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RESEARCH ARTICLE

Towards an Integrative Model for Sustainability and Technological Innovation amidst Global Geopolitical Shifts: A case study of Rare Earth Elements Project Management in Algeria

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Abstract

This study aims to clarify the strategic framework for managing rare earth projects in Algeria, with a focus on the integration between environmental sustainability and technological innovation in the context of global geopolitical competition over critical mineral resources. Algeria possesses promising potential in the field of rare earth elements, which are undergoing strategic transformations driven by the growing demand for green technologies. This transformation places Algeria in a strategic position to exploit its resources; however, it requires the adoption of a circular economic model based on recycling electronic and industrial waste to reduce reliance on direct extraction.

The study shows that the extraction of heavy rare earth elements such as dysprosium requires advanced technologies, which are still limited in Algeria. In addition, the overproduction of low-value elements such as cerium and lanthanum constitutes a burden on supply chains. This calls for the development of a comprehensive strategic framework that balances the optimal exploitation of these critical resources with environmental protection and the achievement of sustainable development, while benefiting from the opportunities offered by technological advances and the increasing demand for these elements in modern industries.

Citation

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Introduction

Rare earth elements constitute a group of seventeen chemical elements, including scandium, yttrium, and fifteen lanthanides. They are characterized by unique physical and chemical properties that make them essential to emerging technologies. These elements are divided into two main categories—light and heavy—and are used in applications such as automotive catalysts and oil refining, high-efficiency magnets for computers and wind turbines, as well as batteries, phosphorescent materials for lighting, and diagnostic medical equipment. This diversity of uses confers strategic importance on rare earth elements in the global economy, particularly with the accelerating transition toward clean energy.

At the continental level, Africa is rich in vast mineral resources that can be harnessed within an integrated mining plan linking development activity with other economic sectors. Algeria, owing to its geographic location in North Africa and its diverse geological formations, occupies a prominent position in this context. Studies indicate the presence of promising reserves in the southwestern sedimentary basins, qualifying Algeria to become a pivotal hub for rare earth production in the Maghreb region.

Global rare earth markets are experiencing notable growth driven by the increasing demand for green technologies and the energy transition. Global demand for critical minerals is expected to exceed available supply by 2035, particularly in light of bans on the sale of conventional gasoline and diesel vehicles in some U.S. states and the European Union. This growth is occurring amid intense geopolitical competition to control supply chains, prompting governments to formulate policies to increase production through partnerships with mineral-rich countries.

At the national level, Algeria faces the challenge of reconciling the exploitation of its natural resources with environmental preservation, in light of its commitment to international agreements to combat climate change (the 1993 Framework Convention and the 2004 Kyoto Protocol). Managing rare earth projects requires an integrated approach encompassing technical, environmental, economic, and social dimensions, alongside strengthening local technological capabilities and establishing investment partnerships. From this perspective, there is a clear need for a flexible strategic framework grounded in solid scientific and technical foundations that balances economic growth, environmental protection, and sustainable development, while keeping pace with technological advances and global geopolitical transformations.

Research Problem. The central issue of this research revolves around the strategic challenge facing Algeria in developing and managing rare earth projects within a changing international environment characterized by increasing geopolitical competition over critical resources and the imperatives of the global energy transition. While global markets are witnessing growing demand for rare earth elements due to the rapid expansion of clean technology and renewable energy industries, Algeria faces fundamental challenges in developing its extraction and technological capacities to capitalize on these strategic opportunities.

This issue is further exacerbated by the environmental and health challenges associated with rare earth extraction and processing, particularly given the limited availability of toxicological data on these elements compared to other heavy metals. Moreover, the complex nature of rare earth production and processing chains, which require advanced and specialized technologies, poses additional challenges for developing countries such as Algeria in building local technological capabilities.

On the other hand, Algeria's energy policy is undergoing a slow transition toward energy transformation, raising questions about the energy-intensive development model accused of contributing to global warming and resource depletion. This reality presents additional challenges in formulating an integrated rare earth strategy that aligns with environmental objectives and Algeria's international climate commitments.

The issue is further complicated by growing concerns that accelerated extraction projects for critical minerals, within the framework of the energy transition, may lead to violations of local communities' rights and the marginalization of poor and vulnerable groups. This necessitates the development of a balanced approach that ensures the utilization of resources while protecting community rights and achieving inclusive development.

Sub-Questions

Several sub-questions arise from the main research problem, which this study seeks to address. These include: How can Algeria develop an integrated strategic framework for managing rare earth projects that balances economic, environmental, and social objectives in light of global geopolitical transformations? What technological and technical requirements are necessary to develop Algeria's capacities for the sustainable and efficient extraction and processing of rare earth elements?

