

Maranhao 2045: from ore exporter to global player – the vertical integration of rare earth minerals

Maranhão 2045: de exportador de minério a player global – a integração vertical de minerais de terras raras

Maranhão 2045: de exportador de minerales a actor global: la integración vertical de los minerales de tierras raras

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ABSTRACT

The growing global demand for Rare Earth Elements (REEs), essential inputs for the energy transition, is marked by a high geopolitical concentration in the supply chain. In this context, Brazil seeks to position itself as an alternative supplier, facing the historical challenge of vertically integrating its mineral production. This article analyzes the prospective potential of the state of Maranhão to consolidate itself as an integrated industrial hub for rare earth elements (REEs), with a horizon up to 2045. The methodology was based on qualitative document analysis, triangulating data from geological reports, infrastructure and business plans, and national strategic studies. The results identify four main geological axes with potential for REE (Lower Itapecuru, Northwest, East/Southeast, and Southwest/South-Central), rich in minerals such as monazite and xenotime. More crucially, the existence of a mature logistical-industrial advantage is noted, composed of the triad of Itaqui Port, Carajás Railway, and the Bacabeira Export Processing Zone (EPZ), which enables local processing. It is concluded that the unique synergy between geological resources and existing logistical infrastructure offers Maranhão the conditions for the vertical integration of the production chain. The success of this vision, however, is contingent upon

overcoming critical challenges, notably the technological mastery of oxide separation metallurgy and the rigorous management of radioactive waste (NORM/TENORM).

Keywords: Rare Earths. Strategic Minerals. Maranhão. Regional Development. Industrial Verticalization.

RESUMO

A crescente demanda global por Elementos de Terras Raras (ETR), insumos essenciais para a transição energética, é marcada por uma alta concentração geopolítica na cadeia de suprimentos. Nesse contexto, o Brasil busca se posicionar como um fornecedor alternativo, enfrentando o desafio histórico da integração vertical de sua produção mineral. Este artigo analisa o potencial prospectivo do estado do Maranhão para se consolidar como um polo industrial integrado de elementos de terras raras (ETR), com um horizonte até 2045. A metodologia baseou-se em análise documental qualitativa, triangulando dados de relatórios geológicos, planos de infraestrutura e negócios, e estudos estratégicos nacionais. Os resultados identificam quatro principais eixos geológicos com potencial para ETR (Baixo Itapecuru, Noroeste, Leste/Sudeste e Sudoeste/Centro-Sul), ricos em minerais como monazita e xenotima. Mais importante ainda, destaca-se a existência de uma vantagem logístico-industrial consolidada, composta pela tríade Porto de Itaqui, Ferrovia Carajás e Zona de Processamento de Exportação (ZPE) da Bacabeira, que viabiliza o processamento local. Conclui-se que a sinergia singular entre os recursos geológicos e a infraestrutura logística existente oferece ao Maranhão as condições para a integração vertical da cadeia produtiva. O sucesso dessa visão, contudo, está condicionado à superação de desafios críticos, notadamente o domínio tecnológico da metalurgia de separação de óxidos e a gestão rigorosa de resíduos radioativos (NORM/TENORM).

Palavras-chave: Terras Raras. Minerais Estratégicos. Maranhão. Desenvolvimento Regional. Verticalização Industrial.

RESUMEN

La creciente demanda mundial de tierras raras (TER), insumos esenciales para la transición energética, se caracteriza por una alta concentración geopolítica en la cadena de suministro. En este contexto, Brasil busca posicionarse como proveedor alternativo, afrontando el desafío histórico de integrar verticalmente su producción mineral. Este artículo analiza el potencial prospectivo del estado de Maranhão para consolidarse como un polo industrial integrado de tierras raras (TER), con un horizonte hasta 2045. La metodología se basó en el análisis cualitativo de documentos, la triangulación de datos de informes geológicos, planes de infraestructura y negocios, y estudios estratégicos nacionales. Los resultados identifican cuatro ejes geológicos principales con potencial para tierras raras (Bajo Itapecuru, Noroeste, Este/Sudeste y Suroeste/Centro-Sur), ricos en minerales como la monacita y la xenotima. De manera más crucial, se observa la existencia de una ventaja logístico-industrial consolidada, compuesta por la tríada del Puerto de Itaqui, el Ferrocarril de Carajás y la Zona Franca de

Exportación (ZFE) de Bacabeira, que facilita el procesamiento local. Se concluye que la sinergia única entre los recursos geológicos y la infraestructura logística existente ofrece a Maranhão las condiciones para la integración vertical de la cadena de producción. Sin embargo, el éxito de esta visión depende de la superación de desafíos críticos, en particular el dominio tecnológico de la metalurgia de separación de óxidos y la gestión rigurosa de los residuos radiactivos (NORM/TENORM).

