

The Importance Of Rare Earth Elements As A Priority Topic On The 21st-Century Global Agenda: An Analysis Of Geopolitics And Its Implications For The International System

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Abstract:

Background: This study addresses the importance of Rare Earth Elements as a priority topic on the 21st-century global agenda. It presents definitions, characteristics, uses, and applications of Rare Earths for the benefit of modern society; characterizes the benefits and advantages associated with the industrialization of these minerals; demonstrates the indispensability of Rare Earths for the global energy transition; and examines the geopolitics of these resources within the contemporary International System.

Materials and Methods: This research adopted a qualitative approach to explore the extent to which Rare Earth Elements could influence the strengthening of industry, the economy, energy, telecommunications, and healthcare, fostering national development while also shaping international relations and altering global geopolitics. The methodological procedure consisted of a literature and documentary review, involving the consultation of sources classified into four categories: (1) those presenting definitions, characteristics, uses, and applications of Rare Earth Elements; (2) those addressing the benefits and advantages of the industrialization of these strategic minerals; (3) those demonstrating the interrelationship between Rare Earth Elements and the global energy transition process; and (4) sources analyzing the geopolitics of Rare Earths within the current International System.

Results: The findings indicated that Rare Earths have the capacity to support economic growth, industrial development, and social well-being in countries that effectively utilize them in high-value technological products.

Conclusion: Rare Earth Elements occupy a central position in contemporary geopolitical and economic dynamics, given their relevance to strategic sectors and their influence on international relations, reinforcing their role within the global agenda of the 21st century.

Key Word: Rare Earths; Strategic minerals; Geopolitics; Development; Energy transition.

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I. Introduction

The exploitation of mineral resources, as a means of promoting economic development and strengthening nations, has been a defining feature throughout human history. Since the Modern Era (1453–1789), numerous instances have demonstrated how wealth extracted from the subsoil has enabled the stability and growth of countries.

Between the 15th and 17th centuries, with the advent of the Age of Exploration, European nations initiated the Commercial Revolution, expanding beyond continental boundaries. In this process, they reached distant regions in Africa and Asia and encountered the Americas (“New World”). This period marked the emergence of Mercantilism, a set of economic practices that characterized the transition from feudalism to capitalism.

Within the framework of Mercantilism, Metalism emerged as an economic policy in which a nation's wealth was measured by the accumulation of precious metals, particularly gold and silver. This dynamic contributed to the rise of major European powers such as Portugal, Spain, England, and France, among others. During the 18th and 19th centuries, with the First Industrial Revolution (1760–1850) in England, the rise of the

British Empire as an economic power was partly associated with the availability of coal, used for energy production, and with the industrial processing of iron ore in metallurgical and steel industries.

In the 20th century, the global consolidation of oil and natural gas as primary energy sources drove economic expansion. Higher levels of consumption were directly associated with improved macroeconomic indicators in countries engaged in their exploitation. At the beginning of the 21st century, increasing awareness of the environmental impacts associated with the intensive use of fossil fuels, particularly greenhouse gas emissions and global warming, led to the recognition of alternative mineral resources as contributors to the global energy transition. Concurrently, advances in research, development, and innovation, along with the growing demand for high-technology goods, fostered the emergence of the Fourth Industrial Revolution, which required specific minerals to enhance industrial efficiency and productivity.

In this context, Rare Earth minerals have gained prominence as key raw materials in the scientific and technological transformation that characterizes the present century. Recognized as strategic resources by several countries, these minerals have demonstrated the capacity to reshape global geopolitical dynamics by strengthening the political and economic position of nations that possess them. The importance of the extraction and industrialization of Rare Earths, combined with their application across various industrial processes and sectors of modern society, has led to the understanding that they can contribute to, influence, and reinforce mineral, energy, and technological sovereignty in countries that utilize them.

Their relevance is such that they have been altering the global geopolitical landscape, with nations seeking to consolidate and control beneficiation processes, while a limited number of countries, notably China, maintain control over the production chain. For this reason, Rare Earths have often been characterized as the gold or oil of the 21st century. Regarding the methodological approach, a qualitative method was adopted. In terms of research procedures, the study was based on bibliographic and documentary analysis, drawing on national and international publications, scientific articles, governmental sources, multinational institutions, and online resources. The consultation and synthesis of these materials enabled the identification of the most relevant issues addressed in this study.

Accordingly, the general objective of this work is to analyze the importance of Rare Earth Elements as a priority topic on the 21st-century global agenda, the geopolitics associated with these strategic minerals, and their implications for the International System. Based on this analysis, the study seeks to provide support to the academic community and to political, economic, and scientific-technological institutions, contributing to greater awareness and prioritization of exploration activities, including extraction, utilization, processing, and industrialization, as well as to the formulation of strategies aimed at economic development.

The specific objectives established are as follows: to present the definitions and characteristics of Rare Earth Elements; to describe their uses and applications; to characterize the benefits and advantages associated with their industrialization; to demonstrate their indispensability for the global energy transition; and to evaluate the geopolitics of these minerals within the current International System. Thus, this article is structured into four sections that provide a comprehensive analysis of the importance of Rare Earth Elements as a priority topic on the 21st-century global agenda. The first section, Introduction, presents the central theme of the study. The second section, Methodology, describes the research approach, including data collection and analysis strategies. The third section, Theoretical Framework, provides an understanding of the definitions, uses, and applications of Rare Earths in high-technology products for modern society; characterizes the benefits and advantages of their industrialization; demonstrates their indispensability for the energy transition; and presents an evaluation of the geopolitics of Rare Earths within the current International System.

The Final Considerations section synthesizes the main findings of the research, emphasizing how the academic community and political, economic, and scientific-technological institutions can achieve greater awareness regarding the use, processing, and industrialization of Rare Earths, supporting the formulation of strategies aimed at economic development.