The study also raises questions regarding how to achieve a balance between the exploitation of rare earth resources and Algeria's environmental commitments, particularly in view of its international obligations related to climate change and the need to assess potential environmental and health risks. In addition, the study explores mechanisms for developing strategic partnerships and international cooperation for technology transfer and capacity building in the field of rare earth elements.

The sub-questions further address how to capitalize on the opportunities created by the expected increase in global demand for rare earth elements as a result of the global energy transition, and how to develop a development model that transforms mining activity from an isolated sector into one integrated with the rest of the national economy. The study also examines ways to ensure the protection of local communities' rights and their participation in the benefits of rare earth projects.

Hypotheses

This study is based on a central hypothesis that developing an integrated strategic framework for managing rare earth projects in Algeria—one that integrates economic, environmental, and social objectives—will enable the country to optimally benefit from its natural resources while ensuring sustainability and inclusive development in the context of global geopolitical transformations. This hypothesis is grounded in Algeria's diverse geological potential and the growing global demand for rare earth elements.

The study assumes that the gradual development of local technological capabilities in the extraction and processing of rare earth elements, through strategic partnerships and technology transfer, will enhance Algeria's ability to compete in global markets and achieve greater local value added. It also assumes that adopting a circular economy approach in managing the life cycle of rare earth elements will contribute to reducing environmental impacts and maximizing resource efficiency.

The study further hypothesizes that integrating a rare earth strategy with national energy policy—particularly in the areas of renewable energy and carbon storage technologies—will strengthen Algeria's position as a strategic player in the global energy transition. It also assumes that developing mechanisms of good governance and transparency in the management of rare earth resources will ensure fair distribution of benefits and protect the rights of local communities.

Significance of the Research. The importance of this research stems from the pivotal role that rare earth elements play in the modern global economy and emerging technologies, particularly in light of the growing shift toward energy transition and clean technologies. These elements have become vital to a wide range of advanced technological applications, from electric vehicles and green power generation systems to computers and communication technologies, making control over their sources a strategic priority for states.

The study is of particular importance in the African context, as the continent possesses vast mineral resources that can play a transformative role in achieving sustainable development when properly managed. Amid increasing geopolitical competition among global powers to control critical mineral supply chains, African countries need to develop advanced strategies to benefit from their resources without falling into the trap of exploitation or technological dependency.

From an environmental perspective, the study gains increasing relevance in light of growing concerns about the environmental impact of critical mineral extraction, especially given the limited toxicological data available on rare earth elements. Moreover, the need to balance resource exploitation with international environmental commitments makes the development of a sustainable model for managing these resources a vital priority for developing countries.

At the economic level, the study contributes to understanding how mining activity can be transformed from an isolated sector into one integrated with the rest of the economy, thereby maximizing local value added and contributing to economic diversification. It also highlights the investment opportunities created by the expected growth in demand for rare earth elements, which is projected to exceed available supply by 2035.

Research Objectives. This research aims to develop a comprehensive and integrated strategic framework for managing rare earth projects in Algeria that balances economic, environmental, and social objectives in the context of global geopolitical transformations. The study seeks to analyze the geological and technological potential available in Algeria for developing the rare earth sector, while examining global best practices in the extraction and processing of these critical elements.

The research also aims to assess the potential environmental and health risks associated with rare earth projects and to develop mechanisms to mitigate these risks and ensure environmental sustainability. In addition, it seeks to explore the investment and commercial opportunities created by the expected growth in global demand for rare earth elements, particularly in light of the global energy transition and the shift toward clean technologies.

Furthermore, the research targets the development of practical recommendations for public policy formulation and national strategies related to the rare earth sector, ensuring their integration with other sectoral strategies such as energy, environment, and sustainable development. It also aims to identify the requirements for building the technological and human capacities necessary to develop the rare earth sector in Algeria, as well as mechanisms for developing strategic partnerships and international cooperation in this field.

Research Methodology. This research adopts a mixed analytical methodology combining the descriptive-analytical approach with the comparative approach, with the aim of developing a comprehensive and in-depth understanding of the challenges and opportunities associated with managing rare earth projects in Algeria. The methodology is based on a comprehensive review of scientific literature and specialized technical reports in the field of rare earth elements.

The methodology includes a comparative analysis of international experiences in managing rare earth resources, with a focus on successful models for developing sustainable mining sectors in developing countries. The research also relies on the analysis of available geological and environmental data on Algeria's mineral resources, including studies addressing sedimentary basins and geological formations in various regions of the country.

The research adopts an integrated approach in analyzing the geopolitical and economic factors influencing global rare earth markets, examining the impact of the energy transition and international competition on these markets. It also employs a life-cycle analytical approach to study rare earth elements from extraction through processing to final use, with an assessment of environmental and health impacts at each stage.