Palabras clave: Tierras Raras. Minerales Estratégicos. Maranhão. Desarrollo Regional. Verticalización Industrial.

1 THE GLOBAL IMPERATIVE AND BRAZIL'S STRATEGIC POSITIONING

Rare Earth Elements occupy a central position in the contemporary economy due to their application in critical technologies, such as wind turbines, electric vehicles, catalysts, and advanced electronic systems. The high global dependence on Chinese production drives supply diversification strategies, opening up space for new production hubs. In this context, Brazil stands out as a relevant alternative, with the state of Maranhão standing out for its unique combination of geological potential and consolidated logistics infrastructure.

The objective of this study is to analyze the potential of Maranhão to structure an integrated REE hub by 2045, evaluating the feasibility of productive verticalization and its strategic insertion in the global critical minerals economy.

2 THE GEOPOLITICS OF VERTICALIZATION: THE DEFINITION AND CRITICALITY OF REEs IN THE NEW ECONOMY

The concept of "strategic mineral" is dynamic and intrinsically linked to national objectives. The National Mining Plan 2030 (PNM-2030) adopts a three-pillar definition, perfectly framing Rare Earth Elements (REEs), a group of 17 chemical elements, as "bearers of the future." These elements are divided into "light" (LREE – Light Rare Earth Elements) and "heavy" (HREE – Heavy Rare Earth Elements). Their criticality stems from their irreplaceable physicochemical properties in cutting-edge applications. The main demand vector is Neodymium-

Iron-Boron (NdFeB) permanent magnets, essential for the efficiency and miniaturization of wind turbine generators (especially offshore, using direct drive technology) and electric and hybrid vehicle motors. Other REEs, such as Lanthanum (La) and Cerium (Ce), are vital in catalysts, and Europium (Eu) and Yttrium (Y) in efficient lighting.

2.1 GEOPOLITICS AND VERTICAL INTEGRATION OF RARE EARTH ELEMENTS

The Rare Earth Elements (REE) market is characterized by a high level of geopolitical concentration, with China dominating more than 90% of global REE oxide production and approximately 75% of permanent magnet manufacturing. This dominance has prompted industrialized economies to seek diversification of supply chains through cooperative initiatives such as the Minerals Security Partnership (MSP). In this scenario, Brazil presents significant geological potential but remains historically constrained to the export of low-value mineral concentrates, a structural limitation associated with the lack of technological capacity in the stages of oxide separation and advanced metallurgy, where value addition is highest.

The overcoming of this bottleneck depends on the vertical integration of the production chain, and the state of Maranhão offers a differentiated institutional and logistical framework for this transition. The Bacabeira Export Processing Zone (EPZ) constitutes the central platform for upstream value addition, enabling the installation of facilities for the separation of rare earth oxides and subsequent industrial processing. Supported by a stable legal and regulatory regime—defined by federal legislation, customs control and fiscal incentives at both federal and regional levels—the EPZ provides predictability and cost efficiency for capital-intensive and technology-driven investments. This configuration positions Maranhão as a strategic hub capable of internalizing value and integrating Brazil into the global REE supply chain.

2.2 ATTRACTIVENESS AND LEGAL SECURITY OF THE ZPE REGIME

The Export Processing Zone (EPZ) regime provides a stable and predictable institutional environment, aligned with global competitiveness standards and particularly suited to industries of high technological complexity and capital intensity, such as Rare Earth Elements (REE) processing. The Bacabeira EPZ offers a set of tax, exchange rate and customs incentives that significantly reduce installation and operating costs, enhancing the economic feasibility of upstream value-added activities.

Key advantages include the suspension and exemption of federal taxes on machinery, equipment and inputs (Import Tax, IPI and PIS/COFINS), as well as the possibility of up to a 75% reduction in Corporate Income Tax through SUDENE incentives. Exchange rate freedom allows the retention of export revenues in foreign currency, mitigating volatility risks and increasing financial liquidity. In addition, the EPZ operates as a primary customs area, ensuring streamlined clearance procedures and objective governance, thereby providing the legal security required for long-term investments in strategic mineral sectors.