II. Material And Methods

The approach adopted in this research was qualitative in nature, as the primary objective was to analyze the importance of Rare Earth Elements as a priority topic on the 21st-century global agenda, the geopolitics associated with these strategic minerals, and their implications for the International System. This approach is widely recognized in the scientific domain for its ability to provide contextual analyses, enabling a comprehensive understanding, in this case, of how the production chain of Rare Earth Elements may influence societal development in the 21st century.

Furthermore, qualitative research emphasizes the interpretation and understanding of complex phenomena, being particularly relevant in areas involving strategic mineral resources that have influenced scientific and technological development, the global energy transition process, industrial expansion, and the consolidation of mineral diplomacy.

With regard to methodological procedures, the research was classified as bibliographic. This type of procedure is based on the systematic analysis of previously published scientific works, constituting one of the foundations of scientific knowledge construction. According to Pereira et al. (2018), bibliographic research contributes to the consolidation of theoretical and methodological frameworks, as it brings together and interprets significant contributions on a specific topic. Yin (2016) further argues that this method enhances the analytical rigor of research by grounding discussions in established theoretical perspectives.

For the development of this review, research sources were selected and organized into four main categories: (1) sources presenting definitions, characteristics, uses, and applications of Rare Earth Elements for the benefit of modern society; (2) sources addressing the benefits and advantages associated with the industrialization of these strategic minerals; (3) sources demonstrating the interrelationship between Rare Earth Elements and the global energy transition process; and (4) sources examining the geopolitics of Rare Earths within the current International System.

The classification of these sources enabled a broader and more contextualized understanding of the significance of the exploration and industrialization of Rare Earths within the framework of mineral, energy, and technological security. The bibliographic and documentary reviews were conducted through the consultation of national and international publications, scientific articles, governmental bodies, multinational institutions, and online sources, ensuring comprehensive coverage that reflects the contributions of these resources to the academic community and to political, economic, and scientific-technological institutions in prioritizing Rare Earths as a strategic theme for economic development.

III. Theoretical Framework

This theoretical framework was structured into five subsections. The first subsection presented the definitions and characteristics of Rare Earth Elements. The second addressed the uses and diverse applications of Rare Earth Elements for the benefit of modern society. The third subsection examined the benefits and advantages associated with the industrialization of Rare Earth minerals. The fourth discussed the rationale underlying the interrelationship between Rare Earths and the ongoing energy transition process. The final subsection provided an assessment of the global geopolitical context as a reflection of these strategic mineral resources.

Definitions and Characteristics of Rare Earth Elements

The first Rare Earth Element identified was cerium, discovered in 1751 by the Swiss mineralogist A. F. Cronstedt, when he obtained a dense mineral known as cerite. However, the year 1787 is commonly regarded as the beginning of Rare Earth history, when Carl Axel Arrhenius identified a dark mineral, ytterbite, also referred to as gadolinite, in a small village near Stockholm. Due to their similar physicochemical properties, Rare Earth Elements require complex and labor-intensive separation processes, which limited their exploration for many years. It was only in 1907 that nearly all Rare Earth Elements had been identified (Martins; Isolani, 2005).

These elements correspond to a segment of the periodic table composed of 15 chemical elements, known as lanthanides, with atomic numbers ranging from 57 (La, lanthanum) to 71 (Lu, lutetium). In addition, scandium ($Z = 21$) and yttrium ($Z = 39$) are included in this classification due to their similar properties (Loureiro, 1994; Reis Melo, 2017; IUPAC, 2017). These elements are primarily found in minerals such as bastnäsite, monazite, ion-adsorption clays, and xenotime (Santos, 2024).

Figure 1: Periodic Table (Rare Earth Elements highlighted in orange).

Rare Earth Elements by Geology.com																					
H																	He				
Li	Be															B	C	N	O	F	Ne
Na	Mg															Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr				
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe				
Cs	Ba	La-Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn				
Fr	Ra	Ac-Lr	Rf	Db	Sg	Bh	Hs	Mt													
Lanthanides																					
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu																					
Actinides																					
Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr																					

Source: Reis Melo (2017) e King (2026).

According to Souza et al. (2019), lanthanides can be classified into:

- Light: lanthanum (La), cerium (Ce), praseodymium (Pr), and neodymium (Nd);
- Medium: promethium (Pm), samarium (Sm), europium (Eu), and gadolinium (Gd); and
- Heavy: terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu).

Cerium, lanthanum, and neodymium are more abundant than heavy metals such as cobalt, nickel, and lead, whereas the less common elements, thulium and lutetium, occur more frequently than silver and platinum group metals (Abrão, 1994, as cited in Souza et al., 2017).

Despite being referred to as rare, these elements are more abundant in the Earth's crust than metals such as silver, gold, and platinum, and are therefore considered strategic resources, often described as the "gold of the 21st century" (Brasil, 2013). The terminology originated in the 18th century, when these elements were first identified and, due to their earthy appearance and the mistaken assumption of scarcity, were labeled as rare (Lapido-Loureiro, 1993).

In this sense, Rare Earths constitute a group of 17 chemical elements (Figure 1) that form a fundamental basis for future technologies. Characterized by their distinctive electronic, magnetic, and optical properties, they are indispensable in a wide range of modern applications and in the production of advanced technological systems (Oliveira et al., 2025; Júnior and Oliveira, 2020 as cited in Santos, 2025).

General Considerations of Fortaleza International Airport

Use and Application of Rare Earth Elements

The industrial history of these elements began with the development, by Carl Auer von Welsbach, of a highly successful device at the time that improved artificial lighting, namely gas lamp mantles composed of oxides and zirconium, in 1883 (Martins; Isolani, 2005).