I. Theoretical Framework and Previous Studies. Most academic research published on the exploitation of rare minerals in Algeria does not go beyond preliminary studies and master's theses, with international publication limited to a small number of peer-reviewed articles.

I.1. Theoretical Framework. Academic inquiry into the exploitation of rare earth elements in Algeria has tended toward understanding the geological formation of deposits associated with carbonatite rocks in the Western Hoggar. The most prominent studies addressing this topic include the following:

I.2. First Study. *Techno-Economic Feasibility of Lithium Extraction in Hoggar* Author: Abir Bousalmi, 2013, University of Batna

Key Findings: The study showed that establishing a refining plant with a capacity of 5,000 tons per year requires an initial investment of USD 120 million, of which 40% could be covered through public–private partnerships with Chinese companies, with an expected internal rate of return of 18% over seven years.

I.3. Second Study. *Regulatory Framework for Critical Mineral Exploitation in Algeria.* Author: Dr. Karim Belkacem, 2022, University of Constantine 2

Key Findings: The study analyzed Algerian laws related to the granting of exploration and extraction licenses and recommended classifying rare earth elements as strategic materials, along with providing tax incentives for foreign investors for a period of five years.

II. Applied Study. *Syenite–Carbonatite Complex of Ihouhaouene (Western Hoggar, Algeria)*

Authors and Institutions: An international team including researchers from Géosciences Montpellier, University of Montpellier (France); the Department of Science and Technology, USTHB, Blida (Algeria); and Mohammed VI Polytechnic University (Morocco).

Year: 2021

This study aims to identify the petrographic and geochemical characteristics of carbonatite rocks and their associated syenites within the Ihouhaouene complex, which is approximately 2 billion years old, and to clarify the mechanisms of rare earth element concentration within them.

Methodology Used in the Study:

- Collection of samples from three main sites along the eastern and western zones of the Ihouhaouene Valley under harsh desert environmental conditions.
- Microscopic studies of the formation of essential minerals (clinopyroxene, apatite, wollastonite) and their distribution between the groundmass and host rocks.
- Precise chemical analyses to measure SiO_2 and CaO contents and rare earth–bearing minerals using X-ray spectroscopy and secondary ion mass spectrometry.

Key Results:

- The rocks exhibited a continuous compositional range between 57–65% SiO_2 in syenites and a calcareous (carbonatitic) composition in carbonatites.
- Localized concentrations of rare earth elements were observed within carbonatitic veins sharply in contact with syenite, without evidence of reaction at the contact zones.
- The data confirmed the role of sodium- and potassium-rich fluids in transporting and concentrating these elements during the late stages of magmatic crystallization, under pressures estimated at 10–11 kbar and temperatures between 800–1050°C.

Environmental Risk Assessment of REE Extraction in the Algerian Sahara. Author: Dr. Hind Cherif, 2023, University of Batna 2

Key Findings: The study confirmed the presence of water pollution risks amounting to 15–20% from acids used in the extraction process. It called for the adoption of closed-loop aqueous processing technologies and the reuse of 60% of solid waste in order to reduce environmental impact.

II.1 Geological and Technological Characteristics of Rare Earth Elements

Rare earth elements represent a link between precise geological characteristics and advanced technological requirements, as their exploitation requires a detailed understanding of their geological formation conditions as well as the efficiency of their separation and purification processes. Despite the environmental and economic challenges associated with extraction, these elements remain a cornerstone of the future of smart industries and global energy policies.

Rare earth elements comprise a group of 17 chemical elements, including the lanthanides in addition to scandium and yttrium. They are characterized by unique geological and technological properties that have made them a focus of both industrial and geochemical interest.

II.1.1 Geological Characteristics

Rare earth elements are concentrated in several types of rocks, most notably carbonatite deposits, where sodium, potassium, and silica control their concentration and geological distribution (Science Advances, 2020). In some clays, such as Xunwu clay, an unusual distribution of rare earth elements has been observed, rich in lanthanum and neodymium with a high proportion of yttrium, indicating specific geological hydration processes operating under particular temperatures and pressures (Institut-seltene-erden.de, n.d.).

Despite their relative abundance in the Earth's crust, their concentration in ores is often low (less than 5% by weight), which necessitates economically viable ore treatment when they are associated with minerals such as zirconium or uranium (Institut-seltene-erden.de, n.d.). Algeria holds approximately 20% of global rare earth reserves, ranking third worldwide after China and Turkey (Africanews, 2024).

II.1.2 Technological Characteristics

Modern industries benefit from the principal chemical property of rare earth elements, namely their ability to exist predominantly in a trivalent oxidation state, with some tetravalent and divalent exceptions for certain elements. This makes them ideal for use in electrochemical and magnetic applications (Institut-seltene-erden.de, n.d.).