2.3 TECHNICAL LOCATION, SIZE AND INFRASTRUCTURE

The Bacabeira Export Processing Zone (EPZ) is a structured and strategically positioned solution for large-scale industries, combining logistical, territorial, and technical conditions that reduce costs and accelerate operations. Located in the municipality of Bacabeira, in a logistically coordinated area close to the capital São Luís, the EPZ is situated within a regional axis that facilitates integration with urban centers and industrial hubs. This location is crucial for optimizing the transport of raw materials and finished products, as well as enhancing connectivity with the Itaqui Port Complex and intermodal terminals, ensuring efficient distribution to the global market.

Figure 1. Location and road and rail networks



Source: Authors (2025).

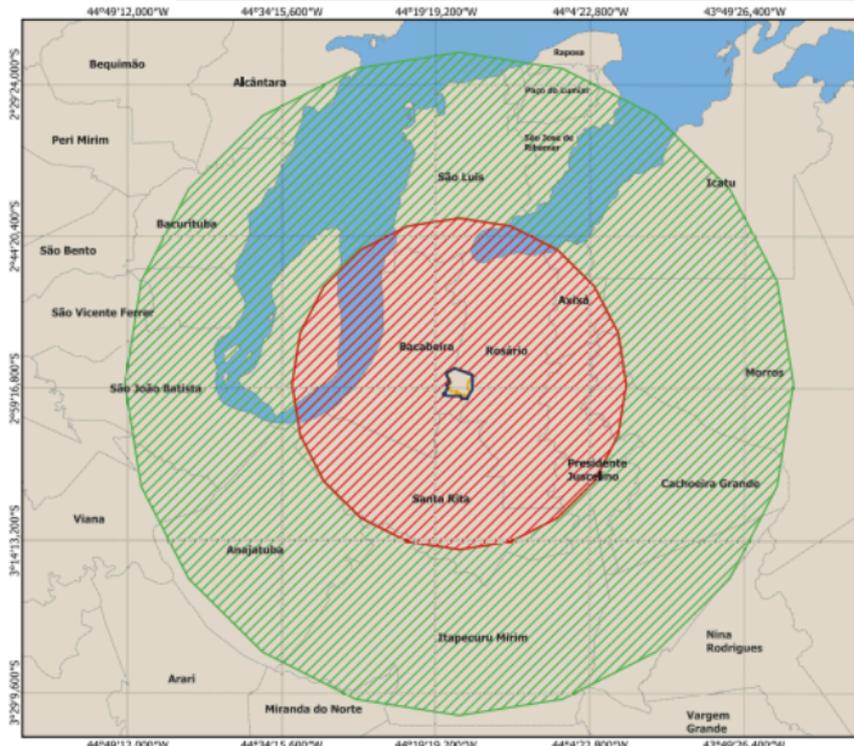
Road access represents another significant advantage. The ZPE has a direct connection to the federal highways BR-135 and BR-402, as well as the state highway MA-110, ensuring efficient mobility for cargo and operational teams.

2.4 THE INTEGRATED MULTIMODAL LOGISTICS MATRIX

Investors in the ETR (Extractable Mineral Resources) sector demand a robust and continuous logistics chain. Maranhão offers an integrated multimodal solution that reduces operational risks and increases competitiveness. Inbound logistics are resolved through the direct integration of the Bacabeira Export Processing Zone (ZPE) with the Carajás Railway, essential infrastructure for receiving mineral concentrates from producing regions. Outbound logistics are guaranteed by the connection to the Port of Itaqui, a deep-water hub crucial for exporting ETR oxides to international markets. The strategic combination of the ZPE (tax/exchange incentives), the Railway (inputs), and the Port (global

distribution) establishes Maranhão as a superior logistics hub for vertical integration of the supply chain.

Figure 2. Direct and indirect area of influence of the ZPE (EPZ)



Source: Authors (2025).

Beyond logistical connectivity, there is a full guarantee of energy sustainability, an indispensable element for highly complex chemical and metallurgical operations. The project has access to the national interconnected system through existing transmission lines in the region, ensuring a stable high-voltage supply. This condition meets the technical requirements of the separation plant and is expressly aligned with the project's framework within the National Energy Policy, reinforcing security and long-term operational viability.