Currently, the demand for Rare Earths has intensified due to the growing need for high-purity metals and oxides used in the production of advanced technological goods (Loureiro, 1994 as cited in Souza et al., 2019). The versatility of each element derives from its magnetic properties, which are essential for permanent magnets in electric vehicles and wind turbines; luminescent properties, applied in LED displays; catalytic properties, used in automotive converters; and electrochemical properties, relevant for rechargeable batteries (Souza Filha and Barreto, 2019 as cited in Santos, 2025).

Compounds of lanthanum (La) and nickel (Ni) are employed in the production of battery cells for energy storage. The presence of lanthanum enables hydrogen (H) absorption within the cell and facilitates the reversibility of this electrochemical process, forming La-Ni-H compounds. These rechargeable batteries are particularly suitable for electric vehicles due to their high efficiency (CGEE, 2013).

The ability to generate strong and lightweight magnetic fields is fundamental for device miniaturization and for improving the efficiency of motors and generators. Neodymium and dysprosium, for example, are used to produce the most powerful permanent magnets, which are essential components in electric vehicles and wind turbines (IEA, 2023 as cited in Santos, 2025).

Rare Earth Elements are present in products that incorporate advanced technologies, including hybrid and electric vehicles, aircraft engines, ships, smartphones, computers, tablets, optical fibers, photovoltaic panels, petroleum refining equipment, display lighting systems, high-performance magnets resistant to high temperatures, nuclear magnetic resonance imaging, and luminescent markers used in the investigation of enzymes, antibodies, cells, and hormones, among other industrial and biological applications. In addition, they may be employed in missiles and precision-guided munitions, which are relevant for defense and technological advancement (Reis Melo, 2017; Martins and Isolani, 2005; Melo, 2017 as cited in Silva, 2025).

Furthermore, Rare Earths are valued for their luminescent and catalytic characteristics. Europium and terbium are used in LED, LCD, and OLED displays, enabling vibrant colors and efficient illumination (Souza Filho and Barreto, 2019 as cited in Santos, 2025). Cerium serves as a key catalyst in automotive converters for reducing carbon emissions, as well as in petroleum refining and glass polishing processes (Júnior and Oliveira, 2020).

In the healthcare sector, gadolinium functions as a contrast agent in magnetic resonance imaging, while yttrium is applied in cancer therapies and surgical lasers (USGS, 2024). In the aerospace and defense industries, alloys containing Rare Earths provide high-temperature resistance and reduced weight for aircraft, missiles, and satellite components (Couto and Reis, 2021 as cited in Santos, 2025).

The miniaturization and efficiency of these components enable the development of lighter, more powerful, and energy-efficient equipment, such as drones, autonomous robots, augmented reality devices, and intelligent industrial monitoring and control systems. Additionally, they support advances in emerging fields, including quantum computing, biomedical sensors, and space technologies, consolidating their role in global technological development (Oliveira et al., 2025).

Cerium oxide is the most widely used compound due to its redox properties, high oxygen mobility, and stabilizing function. Catalysts for automotive emission control are currently employed in most vehicles to reduce pollutant emissions (Martins; Isolani, 2005).

In the military domain, Rare Earth-based metallic alloys are fundamental for the operation of various weapons and equipment. In the absence of these elements, munitions may lose efficiency in reaching their targets, resulting in reduced precision and, consequently, a potential increase in civilian casualties (Kiggins, 2015 as cited

in Reis Melo, 2017). Samarium and neodymium are among the most utilized elements in defense products, including radar systems, guided missiles, precision-guided munitions, and fighter aircraft (Humphries, 2012 as cited in Reis Melo, 2017).

It is noteworthy that the United States Armed Forces also employ these elements in night vision equipment, precision-guided weapons, communication systems, GPS devices, batteries, electronic components, the production of highly resistant alloys for armored vehicles, and projectiles designed to fragment upon impact (King, 2026), providing significant operational advantages.

In the glass industry, Rare Earths are widely used in the production of specialized ophthalmic lenses for solar applications and in the manufacture of glass containers capable of absorbing ultraviolet radiation, which are used to store light-sensitive food products. A mixture of europium and cerium is applied in the production of sunglasses. High-purity glasses containing neodymium and praseodymium are used as specialized filters for calibrating optical instruments (Martins; Isolani, 2005).

Thus, the use of these materials is not only quantitative but also qualitative, as their physicochemical properties are not easily replaceable, ensuring the performance, durability, and efficiency of industrial products.

As a result, they become key components for energy security, industrial competitiveness, and technological sovereignty of nations (Karas, 2025).

The Center for Management and Strategic Studies (CGEE) developed a taxonomy of Rare Earth Elements (Table 1), which demonstrates the breadth of their applications and uses across various industrial processes.