Neodymium and dysprosium are used in the manufacture of ultra-strong neodymium–iron–boron magnets, which are essential for electric vehicle motors and renewable energy generation (Wikipedia, 2010). Nd:YAG laser technology also relies on ytterbium within its crystal structure to achieve high-precision wavelengths in medical and industrial applications (Wikipedia, 2010).

Rare earth elements are used in more than 200 industries, ranging from smartphones—which incorporate around seven rare earth elements in their design—to high-efficiency electrical transformers in power grids (Arabicpost.live, 2023). However, their extraction and purification processes are environmentally complex, beginning with acid leaching followed by solvent extraction or ion exchange to separate impurities such as iron and aluminum. This generates highly toxic waste and requires stringent environmental management (Renovables.blog, 2025).

II.2 Technological Applications and Economic Importance of Rare Earth Elements

Rare earth elements play a pivotal role in a wide range of advanced technological applications, making them critical components of the modern economy and emerging technologies. They are used in the manufacture of high-performance magnets essential for electric vehicles, renewable energy power generation systems, and computers. They are also used in steel production and in catalysts employed in oil refining and automotive industries. This diversity of applications makes control over their sources a strategic priority for countries seeking to maintain technological competitiveness.

In the medical and biological sectors, rare earth elements demonstrate promising potential as nanomaterials for bone regeneration applications, exhibiting unique properties that stimulate bone formation due to their distinctive electromagnetic and optical characteristics. These advanced medical applications open new horizons for investment in research and development and the creation of high value-added industries, thereby enhancing the economic importance of developing the rare earth sector.

Global rare earth markets are experiencing rapid growth driven by increasing demand for clean energy technologies and the global energy transition. According to forecasts, demand for critical minerals—including rare earth elements—is expected to exceed available supply by 2035, particularly with the phase-out of fossil fuel–powered vehicles in several regions. This growth in demand offers significant investment opportunities for countries that possess these resources and develop their extraction and technological capabilities.

Rare earth elements possess unique magnetic and electrochemical properties that make them essential to the electronics, energy, healthcare, and defense industries. The growing demand for these elements reflects a close interconnection between technological progress and economic opportunities for resource-rich countries.

II.2.1 Technological Applications

- Neodymium–iron–boron magnets are used in wind turbines to generate renewable energy with high efficiency, reducing carbon emissions and enhancing grid reliability (Jadolin, 2010).

- Terbium and europium phosphors are used in LED screens to convert blue light into rich and accurate visible colors, improving image quality in televisions and portable devices (Arabicpost.live, 2023).
- Electric and hybrid vehicles rely on permanent magnets derived from rare earth elements to maximize torque while reducing weight, in addition to NiMH batteries that enhance storage capacity and recharging efficiency (Jadolin, 2010).
- Gadolinium is used as a contrast agent in magnetic resonance imaging (MRI), where it improves diagnostic clarity of internal tissues without increasing radiation dose (Arabicpost.live, 2023).

II.2.2 Economic Importance

Algeria holds approximately 20% of global rare earth element reserves, providing it with strategic opportunities to maximize revenues by investing in refining and local production stages rather than limiting activity to raw material exports (Africanews, 2024). China currently controls up to 90% of the global supply chain for production and refining, making the market vulnerable to geopolitical fluctuations and prompting international efforts to diversify supply sources (Africanews, 2024). With global demand for clean energy technologies and electronics expected to grow by around 8% annually, there is potential for producing countries to generate additional revenues of up to USD 150 billion in the coming years, provided that industrial and technological infrastructure is developed (Africanews, 2024).

This dynamic between advanced applications and economic opportunities constitutes a fundamental pillar of industrial development strategies and technological security for countries endowed with abundant rare earth resources.

II.3 Environmental and Health Challenges

The extraction and processing of rare earth elements pose complex environmental and health challenges that require careful assessment and specialized management. Although these elements are considered less toxic than some well-known heavy metals such as cadmium, mercury, lead, chromium, nickel, vanadium, and tin, available toxicological data on them remain limited in comparison. This lack of toxicological information necessitates intensive studies to understand potential health effects before expanding extraction activities.

Recent studies in various regions of the world indicate that exposure to rare earth elements through the food chain may pose health risks, particularly when they accumulate in biological tissues. This requires the development of strict protocols for monitoring levels of these elements in the environment and food, as well as the application of international safety standards in extraction and processing operations.

The extraction of rare earth elements entails significant environmental and health impacts due to the use of harsh chemicals and the generation of toxic and radioactive waste.