2.5 RISK MANAGEMENT, ENVIRONMENTAL COMPLIANCE AND INSTITUTIONAL STABILITY

The long-term viability of Rare Earth Elements (REE) processing projects depends on rigorous environmental risk management, particularly regarding

waste generated during monazite beneficiation, which involves materials with radiological characteristics. Effective control and safe handling of residues classified as NORM and TENORM constitute one of the most critical operational challenges, requiring robust engineering solutions, continuous monitoring and strict compliance with national and international regulatory standards to ensure environmental and operational safety.

In this context, the Bacabeira Export Processing Zone (EPZ) provides a stable and predictable institutional framework for capital-intensive and long-maturity investments. Anchored in a permanent federal legal regime, the EPZ ensures regulatory continuity, standardized governance and administrative coordination, reducing institutional risk. The alignment with ESG principles further strengthens project viability by integrating environmental control, energy efficiency and low-carbon energy sources, including renewable generation and natural gas as a transition fuel. This combination of environmental rigor and institutional stability enhances investor confidence and supports the sustainable development of a vertically integrated REE production chain.

3 POTENTIAL FOR RARE EARTH RESERVES AND COMPETITIVE ADVANTAGES IN MARANHÃO

Maranhão stands out as a strategic rare earth element (REE) province within Brazil, a country that holds the world's second largest estimated REE reserves. The state is characterized by Proterozoic geological formations enriched in monazite and xenotime, hosting critical elements such as neodymium, cerium, lanthanum, yttrium and dysprosium, which are essential for renewable energy systems, advanced ceramics and high-temperature technologies. The integration of these mineral occurrences within established mineral provinces and modern infrastructure supports reliable resource assessment and sustainable exploration through geotechnical studies, detailed surveys and geological modeling.

The development of the REE sector in Maranhão is reinforced by a favorable institutional and policy environment. At the federal level, the National

Mining Plan 2030 recognizes the strategic nature of REEs and promotes industrial verticalization through regulatory facilitation and support for research and development. At the state level, fiscal and exchange incentives, legal stability and continuous investments in logistics infrastructure particularly the Porto do Itaqui and the Carajás Railway reduce regulatory risk and enhance predictability, positioning Maranhão as an attractive REE cluster aligned with global markets.

In addition to geological and institutional strengths, Maranhão offers significant cost advantages in exploration and processing. The proximity between deposits and the Export Processing Zone (EPZ) reduces CAPEX and OPEX associated with internal logistics, shortens lead times and improves economies of scale from the early stages of implementation. Exchange rate freedom, combined with tax incentives and a mature multimodal logistics system, enhances financial predictability and competitiveness, placing Maranhão in a favorable cost position relative to established REE centers in Asia, North America and Africa.

4 METHODOLOGY

This qualitative research adopts an exploratory and prospective approach, based on documentary and content analysis (BARDIN, 2011), synthesizing and triangulating relevant secondary data from technical reports, government plans (PNM-2030) and sectoral analyses to construct a prospective scenario for Maranhão 2045 on the vertical integration of the ETRs chain.

The procedure followed three sequential steps: (1) protection and systematization of geological (Proterozoic formations, monazite/xenotime), logistical (Porto Itaqui, Carajás Railway, Bacabeira ZPE) and economic (tax incentives, governance models) data; (2) cross-triangulation comparing Maranhão's competitive advantages with global geopolitical challenges (Chinese dominance) and national R&D bottlenecks; (3) construction of prospective scenarios via adapted SWOT matrix, evaluating technical, economic and regulatory solutions up to 2045.

The validation occurred through convergence of independent sources (ALVES, 2025; ZEE MARANHÃO, 2021), ensuring analytical robustness without generating primary geological data.

