

Environmental Issues of Rare Earth and Critical Mineral Mining in Vietnam: Towards a Sustainable Future

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ABSTRACT

Rare earth elements (REEs) and critical minerals are essential for modern technologies, renewable energy systems and strategic industries. Vietnam hosts significant occurrences of several REEs and other critical minerals, making the country an increasingly important player in global supply chains. However, extraction and processing of these minerals can cause severe environmental, social and health impacts when not managed sustainably. This paper examines the current status of rare earth and critical mineral resources in Vietnam, documents environmental impacts (water, soil, air, biodiversity and social health) and evaluates the regulatory framework and policies governing mining activities. The study reviews sustainable practices, cleaner technologies, mine rehabilitation strategies and waste management approaches, identifies key challenges and opportunities for sustainable mining and proposes policy recommendations to strengthen environmental protection, governance and stakeholder engagement. The paper concludes with suggested directions for future research and implementation priorities to balance economic benefits with environmental sustainability and social responsibility.

Keywords: *Rare earth, critical minerals, environmental impact, sustainable mining.*

1. Introduction

The escalating global demand for rare earth elements and critical minerals, pivotal for the green energy transition, has intensified mining activities in mineral-rich nations like Vietnam (U.S. Geological Survey, 2015; European Union, 2020; Dugoua and Noailly, 2025). However, this burgeoning sector presents significant environmental challenges, including deforestation, hazardous waste generation and pervasive water contamination, which necessitate a re-evaluation of current mining practices to foster long-term ecological and societal well-being (Sysolyatina and Olkova, 2023; Wang et al., 2024). Addressing these multifaceted impacts requires a transition towards sustainable mining practices, integrating stringent environmental regulations and innovative technologies to mitigate ecological degradation and promote responsible resource management (Nguyen et al., 2021). This paper examines these impacts and explores strategies for mitigating these effects through sustainable mining practices, advanced technologies and robust regulatory frameworks. Ultimately, the goal is to develop a comprehensive framework that ensures the economic benefits of critical mineral extraction are balanced with ecological preservation and community welfare, thereby securing a sustainable future for Vietnam's mining industry. Figure below shows projected demand for critical minerals is produced based on a scenario reflecting announced climate

targets in May 2024 of International Energy Agency (IEA).

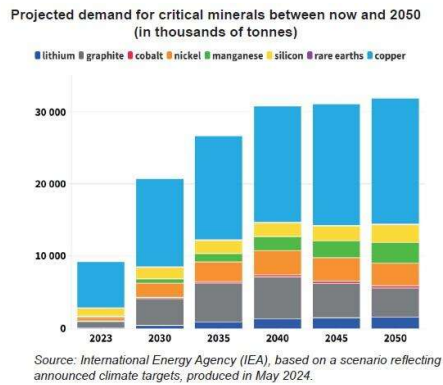


Figure 1. Demand of critical minerals from 2024 to 2050 (in thousands of tonnes)

The extraction of these vital resources, while critical for technological advancement, often entails substantial environmental consequences such as extensive chemical use, high energy consumption and the generation of radioactive tailings, thereby necessitating a thorough examination of their broader ecological footprint (Zapp et al., 2022). These environmental burdens are compounded by historical shortcomings in environmental management within Vietnam, leading to significant land degradation and pollution, particularly in agricultural soils, that poses direct health risks to local populations. This necessitates a comprehensive shift towards sustainable mining models that integrate green mining technologies to minimize ecological disruption and address the legacy of environmental damage (Zapp et al., 2022; Mohamed et al., 2025). Such models prioritize technological innovations, like the strategic repurposing of mine tailings and enhanced community engagement to ensure resource extraction aligns with environmental conservation and economic viability (Trifuoggi et al., 2018). This approach is crucial for mitigating the widespread environmental degradation often associated with mineral extraction, which includes habitat destruction, soil erosion, water contamination and significant contributions to climate change through greenhouse gas emissions (Trapasso et al., 2021; Paleologos et al., 2025).

Vietnam's mineral endowment, strategic location and growing industrial capabilities position it to contribute to global critical mineral supply diversification. Rare earth elements and other critical minerals are indispensable to high-tech industries-electric vehicles, wind turbines, electronics, military systems and green technologies (Phan et al., 2019). However, mining and processing of REEs and other critical minerals often involve complex geochemistry, radioactive by-products, use of acids and heavy chemicals and generation of fine grained tailings, posing substantial environmental and social risks. Sustainable mining is therefore crucial to ensure long-term economic benefits while minimizing ecological damage and protecting community health.