Table 1: Unified taxonomy for the prospective study of Rare Earths

Industrial Use	Application	Functionality	Rare Earths
Electric vehicles, hybrid vehicles, plug-in vehicles	Motors	Powerful permanent magnets, low energy consumption and improved fuel economy for vehicles	Neodymium, Praseodymium, Dysprosium, Terbium, Samarium
Wind turbines in wind farms	Power generation	Power generation for renewable energy, improved component performance, lower costs, and use of higher magnetic volumes	Neodymium, Praseodymium, Dysprosium, Terbium, Samarium
Integrated defense system	Permanent magnets	High-performance magnetic alloys used in weapons and communication systems	Neodymium, Dysprosium, Terbium
Data processing units for computers	Electric motors, fans, etc.	More powerful electric motors	Neodymium, Dysprosium, Terbium
Personal mobile devices	Compact devices, screens, etc.	More compact, lightweight, and efficient devices	Praseodymium, Dysprosium, Terbium
Equipment for medical diagnosis by imaging	Magnetic field generation	Generation of magnetic fields for medical imaging	Neodymium, Praseodymium, Dysprosium, Terbium
Automotive catalytic converters and petroleum refining	Catalysts	Promote chemical reactions to reduce emissions	Lanthanum, Cerium, Praseodymium, Neodymium
Glass industry	Glass polishing	Modification of optical properties, making glass clearer and more transparent	Cerium
Metallurgical industry, electronics industry, energy generation, and transportation	Metallic alloys	Modification of physical and chemical properties to enhance alloy performance	All Rare Earth Elements
Chemical industry and agriculture	Catalysts	Reduction of chemical processes, lower energy consumption, and improved chemical reactions	All Rare Earth Elements
Lighting and display technologies	Phosphors	Improvement of brightness and color reproduction in displays	Europium, Terbium, Yttrium
Personal mobile devices	Phosphors	Displays in television screens and mobile devices	Europium, Gadolinium, Yttrium
Flat-screen TVs and LED displays	Phosphors	High color performance, vibrant displays, and high brightness levels	Cerium, Terbium, Yttrium
X-ray detectors	Phosphors	Capture of X-rays for medical imaging and industrial applications	Cerium, Lanthanum
Glass and lens polishing	Polishing	Improvement of optical properties in lenses and glasses	Cerium

Industrial Use	Application	Functionality	Rare Earths
Glass and lens manufacturing	Glass polishing and special lenses	Manufacture of special lenses for solar use and ultraviolet radiation absorption	Cerium, Neodymium, Praseodymium, Erbium, Holmium
Optical fibers for telecommunications	Optical fibers doped with Rare Earths	Signal amplification	Yttrium, Europium, Neodymium, Erbium, Holmium
Gas sensors, including CO ₂	Amplifiers	Monitoring and control of gas emissions and environmental measurement	Yttrium
Ceramic materials for industrial use	Ceramics	Improvement of mechanical and thermal properties	Yttrium, Neodymium
Energy devices	Alloys and compounds	High capacity for energy storage and conversion	All Rare Earth Elements
Energy storage devices	Nickel-metal hydride (NiMH) batteries	Higher energy storage capacity and improved battery performance	Lanthanum

Source: Center for Management and Strategic Studies (2013)

In electronic devices, Rare Earth Elements play a central role in the operation of products such as smartphones, computers, televisions, medical equipment, and optical fibers. This relevance is directly associated with their specific physicochemical properties, which enable the development of materials with unique characteristics and limited possibilities for substitution (IEA, 2023; UNCTAD, 2023 apud Santos, 2025).

It is important to note that the consumption of Rare Earth Elements has nearly tripled over the past 15 years, with a continuing upward trend. Research and development activities have contributed significantly to this expansion, broadening access to emerging markets such as solar cells, supermagnets, and high-temperature superconductors, which are applied in wind generators and electric vehicles (Brasil, 2013).

At present, Rare Earths are increasingly utilized in industries associated with energy, leading to a sustained demand for these elements. So-called green industries rely on them for the development of hybrid vehicles and electric motors used in wind turbines, reinforcing their status as strategic resources (Loureiro and Santos, 2013 apud Souza, 2019).

In biological systems, Rare Earth Elements have been extensively investigated due to their notable spectroscopic and magnetic properties, which are applied in studies of biomolecules, particularly calcium-binding proteins (Martins; Isolani, 2005). Among their applications are biological tracers used to monitor the pathways of pharmaceuticals in humans and animals, such as in fluoroimmunoassays (CGEE, 2013).

Considering these aspects, it becomes evident that Rare Earths are closely associated with a range of disruptive technologies, contributing to the emergence of new services and innovative products (Heider, 2021).

Thus, it can be partially concluded that Rare Earths present a wide spectrum of civil and military applications. Mastery of the complex and costly industrialization processes of these elements may provide competitive advantages for certain countries over others in the development of high-value technological industries. Consequently, control over this production cycle also contributes to strengthening scientific and technological sovereignty for the benefit of society.

Benefits and Advantages of the Industrialization of Rare Earth Elements

As previously observed, Rare Earth Elements present a wide range of applications throughout the industrialization process, encompassing the entire production chain. These processes are characterized by high levels of technical complexity and require substantial investments in research and development.

Beyond their role as mineral inputs, Rare Earth Elements are regarded as the “oil of the 21st century” due to their strategic importance and their central function in advanced technologies, with applications across sectors such as energy, defense, healthcare, transportation, and communication (Oliveira et al., 2025).

As illustrated in Table 2, the benefits derived from the exploration and industrialization of Rare Earths have the capacity to promote and support societal development in a broad sense. In the fields of transportation and energy, for instance, these elements contribute to improving the conditions for the energy transition, reducing reliance on fossil fuels and mitigating greenhouse gas emissions.

Table 2: Benefits and Advantages of the Industrialization of Rare Earth Elements

Areas of Interest	Description
Transportation	- Hybrid and electric vehicles, automotive converters; - Rechargeable batteries and electric motors.
Energy	- Wind turbines, aerogenerators, photovoltaic panels; - Nuclear energy generation and power transmission lines; - Energy storage devices and petroleum refining.

Areas of Interest	Description
Electronics	- LED and LCD displays, smartphones, computers, and tablets; - Augmented reality equipment; - Industrial control and monitoring systems.
Naval industry	- Ship engines.
Defense industry	- Missiles, precision-guided weapons, drones, autonomous robots; - Night vision equipment and GPS devices.
Aerospace industry	- Aircraft engines, satellite manufacturing; - Communication equipment and space technologies.
Healthcare	- Biomedical sensors, X-ray and gamma-ray detectors; - Contrast agents for magnetic resonance imaging; - Luminescent markers for the investigation of enzymes, antibodies, cells, and hormones; - Cancer therapies and surgical lasers.
Telecommunications	- Optical fibers and quantum computing.