5 RESULTS AND DISCUSSIONS

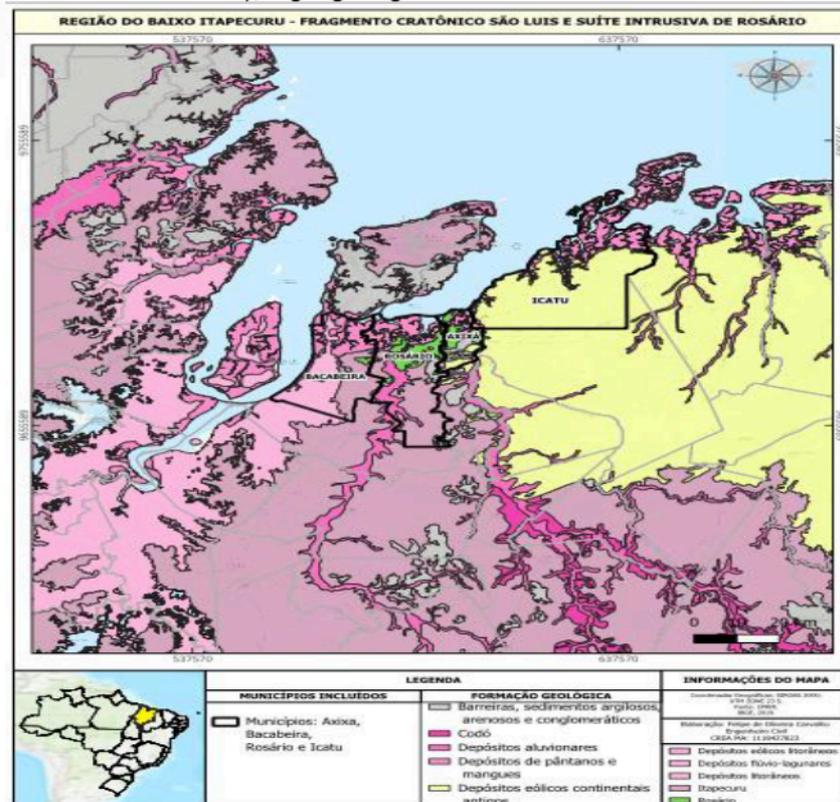
5.1 VALIDATION OF STRATEGIC GEOLOGICAL POTENTIAL AND INDUSTRIAL SYNERGY

This section consolidates the geological basis of the project, demonstrating the clear link between the potential for REEs and the capacity for industrial verticalization in Maranhão, a critical factor for cost optimization and the attractiveness of capital-intensive investments.

The prospecting for REEs focuses on middle and upper Proterozoic igneous and volcano-sedimentary units, environments developed by magmatic and hydrothermal concentration (ZEE MARANHÃO, 2021) of monazite (main source of REEs levels: Ce, La, Nd) and xenotime (heavy REEs: Y, Dy, Tb) (MARTINS *et al.*, 2014).

The area of greatest strategic relevance, due to logistical synergy, is the Lower Itapecuru Axis (Rosário, Bacabeira, Axixá, Icatu), associated with the São Luís Cratonic Fragment and, mainly, with the Rosário Intrusive Suite — alkaline granites with magnetic differentiation favorable to level and medium REEs (Ce, La, Nd, Pr, Y, Dy) (ZEE MARANHÃO, 2021; BUSINESS PLANO, 2024).

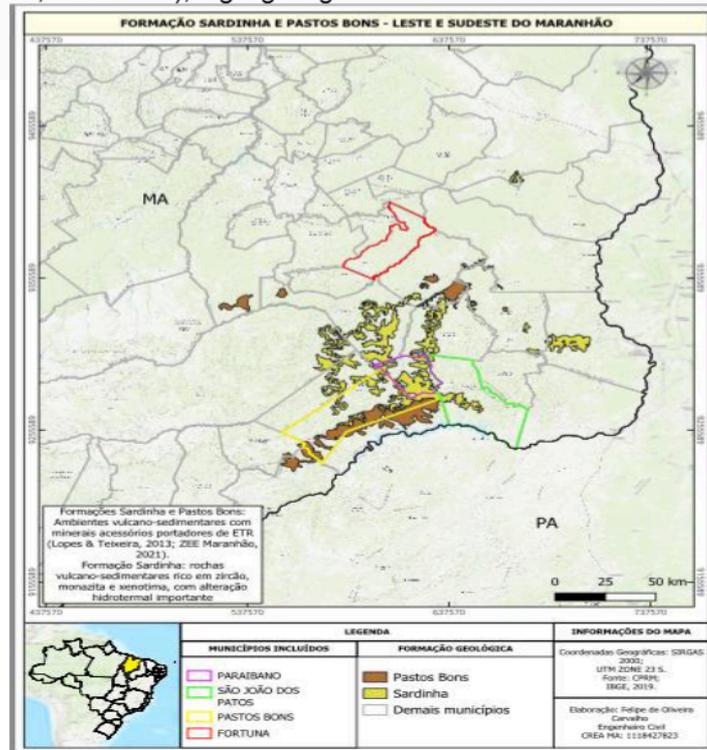
Figure 3. Detail of the Lower Itapecuru Region Axis (Municipalities of Rosário, Bacabeira, Icatu and Axixá), highlighting the Rosário Intrusive Suite.