II.3.1 Environmental Challenges

a. Water and Soil Pollution: Sulfuric acid and chemical solvents can seep into surface and groundwater, leading to contamination of irrigation systems and drinking water (Renovables.blog, 2025). Acid rain resulting from mining activities also alters soil acidity and dissolves heavy metals, causing plants to lose essential nutrients and increasing concentrations of toxic metals near mining sites (Sigma Earth, n.d.).

b. Large-Scale Production of Radioactive Waste: Some rare earth deposits contain thorium and uranium, resulting in radioactive waste during refining processes that requires secure storage to prevent radiation leakage into the surrounding environment (Renovables.blog, 2025). In China's Baotou region, a toxic waste lake formed and radioactive pollutants spread, affecting soil and water for many years (Anadolu Ajansi, 2023).

c. Destruction of Natural Habitats: The removal of vegetation cover and soil layers facilitates erosion and land degradation, uprooting plants, displacing wildlife, and weakening biodiversity in areas adjacent to quarries (Sigma Earth, n.d.).

II.3.2 Health Challenges

a. Air Pollution and Fine Particulates: Crushing, screening, and solvent combustion processes release dust carrying fine, toxic mineral particles that are inhaled by workers and nearby residents, increasing rates of acute and chronic respiratory diseases (Renovables.blog, 2025).

b. Exposure to Heavy Metals: Mining areas often experience elevated levels of cadmium, lead, and mercury in the air and deposited dust. These metals accumulate in human bodies through food and water, and are associated with nervous system disorders and kidney and bone diseases (Africanews, 2024).

c. Radiological Risks: Rare earth mine workers may suffer prolonged exposure to radiation from thorium and uranium, increasing the likelihood of blood and soft tissue cancers, particularly in mines lacking adequate protective measures (Anadolu Ajansi, 2023).

Understanding these challenges helps guide research efforts toward developing cleaner mining technologies and rigorous health monitoring programs to mitigate adverse effects on the environment and human health.

In the Algerian context, the importance of assessing environmental and health risks associated with potential toxic elements in water systems is particularly evident, especially in desert regions where studies indicate environmental and health risks linked to pollutants in groundwater reservoirs. This reality calls for the development of an integrated environmental risk management approach that takes into account local geological and climatic characteristics.

II.4 Technological Strategies and Innovation

Developing the rare earth sector in Algeria requires the adoption of advanced technological strategies focused on innovation and the development of local capacities. These strategies include the development of more efficient and environmentally friendly extraction technologies, such as advanced molecular techniques aimed at improving the precision and efficiency of rare earth separation processes while reducing losses. Such advanced technologies enable more selective and efficient extraction, reducing waste and maximizing resource utilization.

Circular economy technologies are particularly important in managing the life cycle of rare earth elements. Studies indicate that industrial recycling of these elements currently occurs only at the magnet manufacturing stage, while post-consumer recycling processes are virtually nonexistent. This situation presents significant opportunities for developing advanced recycling technologies and recovering used rare earth elements, thereby reducing pressure on natural resources and improving environmental sustainability.

The technological strategy should focus on strengthening local research and development capacities, while establishing strategic partnerships with advanced scientific and technological institutions for knowledge and expertise transfer. This also requires investment in the development of specialized human resources and the establishment of advanced research centers capable of keeping pace with rapid technological developments in this field.

II.4.1 Technological Strategies

Technological strategies and innovations related to rare earth elements combine improved extraction efficiency, reduced environmental impact, and the development of recycling methods to ensure supply sustainability and achieve high value added.

a. Development of Environmentally Friendly Extraction Processes: One strategy involves replacing strong acids with innovative solvents such as ionic liquids and deep eutectic solvents, which improve the selectivity of rare earth extraction and reduce the volume of acidic waste generated (eSyria, 2023).

b. Automation of the Production System: Artificial intelligence is integrated into monitoring mining operation conditions and analyzing geological and environmental data in real time, improving ore localization accuracy and reducing energy and water consumption. It also contributes to accident prediction and the reduction of operational risks (RMG-SA, 2025).

c. Solvent Recycling and Waste Management: New plants rely on the design of closed-loop systems to recycle up to 95% of extraction solvents, in addition to using electro-precipitation to separate rare earth elements from impurities, thereby reducing gas emissions and toxic spills (FasterCapital, 2025).

II.4.2 Innovation: Key Areas

a. Bio-based Extraction Technologies: Gluconobacter bacteria have been used to produce organic acids capable of releasing lanthanides from industrial waste without the need for harsh chemical acids, reducing carbon footprints and toxic waste (eSyria, 2023).

b. Acid-Free Recycling from Hard Disk Drives: A pilot project demonstrated acid-free dissolution (ADR) technology for extracting rare earth elements from hard disk drives, achieving recovery rates of up to 90% while reducing greenhouse gas emissions by approximately 95% compared to conventional mining (Attaqa Net, 2025).

c. Multilateral Research Partnerships: Joint initiatives between universities and public and private companies aim to develop research platforms that integrate spectral data, geological mapping, and machine learning techniques. These efforts contribute to more precise and efficient solutions for technology transfer and the enhancement of local capacities (FasterCapital, 2025).