This paper aims to analyze environmental impacts associated with extraction and processing, and then evaluate the current regulatory and policy framework and identify enforcement challenges. By identify the challenges and opportunities, this research proposes policy recommendations for sustainable development of Vietnam's critical mineral sector.

2. Background of rare earth and critical minerals in Vietnam

2.1. Major mineral types

Vietnam lies along complex Proterozoic-Cenozoic belts and hosts diverse mineralization styles, including of carbonatite- and monazite-associated REE, lateritic nickel-

cobalt in ultramafic weathering profiles, heavy-mineral coastal placers (ilmenite, rutile, zircon), polymetallic skarn/vein and hydrothermal deposits (W, Sn, Cu, Pb-Zn) and iron-titanium occurrences. The geological settings control distribution, depth and ore characteristics, which in turn determine environmental risk profiles (e.g., thorium-bearing monazite sands versus non-radioactive carbonatite REE). Vietnam's mineral resources include economically significant occurrences of rare earth elements (particularly in the Northern provinces and the Truong Son belt), polymetallic deposits, titanium, zircon, nickel laterites, cobalt, manganese and barite. Notable REE occurrences have been reported in the provinces of Lai Chau, Son La, Cao Bang, as well as deposits associated with carbonatites and monazite-bearing placers in coastal and riverine sediments. Documented occurrences of REEs in northern mountainous provinces (Cao Bang, Bac Kan/Thai Nguyen, Lai Chau, Son La), coastal placer monazite in central provinces and carbonatite-hosted prospects. Nickel-cobalt appear in Lai Chau, Lao Cai provinces and laterite deposits of nickel-cobalt in Central Highlands (Kon Tum/Quang Ngai, Gia Lai, Dak Nong/Lam Dong) and parts of the Truong Son belt. Heavy mineral sands (Ti, Zr) are widely distributed in coastal provinces (Nghe An, Ha Tinh, Quang Ngai, Binh Thuan/Lam Dong). Other critical minerals such as tungsten and tin in Northern provinces (Nghe An, Son La, Cao Bang), lithium occurrences have been reported in pegmatite-hosted localities and brines under preliminary exploration.

While Vietnam's absolute reserves of REEs are not as large as China's or Australia's, the country's relative diversity of critical minerals and growing exploration suggests potential for regional supply. Many deposits are at reconnaissance to exploration stages and exploration intensity is increasing due to global demand.

2.2. Current mining operations and practices

Mining in Vietnam is a mix of state-owned companies, local private enterprises and foreign-invested projects. Many operations use conventional open-pit or dredging methods for mineral sands and strip-mining or shallow pit methods for laterites. Small-scale and artisanal mining also occurs, sometimes informally. Processing practices range from basic concentration and gravity separation to chemical leaching for REE and nickel recovery. Some operations combine beneficiation with hydrometallurgical or pyrometallurgical processing, often conducted domestically or through partnerships with foreign processors.

Critical minerals support Vietnam's domestic industrialization, export sectors and integration into global value chains. As the global demand for green technologies grows, Vietnam's capacity to supply nickel, cobalt, titanium and REEs could deliver export revenues, employment and technological development. Additionally, securing stable supply chains for downstream industries (battery manufacturing, electronics) is strategically important. However, export-oriented extraction must be balanced with environmental safeguards to avoid long-term degradation that undermines local livelihoods.

3. Environmental impacts and environmental policies in Vietnam

3.1. Environmental impacts of mining activities

3.1.1. Water and soil pollution

Water resources face major risks from mineral extraction. Acid mine drainage (AMD) can occur where sulfide-bearing ores are exposed to oxygen and water, producing sulfuric acid that mobilizes heavy metals (Fe, Mn, Zn, Cu, Pb) and toxic elements (As, Cd). For some REE and associated polymetallic deposits, acidic effluents and leachates from processing plants can contaminate rivers and groundwater. Tailings ponds and heap leach facilities pose risks of

seepage and catastrophic failure, releasing contaminated water. Inadequate treatment of effluents exacerbates downstream contamination, affecting drinking water sources, irrigation and aquatic ecosystems.

Open-pit mining, stripping of topsoil and deposition of tailings lead to soil loss, compaction and contamination with heavy metals and radionuclides sometimes associated with monazite-rich REE ores (thorium, uranium). Soil contamination affects agricultural productivity and food safety when contaminants enter the food chain via crops and livestock. Erosion and sedimentation from disturbed lands degrade downstream habitats and reduce reservoir storage capacity.