Source: Authors (2025)

A second axis of interest is located in the Northwest of the state (municipalities of Centro Novo do Maranhão, Carutapera, Luís Domingues and Cândido Mendes). This region presents a complex geology with multiple units of interest, highlighting the Chega-Tudo and Igarapé de Areia Volcanic and Volcano-Sedimentary Formations, which record the presence of the accessory minerals monazite and xenotime. Additionally, plutonic formations such as the Itapecuru Complex are cited as potential hosts of REE (ZEE MARANHÃO, 2021; LOPES; TEIXEIRA, 2013).

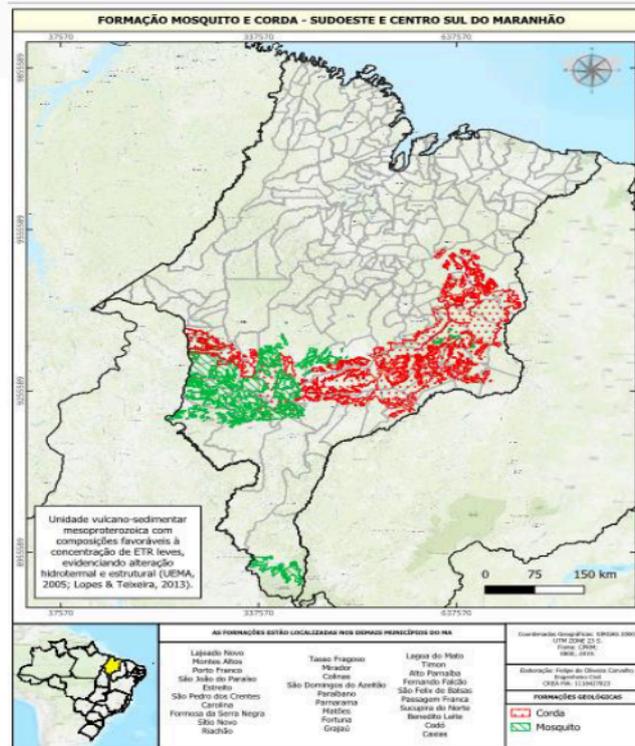
Figure 04. Detail of the East/Southeast Region Axis (Municipalities of São João dos Patos, Pastos Bons, Paraibano), highlighting the Sardinha and Pastos Bons Formations



Source: Authors (2025)

Further inland, the East/Southeast Axis (São João dos Patos, Pastos Bons, Paraibano, Fortuna), located on the border of the Tocantins Province, presents the Sardinha and Pastos Bons Formations. These are described as volcano-sedimentary environments with significant hydrothermal alteration, rich in accessory minerals bearing REEs (ZEE MARANHÃO, 2021; UEMA, 2005).

Figure 5. Detail of the Southwest/South-Central Region Axis, highlighting the Mosquito and Corda Formations.

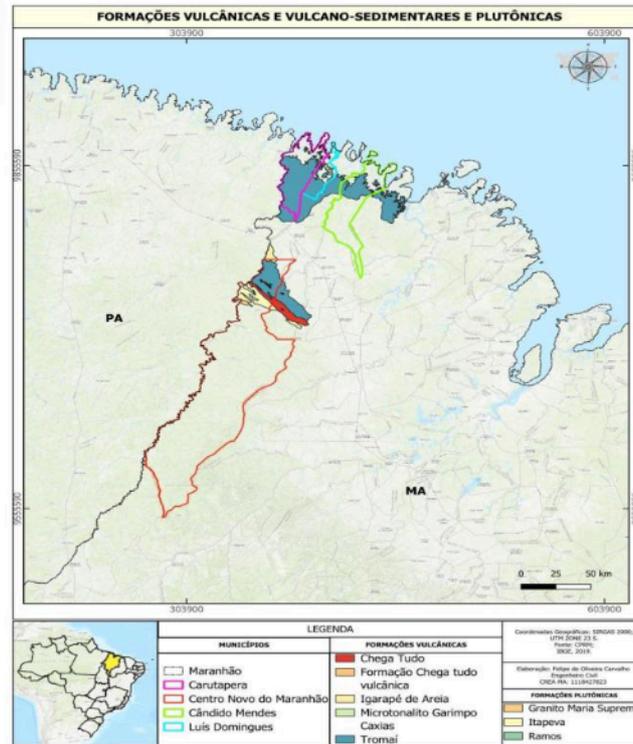


Source: Authors (2025)

The Southwest/South-Central Axis (Grajaú, Codó, Barra do Corda region) includes the Mosquito Formation, a Mesoproterozoic volcano-sedimentary unit favorable to the concentration of light REEs (LOPES; TEIXEIRA, 2013), and the Corda Formation, which indicates potential for prospecting (BUSINESS PLAN, 2024; UFPA, 2024).