The sustainable future of the rare earth industry depends on integrating these strategies and innovations across value chains in order to secure supply, reduce environmental impact, and maximize economic returns.

II.5 Current Status of Rare Earth Projects in Algeria

II.5.1 Diverse Geological Potential in Algeria

Rare earth elements constitute a strategic محور for achieving economic diversification in Algeria. The country holds approximately 20% of global reserves of these minerals (Africanews, 2024). Given the growing importance of these resources in modern industries and clean energy leadership, this research seeks to explore best practices in project management within this vital sector and to propose recommendations for regulating operations from discovery through exploitation.

The following table illustrates Algeria's diverse geological potential, describing reserves and the main regions for each natural resource.

Table (1): Algeria's Diverse Geological Potential, with Descriptions of Reserves and Main Regions for Each Natural Resource

Resource	Description / Reserves	Main Regions
Rare earth elements	20% of global rare earth reserves	Algerian Sahara
Phosphates	More than 2 billion tons of phosphate	Ziban region, southeast Algeria
Iron	Large iron ore reserves	Multiple mines across Algeria
Zinc	Large zinc reserves	Multiple mines across Algeria

Source: Africanews, 2024

II.5.2 Diverse Geological Potential in Algeria (Detailed Overview)

Algeria possesses vast mineral resources distributed across diverse geographic regions, forming a fundamental pillar of economic and industrial development. The following overview summarizes the most prominent resources, their geographic distribution, and confirmed reserves.

a. The Algerian Sahara: Hub of Rare Earth Elements. The Algerian Sahara contains nearly 20% of global rare earth reserves, according to estimates by the Geological and Mining Research Office in 2022. These include elements such as lithium and neodymium used in technological industries and renewable energy. Despite the scale of these reserves, full commercial exploitation has not yet begun due to technical and environmental challenges associated with extraction processes.

b. The Ziban Region: Phosphate Stronghold. The Ziban region in southeastern Algeria hosts phosphate reserves estimated at more than 2 billion tons, placing the country among the world's largest producers of this vital mineral for agriculture and the chemical industry. Phosphate production has shown steady growth, reaching 671,500 tons in 2022, with expectations of doubling output following completion of the USD 7 billion Tebessa investment project.

c. Iron Mines: Backbone of Heavy Industry. The Gara Djebilet mines top Algeria's iron reserves, estimated at 3.5 billion tons, of which 1.7 billion tons are extractable. Active operations began in 2022 with an initial production capacity of 3 million tons per year, with plans to increase output to 50 million tons by 2040 through joint Chinese–Algerian investments.

d. Zinc and Lead: Underexploited Wealth. Algeria ranks third globally in zinc reserves, particularly at the Tala Hamza mine, which contains 53 million tons of ore composed of 78% zinc and 22% lead. Once fully developed, the mine is expected to produce 170,000 tons of zinc and 130,000 tons of lead annually starting in 2026, enabling coverage of domestic needs and export of surpluses.

e. Gold and Diamonds: Promising Resources. Algeria's gold reserves reached 173.6 tons by the end of March 2023, ranking third in the Arab world after Saudi Arabia and Lebanon. Preliminary diamond reserves have also been discovered in the Reggane area in the far south, where diamond dust was found in 2014, prompting intensified exploration to identify primary sources.

f. Uranium: Future Potential. Algeria holds confirmed uranium reserves estimated at around 29,000 tons, according to a statement by former Energy Minister Chakib Khelil in 2009. These reserves are currently used in research nuclear reactors, with plans to build civilian nuclear power plants with a capacity of 1,000 MW each by 2040.

g. Hydrocarbons: Backbone of the National Economy. Natural gas reserves are concentrated in northern Algeria and amount to approximately 4.5 trillion cubic meters, while oil reserves stand at about 12.2 billion barrels. The Hassi R'Mel field is the largest, with production reaching 2.4 trillion cubic meters, and constitutes a major source of liquefied natural gas exports to Europe via the TransMed pipeline.

II.6 Project Management in the Rare Earth Sector in Algeria

In Algeria, project management principles are applied within a framework that includes the following stages:

- **Project Initiation:** Defining strategic objectives and assessing economic and environmental feasibility.
- **Planning:** Preparing in-depth geological studies and a comprehensive investment vision supported by remote sensing technologies and reservoir modeling (Alaraby, 2025).
- **Execution:** Forming multidisciplinary teams and introducing directional drilling technology and primary processing through green technologies.
- **Monitoring and Control:** Establishing digital platforms to monitor performance and accelerate decision-making through digital dashboards (Alhurra, 2025).
- **Project Closure:** Transferring knowledge to local communities, assessing social and environmental impacts, and ensuring sustainability for future generations (Tadamsanews, 2025).

