth elements on the interface of WC/α-Fe cemented carbide: A first-principles calculation. Comput. Mater. Sci 230, 112483. https://doi.org/10.1016/j.commatsci.2023.112483.

Zhang, T., Zhang, P., Peng, K., Feng, K., Fang, P., Chen, W., Zhang, N., Wang, P., Li, J., 2022b. Allocating environmental costs of China's rare earth production to global consumption. Sci. Total Environ. 831, 154934 https://doi.org/10.1016/j.scitotenv.2022.154934.

Zhao, G., Geng, Y., Wei, W., Evaluating the Trade Security of Rare Earth Resources in China from a Sustainable Development Perspective. J. China Univ. Geosci. (Social Sciences Edition), 2024a, **24(02)**, 93-105.10.16493/j.cnki.42-1627/c.20240307.001.

Zhao, R., Hu, Y., Ding, W., Ren, K., Gou, X., Zhao, C., Zheng, H., 2023a. Simultaneous oxidation and adsorption of phosphite by magnetic $La_2(CO_3)_3/CoFe_2O_4$/biochar composite with peroxymonosulfate. Chem. Eng. J. 451, 138918 https://doi.org/10.1016/j.cej.2022.138918.

Zhao, R., Luo, Y., Hu, Q., Li, Q., Niu, Y., Su, Y., Wen, Q., Wang, B., Zhu, J., 2024c. Synthesis, bright red-emitting and low thermal quenching behavior of europium(III)-activated sodium borophosphate phosphor. J. Mol. Struct. 1296, 136867 https://doi.org/10.1016/j.molstruc.2023.136867.

Zhao, Y., Sun, X., Meng, D., Liu, X., Zhong, Q., Feng, Z., 2024d. Effect of phase transition during roasting of Mountain Pass rare earth concentrate on leaching efficiency of rare earths. J. Rare Earths 42 (2), 409–414. https://doi.org/10.1016/j.jre.2023.05.004.

Zhao, M., Teng, Z., Ma, X., Jiang, X., Zhang, H., Yang, Y., Li, T., 2024b. Insight into leaching rare earth from ion-adsorption type rare earth ores with citric acid: Performance, kinetic analysis and differentiation leaching. J. Rare Earths. https://doi.org/10.1016/j.jre.2024.02.005.

Zhao, S., Wang, P., Chen, W., Wang, L., Wang, Q.-C., Chen, W.-Q., 2023b. Supply and demand conflicts of critical heavy rare earth element: Lessons from gadolinium. Resour. Conserv. Recycl. 199, 107254 https://doi.org/10.1016/j.resconrec.2023.107254.

Zhao, H., Xia, J., Yin, D., Luo, M., Yan, C., Du, Y., 2019. Rare earth incorporated electrode materials for advanced energy storage. Coord. Chem. Rev. 390, 32–49. https://doi.org/10.1016/j.ccr.2019.03.011.

Zhdaneev, O.V., Frolov, K.N., Kryukov, V.A., Yatsenko, V.A., 2024. Rare earth permanent magnets in Russia's wind power. Mater. Sci. Energy Technol. 7, 107–114. https://doi.org/10.1016/j.mset.2023.07.007.

Zheng, B., Zhang, Y., Chen, Y., 2021. Asymmetric connectedness and dynamic spillovers between renewable energy and rare earth markets in China: Evidence from firms' high-frequency data. Resour. Policy 71, 101996. https://doi.org/10.1016/j.resourpol.2021.101996.

Zheng, B., Zhang, Y.W., Geng, Y., Wei, W., Tan, X., Xiao, S., Gao, Z., 2023. Measuring the anthropogenic cycles of light rare earths in China: Implications for the imbalance problem. Sci. Total Environ. 879, 163215 https://doi.org/10.1016/j.scitotenv.2023.163215.

Zhong, Y.W., Qian, X.N., Ma, C., Liu, K., Zhang, H.J., 2023. Rare Earth Biological Manufacturing and High Value-added Material Application. Acta Chim. Sin. 81 (11), 1624–1632. https://doi.org/10.6023/A23070323.

Zhou, L., Ge, J., 2021. Estimating the environmental cost of mixed rare earth production with willingness to pay: A case study in Baotou, China. Extract. Industr. Soc. 8 (1), 340–354. https://doi.org/10.1016/j.exis.2020.11.010.

Zhou, M.-J., Huang, J.-B., Chen, J.-Y., 2022. Time and frequency spillovers between political risk and the stock returns of China's rare earths. Resour. Policy 75, 102464. https://doi.org/10.1016/j.resourpol.2021.102464.

Zhou, H., Liu, S., Yi, H., Song, S., Jia, F., 2023a. Flotation of bastnaesite by mixed collectors and adsorption mechanism. Chem. Phys. Lett. 830, 140793 https://doi.org/10.1016/j.cplett.2023.140793.

Zhou, J., Mogollón, J.M., van Bodegom, P.M., Beusen, A.H.W., Scherer, L., 2024b. Global regionalized characterization factors for phosphorus and nitrogen impacts on freshwater fish biodiversity. Sci. Total Environ. 912, 169108 https://doi.org/10.1016/j.scitotenv.2023.169108.

Zhou, Y., Schulz, S., Lindoy, L.F., Du, H., Zheng, S., Wenzel, M., Weigand, J.J., 2020. Separation and recovery of rare earths by *in situ* selective electrochemical oxidation and extraction from spent fluid catalytic cracking (FCC) catalysts. Hydrometall. 194, 105300 https://doi.org/10.1016/j.hydromet.2020.105300.

Zhou, H., Zheng, Z., Chen, Y., Wan, Y., Sun, J., Zhang, T., Chen, D., Shi, S., Ju, P., 2023b. A novel ion exchange-electrodialysis hybrid system to treat rare-earth oxalic precipitation mother liquid: Contamination reduction, efficient Y^{3+} recovery, and acid separation. Desalination 565, 116815. https://doi.org/10.1016/j.desal.2023.116815.

Zhou, H., Wang, J., Yu, X., Kang, J., Qiu, G., Zhao, H., Shen, L., 2024a. Effective extraction of rare earth elements from ion-adsorption type rare earth ore by three bioleaching methods. Sep. Purif. Technol. 330, 125305 https://doi.org/10.1016/j.seppur.2023.125305.

Zhü, K., Zhao, S.-Y., Yang, S., Liang, C., Gu, D., 2016. Where is the way for rare earth industry of China: An analysis via ANP-SWOT approach. Resour. Policy 49, 349–357. https://doi.org/10.1016/j.resourpol.2016.07.003.

Zou, X., Yuan, C., Dong, Y., Ge, H., Ke, J., Cui, Y., 2020. Lanthanum orthovanadate/bismuth oxybromide heterojunction for enhanced photocatalytic air purification and mechanism exploration. Chem. Eng. J. 379, 122380 https://doi.org/10.1016/j.cej.2019.122380.

Zuo, Z., McLellan, B.C., Li, Y., Guo, H., Cheng, J., 2022. Evolution and insights into the network and pattern of the rare earths trade from an industry chain perspective. Resour. Policy 78, 102912. https://doi.org/10.1016/j.resourpol.2022.102912.