Source: CGEE (2013); IEA (2023); UNCTAD (2023); Oliveira et al. (2025); Santos (2025).

In the healthcare sector, Rare Earths would contribute to the production of equipment used in a wide range of medical treatments and diagnostic procedures, with direct implications for improving quality of life. Within the Defense Industrial Base, through aerospace, naval, and military components, their use would enhance security capabilities, functioning as a deterrent against threats to national sovereignty.

It is also important to note that telecommunications would benefit from the expansion of optical fiber infrastructure and advances in quantum computing, enabling equipment and materials to support the digital transformation that characterizes the contemporary era.

In this context, within the current global political and economic environment marked by uncertainties, challenges such as volatility in international relations and climate change, and opportunities related to digitalization, technological autonomy, and energy security, the importance of exploring and industrializing the Rare Earth production chain would increase, contributing to technological sovereignty, industrial efficiency, and the economic strengthening of nations.

The Indispensability of Rare Earths in the Global Energy Transition

Global warming is already a tangible reality, as climate change has led to extreme events occurring with unprecedented frequency, directly affecting the socioeconomic conditions of millions of people. One of the responses to this scenario has been the intensification of the energy transition through the expansion of renewable energy sources and the decarbonization of the global economy, aiming to mitigate environmental impacts across all continents (Barbosa and Gomes, 2024).

Droughts, floods, storms, and extreme temperatures have become increasingly evident in recent decades. In response to these phenomena, national and international organizations have sought to promote environmental awareness, with the objective of reconciling economic activities while preserving natural resources for future generations (ESG, 2009). This context reinforces the need to adopt alternative energy generation models based on renewable, environmentally cleaner, and ecologically sustainable sources, in contrast to fossil fuel-based systems (Barbosa and Gomes, 2024).

Under these circumstances, the global demand for green technologies, driven by growing environmental concerns and the need to mitigate climate change, has reinforced the strategic importance of Rare Earths. The transition toward renewable energy matrices, particularly solar and wind, depends significantly on the use of Rare Earth Elements in components such as magnets in wind turbines and semiconductors in high-efficiency solar panels (Andrade and Oliveira, 2020; Oliveira et al., 2025).

This transition, understood as the gradual replacement of fossil fuels with renewable and low-carbon alternatives, is directly dependent on the supply of critical minerals. Key technologies for decarbonization, including lithium-ion batteries, wind turbines, photovoltaic panels, electric motors, and energy transmission systems, require mineral inputs such as lithium, cobalt, nickel, copper, graphite, and Rare Earths (Karas, 2025).

In this context, so-called green minerals play a central role in the development of clean technologies, supporting industrial activities and enabling the generation of renewable energy, while also contributing to low-carbon infrastructure and technological systems (Hine; Gibson; Mayes, 2023 apud De Tomi et al., 2024).

Elements such as neodymium, praseodymium, dysprosium, and, to a lesser extent, terbium are particularly relevant, as they are used in the production of permanent magnets subsequently applied in green technologies (Gielen; Lyons, 2022). The use of these magnets in wind turbine generators offers several advantages, including the elimination of gearboxes, higher energy efficiency and power-to-weight ratio, reduced need for excitation energy supply, increased reliability due to fewer mechanical components, and improved cost-effectiveness in systems with power outputs exceeding 3.6 MW (CGEE, 2013).

Consequently, the supply of inputs for permanent magnets becomes essential to meet the demands of a growing automotive industry. In a scenario characterized by energy transition, projections indicate that the total demand for permanent magnets and Rare Earths used in electric vehicles and wind energy could more than double by 2030 (Gielen and Lyons, 2022).

Regarding green technologies and atmospheric emission control, production chains are highly dependent on Rare Earths, which are fundamental in the manufacture of four key products (CGEE, 2013): a) Permanent magnets for wind turbines and electric vehicles; b) Advanced batteries for electric vehicles; c) Thin-film semiconductors for photovoltaic energy systems; and d) Phosphors for more efficient lighting systems.

Beyond commercial implications, Rare Earths occupy a central position in discussions on energy sovereignty and technological autonomy. They are strategic resources in the production of electric motors, wind turbines, and high-efficiency batteries (Oliveira et al., 2025). Therefore, the sustainable management of Rare Earths is essential for advancing technologies associated with energy generation and storage systems (Gomes et al., 2025).

Finally, studies conducted by Kursunoglo and Kursunoglo (2022) highlight the extent to which Rare Earth Elements are indispensable for the energy transition, as illustrated in Table 3 below:

Table 3: Beneficiaries of Clean Technologies

Green Technology	Consideration
Wind Energy	- One of the most promising renewable energy sources in addressing climate change; - Wind turbines, particularly larger and more efficient models, rely heavily on Rare Earths to enhance performance and reduce operational costs, notably neodymium (Nd), praseodymium (Pr), and dysprosium (Dy), which are used in the production of high-strength neodymium-iron-boron (NdFeB) permanent magnets.
Automotive Industry	- Electric vehicles designed to reduce greenhouse gas emissions; - These vehicles depend on Rare Earths, especially in their electric motors, where neodymium (NdFeB) magnets are applied; - Such magnets are essential for the production of lightweight and high-performance motors, improving energy efficiency and vehicle autonomy; - Neodymium-based magnets provide high energy density, enabling more compact and efficient motors compared to traditional induction motors; - Dysprosium is frequently added to neodymium magnets to enhance thermal stability, making them more suitable for high operating temperatures in electric vehicle motors.
Energy Storage Systems	- Essential for balancing the intermittent nature of renewable energy sources, such as solar and wind; - As renewable energy generation fluctuates depending on climatic conditions and time of day, advanced storage systems are required to ensure a reliable electricity supply; - Rare Earths contribute both to materials science and to technological advancements that drive innovation in this sector.