The main challenges lie in securing long-term financing and advanced analytical and extraction technologies without causing significant environmental damage (Africanews, 2024). This requires activating partnership strategies with international experts and establishing local refining facilities to generate added value and create sustainable employment opportunities.

Algeria offers a solid foundation for managing rare earth projects, supported by vast reserves and a political vision focused on preserving these resources for future generations. The opportunity lies in strengthening the national economy through the application of advanced project management methodologies, attracting foreign direct investment, and developing complete national value chains.

Algeria is also seeking to enhance its capabilities in rare earth exploitation by concluding strategic partnerships with a number of leading countries in mining and technology. These agreements focus on exchanging technical expertise, financing exploration projects, and developing primary processing operations locally.

II.6.1 Algeria's International Partnerships in the Field of Rare Earth Elements

Table (2): Algeria's International Partnerships in the Field of Rare Earth Elements

Country	Type of Partnership	Activities / Projects
China	Technical and exploratory alliance	Algerian–Chinese task force to explore lithium and rare earth elements in Tamanrasset and In Guezzam; Chinese investment in the Gara Djebilet mine (over USD 3 billion)
Russia	Technical and prospective consultations	Consultations to exchange expertise and plan joint projects in geological mapping and the development of extraction technologies
France	Investment and technical cooperation	Announcement by the French President of willingness to cooperate in developing rare earth exploitation; visit by Prime Minister Borne with a business delegation to enhance investments
Japan	Consultations and research	Consultations with Japanese research institutes to develop advanced geological mapping and evaluate reserves

Source: Secondary data issued by government bodies and official media sources for the period 2020–2025

From the table above, the most notable partnership steps can be summarized as follows:

- In 2022, Algeria launched the preliminary exploration phase with the participation of Chinese–Algerian teams aimed at estimating lithium and other critical mineral resources in the south.
- The Minister of Energy and Mines held talks with his Russian counterpart to benefit from Russian expertise in managing large-scale mining projects and processing technologies.
- Cooperation with France was marked by high-level visits, including meetings with French business leaders to discuss the transfer of environmentally friendly processing technologies and the reduction of chemical impacts.
- Japanese research institutions became involved in preparing detailed geological maps to identify rare earth concentrations and facilitate exploration operations.
- Algeria launched initiatives to attract European investors by establishing regulatory frameworks that ensure compliance with environmental standards and streamline licensing procedures.

These partnerships reflect Algeria's orientation toward building sustainable local capacities in the rare earth sector, while leveraging foreign expertise to create an integrated value chain from discovery to processing and marketing.

Main Findings in the Field of Rare Earth Elements in Algeria

- Reserve estimates indicate that Algeria hosts approximately 20% of the world's rare earth reserves (Defense-Arab, 2025).
- Existing projects include the establishment of Algerian–Chinese task forces to explore lithium in Tamanrasset and In Guezzam (Al-Araby, 2025).

- Expected revenues from strategic minerals are projected to reach USD 150 billion over the next decade (Africanews, 2024).

II.7 A Comparative Analysis of International Experiences in Managing Rare Earth Resources and Their Application in Algeria: Toward a Sustainable Model

Rare earth elements constitute a strategic pillar in the transition toward green economies. China controls about 60% of global production and 90% of refining operations, while Algeria holds 20% of global reserves and faces challenges related to technology transfer and the development of value-added supply chains. This study analyzes Chinese and Australian models, as well as the World Bank framework, to extract lessons and link them to Algerian geological data from sedimentary basins and desert formations.

International Models for Rare Earth Management

II.7.1 The Chinese Model: Regulatory and Technological Dominance. China implemented the "Rare Earth Management Regulation" in 2024, imposing state control over mining through exclusive licenses and digital resource tracking. The regulation includes:

- Restricting mining to government-approved companies.
- A tracking system for products from the mine to export.
- Encouraging the recycling of secondary resources using advanced technologies.

Despite its effectiveness, China faces international criticism due to monopolistic practices and environmental impacts, as its mines contribute approximately 40% of global rare earth–related emissions.

II.7.2 The Australian Experience: Investment in Local Refining. Australia opened its first rare earth refining plant in Kalgoorlie in 2024, with an annual production capacity of 400 tons of neodymium and praseodymium, benefiting from deposits at the Mount Weld mine. This model relies on:

- Public–private partnerships to finance infrastructure.
- Localization of technologies through training of local personnel.

II.7.3 World Bank Framework for Sustainable Artisanal Mining. In 2024, the World Bank launched a new framework to support artisanal mining by:

- Enhancing transparency through environmental compliance tracking systems.
- Integrating local communities into health impact monitoring.
- Financing environmental rehabilitation projects at rates of up to 30% of total investments.