The map below shows the distribution of volcanic, volcano-sedimentary, and plutonic formations in northwestern Maranhão and part of Pará, highlighting geological units such as Chega Tudo, Tromaiá, Igarapé de Areia, and associated granitic formations with distinct colors. The cartographic representation shows areas where ancient magmatic, intrusive, and extrusive events occurred, allowing visualization of the spatial relationship between these units and the municipalities of Carutapera, Centro Novo do Maranhão, Cândido Mendes, and Luís Domingues.

Figure 6. Sedimentary formations in the State of Maranhão



Source: Authors (2025).

Operating in Special Economic Zones (SEZs) offers specific tax and exchange incentives for companies, making the business environment more attractive for long-term investments in beneficiation and industrialization, stages with high capital costs and technological expertise. The presence of these zones strengthens Maranhão's capacity to transcend the "resource trap" (OLIVEIRA, 2014), promoting the creation of a true REE industrial cluster, which could even foster research and local development through partnerships with universities (BUSINESS PLAN, 2024).

5.2 LOGISTICS AND INDUSTRIAL INFRASTRUCTURE AS A COMPETITIVE ADVANTAGE

Project forecasts for ETRs (Extractive Mineral Resources) depend not only on geological resources, but crucially on local transportation and processing capacity for value aggregation. Maranhão has a mature logistics-industrial

platform (BUSINESS PLAN, 2024), significantly reducing initial CAPEX and enabling a cluster of mineral strategies.

The first pillar is the São Luís Port Complex, especially the Port of Itaqui a world-class deep-water port that facilitates the export of refined concentrates/oxides and the import of chemical inputs for processing.

The second pillar is land connectivity via the Carajás Railway (EFC) and the BR-135 highway, linking production zones to the port. The third is the incentivized ZPE (Special Economic Zone) with ready-made energy infrastructure (including renewables) and logistics, eliminating downstream plant construction costs and positioning the Lower Itapecuru Axis (Bacabeira) as an initial strategic focus.

5.3 OPPORTUNITY FOR VERTICAL INTEGRATION: THE SYNERGY BETWEEN GEOLOGY AND LOGISTICS

The results revealed a rare confluence between geological potential (Rosário Intrusive Suite, northwest formations) and mature logistical-industrial infrastructure (Port of Itaqui, Carajás Railway, ZPE). Although geology is a necessary condition, the existing infrastructure creates sufficient conditions for the development of an industrial hub.

This synergy differentiates Maranhão, overcoming the Brazilian bottleneck in REEs not due to a lack of reserves, but a historical deficit in R&D and the absence of beneficiation/refining plants (MARTINS *et al.*, 2014; CGEE, 2013). The Bacabeira ZPE offers a ready-made industrial platform, reducing CAPEX for a pilot plant for separating REE oxides (REO) and proposing an integrated value chain instead of exporting raw ore.

The cluster model mining + processing in the ZPE + transportation through Itaqui represents the Brazilian paradigm for internalizing the most profitable stages of the chain (MARTINS *et al.*, 2014, p. 50), reinforced by the proximity of the Lower Itapecuru Axis to the reserves of rare earth elements.

5.4 STRATEGIC CRITICALITY ANALYSIS OF MARANHÃO'S RETAINING MINERALS

To validate vertical integration, the Strategic Value Matrix of Martins *et al.* (2014, pp. 141-143) is applied, which evaluates minerals based on five criteria (geological criticality, supply concentration, demand growth, revenues/profits, importance for sustainable development), classifying the target REEs of Maranhão as a priority focus.

Identified elements — neodymium (Nd), praseodymium (Pr), dysprosium (Dy), and yttrium (Y) — receive a "High" rating in almost all criteria (MARTINS *et al.*, 2014, Table 39). Nd and Dy score "High" in all five, with Nd being the main component of permanent magnets (NdFeB) and Dy being essential for high-temperature operation (electric vehicle motors) (MARTINS *et al.*, 2014, pp. 88-89).