Source: Kursunoglo and Kursunoglo (2022).

Therefore, it can be partially concluded that there is a clear interrelationship between the industrialization and use of Rare Earths, such as neodymium, praseodymium, dysprosium, and terbium, and the ongoing global energy transition process. The analyses conducted indicate that part of the response to global warming and climate change, particularly in mitigating greenhouse gas emissions, lies in the adoption of clean or green technologies that incorporate Rare Earths. These findings contribute to the expansion of research and innovation efforts aimed at advancing the energy transition, fostering technological development, and improving the industrial capacity of nations.

The Geopolitics of Rare Earths in the Current International System

The increasing demand for clean technologies has intensified global competition for strategic resources, equipment, and technical expertise. Critical minerals such as lithium, cobalt, and Rare Earths have become essential to the production chains of energy technologies, playing a determining role in national industrial security (IEA, 2023b).

The International Energy Agency projects that demand for these minerals may increase up to sixfold by 2040, reinforcing their limited substitutability (IEA, 2023a). In this context, there is an understanding that a nation's level of development may be associated with its consumption of Rare Earths for advanced technological applications (Sousa Filho and Serra, 2014 apud Silva, 2025).

This global competition, combined with the pursuit of national sovereignty, has stimulated geopolitical disputes, leading to the creation of mechanisms aimed at securing access to these minerals through bilateral or commercial agreements. Notably, major cooperation frameworks related to mineral security include the Minerals Security Partnership, comprising countries such as the United States, Australia, Canada, Finland, France, Germany, Japan, Norway, South Korea, Sweden, the United Kingdom, and the European Union, as well as the BRICS group, formed by Brazil, Russia, India, China, and South Africa (De Tomi et al., 2024).

In this context, partnerships with multinational companies and cooperation agreements with countries that possess advanced extraction and processing technologies have become increasingly relevant, as both are considered strategic for supporting sectoral growth (Santos, 2024). Countries such as Japan, the United States, Australia, and Germany, seeking to reduce dependence on China, have encouraged the production of Rare Earth Elements in resource-rich nations, aiming to diversify supply chains and promote technology transfer (Filho and Serra, 2014 apud Oliveira et al., 2025).

These and other countries recognize that the global Rare Earth market is characterized by structural challenges and vulnerabilities, particularly due to the high concentration of the production chain in China, which leads the market in extraction, processing, and export activities. This concentration generates significant geopolitical risks for countries dependent on external supply (Oliveira et al., 2025).

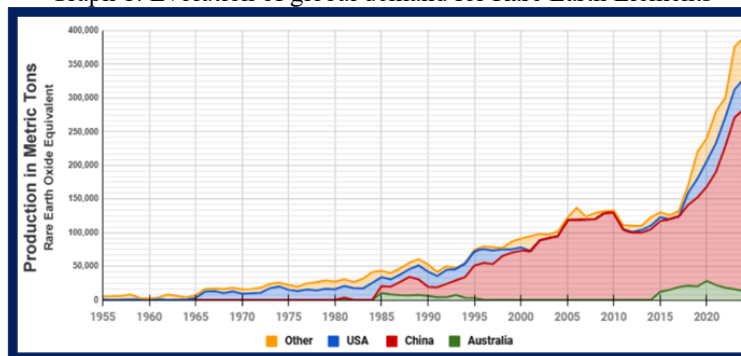
An important dimension for understanding this international cooperation lies in the existence of three major asymmetries in the sector (PSI, 2025): a. Supply concentration: China has consolidated a dominant position in supply, processing, and refining, controlling between 60% and 90% of segments within the supply chain and acting as the leading refiner of 19 out of the 20 most critical minerals; b. Accelerated demand: electrification, energy transition, digital transformation, artificial intelligence, and defense industries rely on a combination of renewable raw materials and Rare Earths, accelerating demand and transforming these resources into a central concern for foreign policy and economic security; and c. Strategic response: mineral diplomacy has emerged as a key instrument for geoeconomic actors, including the United States and the European Union, to secure access to these resources through a combination of cooperative, coercive, and binding mechanisms.

Another relevant aspect concerns the resurgence of more proactive industrial policies. In recent decades, initiatives aimed at fostering technological development, protecting strategic sectors, and strengthening domestic industry have become more frequent. This movement is associated with the pursuit of greater economic security, enhanced technological autonomy, and increased resilience in global supply chains, particularly in sectors considered strategic for the energy transition (Evenett et al., 2024).

The complexity of this topic is further highlighted by the fact that, although Rare Earths are found in several countries, including China, Australia, Canada, the United States, India, Malaysia, Russia, and Brazil, their extraction in economically viable volumes remains challenging (CGEE, 2013). Additionally, the concentration of reserves and production in a limited number of countries, particularly China, creates a complex geopolitical and logistical landscape (Oliveira et al., 2025).

For a more comprehensive understanding of these dynamics, Graph 1 presents the historical evolution of Rare Earth production, measured in metric tons of rare earth oxide equivalent, between 1950 and 2024. When China began offering these materials at significantly lower prices in the late 1980s and early 1990s, mining operations in the United States were forced to close due to reduced profitability. Subsequently, when China restricted exports in 2010, prices increased substantially, leading to the resumption of production in countries such as the United States, Australia, Russia, Thailand, and Malaysia (King, 2026).

Graph 1: Evolution of global demand for Rare Earth Elements



Source: King (2026)

These are, therefore, the reasons why Rare Earths have come to be classified as critical minerals, due to the dominance of a single producer in the global market and their limited substitutability in strategic technologies, positioning them at the center of the global economic agenda and geopolitics (IEA, 2023). Within this context, different countries have intensified efforts toward sovereignty over critical and strategic minerals, leading to a dynamic in which cooperation and competition coexist in shaping a more diversified and multipolar international order (De Tomi et al., 2024).