II.7.4 The Algerian Context: Potential and Challenges

a. Geological Structure and Resources. Approximately 80% of Algeria's rare earth resources are concentrated in the Algerian Sahara, within Cambrian sandstone formations, with secondary deposits in the sedimentary basins of the Ziban region. Geophysical studies have shown:

- Oceanic crust thickness in the Algerian basin reaching 4 km, with volcanic rocks dating back to the Miocene.
- High lithium concentrations in dolomite layers within Miocene–Pliocene formations.

b. Economic and Environmental Indicators

Table (3): Economic and Environmental Indicators

Indicator	Value (2024)
Confirmed reserves	44 million tons
Current production	Less than 1% of reserves
Carbon emissions	8.2 tons CO_2 per ton

Source: Secondary data issued by government bodies for 2024

Algerian mines suffer from a high carbon footprint compared to the global average (5.5 tons CO_2 per ton), due to reliance on open-pit mining techniques.

II.7.5 Policy Comparison and Potential Applications

a. Legislation and Environmental Compliance

- China: Imposes fines of up to 200% of the value of environmental violations.
- Australia: Requires rehabilitation plans prior to granting licenses.
- Algeria: The legal framework needs to activate satellite-based monitoring mechanisms, similar to China's "product tracking" model.

b. Community Participation. A study of the Gara Djebilet iron mine showed that 70% of local labor is not trained in safety standards. It is proposed to adopt the World Bank's "community monitoring" model, which reduces accidents by up to 40%.

III. Results and Discussion

The findings of this research indicate that developing an integrated strategic framework for managing rare earth projects in Algeria requires a comprehensive approach that balances economic, environmental, and social objectives within the context of global geopolitical transformations. This framework must be grounded in a deep understanding of the geological and technological characteristics of rare earth elements, while leveraging Algeria's available potential and the opportunities created by the expected growth in global demand for these critical resources.

It is evident that Algeria hosts approximately 20% of global rare earth reserves, ranking third worldwide after China and Turkey. The actual exploration phase began in 2022 with the launch of 26 exploration and prospecting projects, aimed at confirming resources and strengthening international partnerships with China, Russia, France, and Japan. Future revenues from lithium resources alone are estimated at around USD 150 billion. However, technical and environmental challenges, along with dependence on foreign expertise, hinder the effective transition toward sustainable commercial exploitation.

VI. Conclusion

Algeria possesses the fundamentals necessary to become a major player in the rare earth market. Achieving this, however, requires adopting hybrid policies that combine the regulatory rigor of the Chinese model with the flexibility of the Australian model. Future strategies should focus on linking geological reserves with green technologies, while ensuring effective participation of local communities in economic and environmental decision-making.

The study concludes that it is essential to develop local technological capabilities through investment in research and development and the establishment of strategic partnerships, with an emphasis on sustainable extraction and advanced processing technologies. It also highlights the importance of applying circular economy principles in managing the life cycle of rare earth elements, ensuring optimal resource utilization and minimizing environmental impact.

Recommendations

- Develop local manufacturing capacities to process rare earth elements and convert them into manufactured products, reducing dependence on foreign refining companies.

- Strengthen the regulatory and institutional framework by enacting laws that encourage investment, ensure transparency, and enforce environmental monitoring, including a review of the 2025 draft law regulating mining activities.
- Establish research alliances between Algerian universities and specialized international centers to develop environmentally friendly extraction technologies and reduce the use of toxic chemicals.
- Launch specialized training programs to build Algerian expertise in geology, processing, and refining, in cooperation with global experts.
- Adopt blended financing strategies (public–private) to reduce financial risks associated with the extraction phase, while granting tax incentives to investors who comply with sustainability standards.
- Integrate local communities into planning and implementation stages through accompanying development projects to ensure social acceptance and deliver direct economic benefits to residents.

Appendices

Appendix (1): Rare Earth Reserves in Algeria

Category	Value
Share of Algeria's rare earth reserves	20%

Appendix (2): Indicators of the Mining Sector in Algeria (2020)

Indicator	Value
Number of exploited mineral substances	31
Number of investors	1,400
Sector contribution to GDP	Less than 1%

Appendix (3): Estimated Potential Revenues from Strategic Minerals

Mineral / Trade	Expected Revenue (USD billion)
Lithium	150
Rare earth trade	1.5

Ethical Considerations

This study is based exclusively on secondary data sources, including publicly available reports, policy documents, scientific literature, and strategic analyses related to rare earth elements, sustainability, and technological innovation. No human participants, personal data, or animal subjects were involved in the research process. Consequently, ethical approval from an institutional review board was not required. The authors adhered to principles of academic integrity, transparency, and responsible research conduct throughout the study.

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Conflict of Interest

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