The geological targets of Maranhão are not generic rare earth minerals (REMs), but the most critical and highest value-added minerals for a new economy, with a "High Concentration of Supply" that reinforces the geopolitical urgency of diversification. Vertical integration in the state is justified by the high criticality of these strategic minerals.

5.5 CRITICAL CHALLENGES: TECHNOLOGY, RADIOACTIVITY AND GOVERNANCE

Despite the favorable convergence of geological potential and infrastructure, the consolidation of a Rare Earth Elements (REE) hub in Maranhão is conditioned by three critical challenges that have historically constrained similar projects in Brazil: technological capacity, environmental management and regulatory governance. The primary bottleneck is technological, as the highest value of REEs is concentrated in the separation of pure oxides and subsequent metallurgical processing—stages dominated globally by China. Brazil's structural deficit in mineral R&D necessitates substantial and coordinated investments to

internalize these technologies and avoid the continued export of low-value concentrates.

A second challenge relates to environmental licensing, particularly the management of residues classified as NORM and TENORM. Minerals such as monazite and xenotime contain thorium and uranium, which become concentrated in tailings after chemical processing, requiring stringent monitoring, engineered containment and compliance with nuclear regulatory standards. Although these risks are recognized in project planning, their technical and financial execution has historically undermined project feasibility.

The third constraint involves governance and regulatory efficiency. Procedural bottlenecks and institutional delays in mining and environmental agencies increase uncertainty and inhibit long-term capital allocation. The viability of a Strategic Minerals Cluster in Maranhão therefore depends on a coordinated public–private governance model, combining legal certainty, regulatory agility and effective environmental and nuclear licensing frameworks.

6 PROJECTION "MARANHÃO 2045": AN INTEGRATED INDUSTRIAL HUB

The geological and logistical results, weighed against critical challenges, project a scenario conditioned by "Maranhão 2045": outdated technology, radioactivity, and governance, the protected state transcends to become an integrated REE industrial hub. The ZPE will house oxide separation (REO), alloy metallurgy, and permanent magnets, using Porto Itaqui and Ferrovia Carajás to export to the USA/EU/Japan (ALVES, 2025) and supply Brazilian neo-industrialization with Nd, Pr, and Dy for wind turbines and electric vehicles (MARTINS *et al.*, 2014).

The prospecting focuses on Proterozoic igneous/volco-sedimentary units, rich in monazite (light REEs) and xenotime (heavy: Y, Dy, Tb). The Lower Itapecuru Axis (Rosário, Bacabeira, Axixá, Icatu), linked to the São Luís Cratonic Fragment and the Rosário Intrusive Suite (alkaline granites), is a geological hotspot for medium/level REEs.

The ZPE in Bacabeira (2,059 ha) creates direct synergy: proximity to the deposit-processing area optimizes costs, converts concentrate into pure oxides on-site, and integrates logistics (Carajás Railway, BRs 135/402/MA-110, Itaqui) for export, positioning Maranhão as a globally competitive hub for high-value/high-technology REEs.

7 STRATEGIC OUTLOOK: MARANHÃO AS A GLOBAL REE HUB (HORIZON 2045)

This analysis is valid for the prospective potential of Maranhão to consolidate an industrial cluster of REEs by 2045, with a unique confluence of geological assets (Rosário Intrusive Suite, Lower Itapecuru Axis; ZEE MARANHÃO, 2021; CPRM, 2023) and logistical assets (Bacabeira EPZ, Carajás Railway, Itaqui Port), attracting FDI and mitigating risks in the global critical REE chain (Nd, Dy, Y; MARTINS *et al.*, 2014).

Operational synergy minimizes logistical frictions, verticalizing the chain via the production of pure oxides (REO) in the EPZ, overcoming the export of crude concentrates (CGEE, 2013). However, success depends on overcoming three challenges: (1) massive investment in R&D for hydrometallurgy; (2) rigorous management of NORM/TENORM (monazite/xenotime); (3) Agile and secure regulatory governance.

It is concluded that Maranhão possesses fundamental assets for a REE hub, conditioned on holistic investments in human capital (UFMA/UEMA/IFMA) and technology (BNDES/FINEP). Studies of technical-economic forecasts for beneficiation routes of the Rosário Suite and mass balance of radionuclides in tailings are recommended.

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