China's Global Primacy in the Rare Earth Value Chain

From the late 1980s onward, China, supported by extensive reserves, low labor costs, and competitive pricing, came to dominate the Rare Earth market. As a result, mining operations in other countries, including those with existing reserves, lost competitiveness and were discontinued. With nearly full control of international sales, China regulated production levels, leading to a sharp increase in prices in 2011 and triggering renewed global interest in Rare Earth production (Brasil, 2013). The country has implemented a structured planning framework, with clearly defined objectives and targets, allocating significant human resources to specialization and fostering innovation systems aimed at developing competitive, technology-driven industries (Heider, 2021).

During the 1990s, as China consolidated its dominance, Rare Earth mining activities declined in the United States, with only the company Molycorp continuing to produce neodymium, praseodymium, and lanthanum oxides. Following the price increases driven by Chinese policies in 2011, production activities resumed both in Brazil and globally (Brasil, 2013).

From 2010 onward, China, which holds the largest global reserves of Rare Earths, implemented export restrictions, limiting shipments to approximately 35,000 tons of Rare Earth oxides annually. This led governments and the global mining industry to seek alternative sources to meet demand (Antoniassi, 2017).

Over approximately two decades, China developed the entire Rare Earth production chain (Salomão, 2023 apud Silva, 2025). Its market dominance, including in magnet production, reflects not only favorable conditions such as resource availability and low labor costs, but also long-term strategic planning. Regardless of intent, other producers effectively allowed China to operate with limited competition (Brasil, 2013).

China's ability to control production and, consequently, global supply of economically significant metals, supported by sustained industrial policies and research investments, has prompted major consuming countries to pursue alternative supply sources in an increasingly unstable geopolitical environment (Gielen and Lyons, 2022).

Within China, strategic minerals are regarded as pillars of economic security and national defense. Since 1959, the country has adopted a protectionist approach to support its domestic industry, combined with investments in technology and innovation (Gulley; McCullough; Shedd, 2019 apud De Tomi et al., 2024).

Currently, China accounts for approximately 90% of the production of materials containing Rare Earth Elements and 85% of Rare Earth oxides, corresponding to around 122,220 tons in 2016. The remaining global production is distributed among countries such as Australia, Malaysia, Brazil, India, Russia, and Vietnam (Zhou et al., 2017 apud Souza et al., 2019).

As a result of its control over the Rare Earth value chain, China competes for global leadership in information and communication technologies, represented by companies such as Huawei, Xiaomi, and ZTE; high-speed rail systems; renewable energy technologies; and advanced computing systems such as the TaihuLight supercomputer (Heider, 2021).

Uncertainties regarding supply security, particularly in light of China's export quota policies, have encouraged consuming countries to seek alternative sources through cooperation agreements and partnerships. These initiatives aim to develop projects focused on the production and processing of Rare Earths across various applications (CGEE, 2013).

These dynamics explain how the current geopolitical configuration surrounding Rare Earths influences the structure of the International System, as further examined below.

The Current Global Geopolitical Scenario in Rare Earth Exploration

Variations in supply and limited access to strategic resources can reshape international geopolitics. Historical events, such as the oil crises of the 1970s, illustrate how control over key natural resources can redefine economic power structures (Reis Melo, 2017).

In the present context, a central issue related to Rare Earths in a low-carbon economy is the concentration of production in a limited number of countries, particularly China, which controls more than 60% of global production and 85% of refining capacity. This concentration has raised concerns regarding supply chain security, especially in light of trade tensions and geopolitical uncertainties. Previous export restrictions and policy measures have led to supply disruptions, price increases, and concerns over access to these essential resources (Kursunoglo and Kursunoglo, 2022).

For this reason, industrialized regions such as the European Union, the United States, and Japan have expressed concerns about access to specific Rare Earths, as supply constraints could directly affect their economic performance. Increased global competition has encouraged some countries to adopt industrial and trade strategies aimed at reserving resources for domestic use (Reis Melo, 2017).

Historically, the United States led Rare Earth exports for approximately two decades during the period known as the "Mountain Pass Era," named after its principal mining site. In the 1980s, production reached around 20,000 tons annually. However, with China's growing dominance in the following decade, mining activities declined, and only Molycorp continued operations using existing stockpiles. Subsequent price increases and Chinese export restrictions renewed U.S. interest in the approximately 30 million tons of Rare Earth reserves at Mountain Pass (Brasil, 2013).

Japan, recognized as a major consumer and a leader in Rare Earth processing technologies, experienced the relocation of companies to China in search of lower costs and supply stability. This movement resulted in the transfer of expertise, employment, and technological advantages. In response, Japan implemented strategic measures to retain industrial capacity, including investments in innovation and supply diversification. In 2023, the Japanese government provided additional financing to the company Lynas to establish facilities for the separation and production of heavy Rare Earths, aiming to reduce dependence on China (IEA, 2023b).

Similarly, the European Union has developed supply security policies focused on long-term agreements, financing exploration and processing activities, and promoting recycling initiatives (European Commission, 2023). The International Energy Agency estimates that, by 2040, global demand for neodymium and dysprosium may double or triple, driven by the expansion of clean energy and electric mobility (Cuadros-Muñoz et al., 2024).

These developments indicate that the political, economic, scientific-technological, energy, digital, industrial, and military relevance of Rare Earths has led countries to recognize their importance in shaping national and international strategies. In alignment with their interests, priorities, and long-term planning, various nations have reassessed how access to Rare Earths, including exploration, extraction, separation, and industrialization, can support their development trajectories (Table 4).

Table 4: Purpose of the Industrialization of Rare Earth Elements

Countries	National Strategic Priority
China	- Economic and national defense security; - Strengthening of domestic industry; - Investment in Research, Development, and Innovation; - Consolidation of mineral processing within the country; - Expansion of partnerships and alliances with countries holding mineral reserves; - Promotion of energy transition technologies; and - Acquisition of geological knowledge.
United States	- Stability of economic development; - National defense (military interests) and supply chain security; - Geopolitical resilience; and - Production of essential goods for the industrial and security sectors.
European Union	- Development of key technologies; - Promotion of key technologies related to the energy transition; - National defense (military and aerospace interests); and - Reindustrialization strategy.
Australia and Canada	- Stability of economic development in response to risks of supply chain disruptions; - Strengthening of domestic industry and national defense; and - Promotion of key technologies related to the energy transition.
India	- Stability of economic development; and - National defense (military and aviation interests).
South Africa	- Stability of economic development in response to risks of supply chain disruptions; - Reindustrialization strategy; - Investment in Research, Development, and Innovation; and - Promotion of key technologies related to the energy transition.
Russia	- Stability of economic development in response to risks of supply chain disruptions; - Strategic importance of consolidating energy security; - Investment in Research, Development, and Innovation; and - Promotion of key technologies related to the energy transition.

Source: De Tomi et al. (2024).

In light of the global context, several countries have resumed investments in exploration projects, including the United States, Canada, Australia, and Greenland. However, the challenges remain substantial. Given that Rare Earth mining is a complex and high-cost activity, ensuring investment returns requires the integration of the entire production chain; otherwise, market viability may be compromised due to the absence of sufficient demand (Brasil, 2013).

Regarding Brazil, the country currently holds the second-largest Rare Earth reserves in the world, estimated at approximately 21 million tons, second only to China, which possesses around 44 million tons (USGS, 2025).

From a geopolitical perspective, and consistent with its prominent global position, the strategic management of Rare Earths in Brazil requires the definition and implementation of a national strategy that integrates economic, environmental, and technological interests. This would involve strengthening research institutions, expanding investments in science and technology, and fostering incentives for the development of industries that incorporate Rare Earth Elements into their production processes (Oliveira et al., 2025). In this context, Brazil's alignment with international cooperation frameworks focused on the supply of critical and strategic minerals is consistent with the objective of enhancing mineral sovereignty (De Tomi et al., 2024).

Finally, it can be inferred that advancing these discussions represents a priority within the scope of global geopolitics, as it encompasses environmental, economic, political, strategic, military, security, and developmental dimensions (Melo and Dias, 2015 apud Reis Melo, 2017).

Thus, it may be partially concluded that the International System has recognized the importance of the Rare Earth production chain and the limited substitutability of these elements, given the benefits associated with their industrialization. Nevertheless, their uneven geographical distribution results in a scenario in which some countries depend on imports, while others dominate the value chain and impose export restrictions. Moreover, China's global leadership in this sector has contributed to the reconfiguration of mineral geopolitics, prompting a range of strategic responses from countries that depend on these resources for their national development.

IV. Final Considerations

Mineral resources have consistently played a significant role in strengthening national economies. Historically, since the Modern Era, gold, silver, ores, oil, gas, and coal have directly influenced the consolidation of States.

In the twenty-first century, economically and technologically advanced countries have clearly recognized the extent to which Rare Earth Elements can contribute to consolidating mineral, energy, digital, technological, and industrial sovereignty, providing conditions for a more prosperous future grounded in the fundamental right to development.

Due to their unique physicochemical properties, Rare Earths, supported by sustained investments in research and development, have become increasingly relevant in addressing contemporary global challenges. The growing demand for high-technology goods, combined with the need to respond to global warming and climate change, has expanded their role across multiple sectors, including healthcare, energy, transportation, industry, telecommunications, and defense.

However, the availability, distribution, and supply of Rare Earth Elements are uneven across the globe. Only a limited number of countries possess significant reserves, and an even smaller group controls the full production chain. These conditions shape a distinct geopolitical configuration within the International System, fostering both cooperation through partnerships and alliances and competition through trade and diplomatic disputes.

In this context, the present study aimed to analyze the relevance of Rare Earth Elements as a priority topic in the global agenda of the twenty-first century, examining the geopolitics associated with these strategic minerals and their implications for the International System. Based on this analysis, the study also sought to provide support to the academic community and to political, economic, and scientific-technological institutions in order to enhance understanding of their exploration and industrialization, as well as to inform strategies aimed at economic development.

The findings indicate that the research objectives were achieved, as the study contributed to a comprehensive understanding of the factors that have led the international community to classify Rare Earth Elements as strategic minerals, given their presence across a wide range of economic activities. Their increasing use in high-value technological products has positioned them as relevant components in the pursuit of sustainable national development.

The analysis also demonstrated the interconnection between climate change, renewable energy, and clean technologies within the broader process of energy transition, highlighting the relationship between these elements and efforts toward decarbonization of the global economy.

Within these dynamics, China's leading position as the largest producer and exporter of Rare Earth Elements was confirmed, influencing other countries to pursue greater scientific and technological autonomy, expand industrial capacity, and strengthen their economic structures. In parallel, mineral diplomacy has emerged as a mechanism through which exporting and importing countries seek to balance their interests.

The qualitative approach, based on literature review and documentary analysis, proved adequate for examining the subject, particularly in demonstrating how the beginning of the twenty-first century has been marked by increasing dependence on these resources, capable of reshaping industrial, economic, environmental, energy, digital, and military structures in countries that effectively integrate them into their development strategies.

Finally, future research is recommended to examine the relationship between the exploration and extraction of Rare Earth Elements and the management of environmental impacts associated with their processing, refining, and industrial use. It is also suggested that further studies assess Brazil's role, capabilities, current position, and future prospects as a producer, consumer, and exporter of Rare Earth Elements.

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