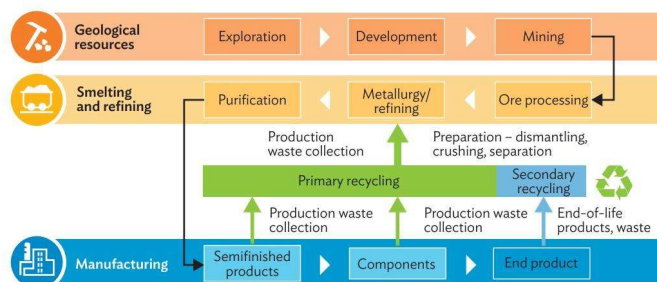


Figure 2. Life cycle diagram of a mining project

3.1.2. Air quality issues and biodiversity loss

Dust generation from mining operations, transport and tailings handling affects local air quality, contributing particulate matter (PM₁₀, PM_{2.5}) and potentially radioactive dust where monazite or thorium-bearing minerals are present. Processing plants can emit gaseous pollutants from mineral roasting and smelting (SO₂, NO_x) and fugitive emissions of volatile organics or fluorides depending on processing chemistries. Chronic exposure to dust and airborne contaminants can affect respiratory health in local communities and workers.

Mining-related habitat loss, fragmentation and pollution threaten biodiversity, particularly in Vietnam's ecologically rich upland and coastal zones. Deforestation for mine expansion or access roads can eliminate critical habitats for endemic species. Aquatic biodiversity suffers from sedimentation, altered flow regimes and chemical contamination (Haque et al., 2014; Sysolyatina and Olkova, 2023). Cumulative impacts from multiple small mines can be significant, even where individual footprints are modest.

3.1.3. Social and health impacts

Communities near mining operations often face displacement, loss of agricultural land, reduced water quality, air pollution, noise and increased health risks (respiratory ailments, skin diseases, heavy metal exposure). Inadequate consultation, inequitable benefit-sharing and weak grievance mechanisms can lead to social conflict (IFC, 2012; Nguyen et al., 2021). Artisanal miners may be exposed to hazardous conditions with limited occupational safety. Indigenous and ethnic minority groups in some regions are disproportionately affected.

3.2. Regulatory framework and environmental policies

3.2.1. Regulatory Framework

National environmental legal framework comprises the Law on Environmental Protection, Mining Law, Water Resources Law, Land Law and associated decrees and circulars. The Law on Environmental Protection provides requirements for environmental impact assessments (EIA), environmental protection plans and permits. The Mining Law governs

exploration, exploitation rights and mine closure obligations. Sectoral regulations set emission standards, wastewater limits and waste classification.

Licensing procedures require exploration and exploitation permits, feasibility studies and environmental compliance documents. Investors must prepare EIAs or environmental impact assessments and secure environmental protection plans and discharge permits. Rehabilitation and mine closure plans are legally required, with bonds or financial assurances prescribed in some cases.

While legislative frameworks exist, implementation and enforcement gaps persist due to limited institutional capacity, fragmented responsibilities across ministries (Ministry of Natural Resources and Environment, Ministry of Industry and Trade, provincial People's Committees) and resource constraints for monitoring. Illegal or informal mining operations evade oversight. Regulatory standards may be outdated relative to modern best practices for REE and critical mineral processing (e.g., handling of radioactive by-products, advanced tailings management). Corruption risks and weak transparency can undermine compliance.

3.2.2. *Environmental policies in Vietnam*

Policies encourage BAT (Best Available Techniques) adoption through normative documents and pilot programs. Key BATs for Vietnam's contexts: filtered/paste tailings, closed-loop water circuits with multi-stage treatment, modular solvent extraction circuits with solvent recovery and dust suppression systems. Tailings storage facilities (TSF) design guidance exists but engineering standards need updates for filtered tailings and seismic resilience in upland regions. Monitoring (piezometers, seepage wells, surface water sampling) is required but not uniformly implemented. On mining land rehabilitation and post-closure land use, progressive rehabilitation is required. Technical guidance emphasizes topsoil segregation, erosion control, reforestation with native species, slope stabilization and post-closure water quality monitoring periods can be multi-decade recommended for some deposits.

Policy instruments reference resettlement frameworks and livelihood restoration; stronger implementation tools (benefit-sharing agreements, independent grievance mechanisms) are recommended (Hayes-Labruto et al., 2013). Vietnam participates in international dialogues on sustainable minerals and has received technical assistance from development partners. There is movement to align with international standards used by financiers, such as IFC Performance Standards (IFC, 2012) for larger projects.

Table 1. Common environmental issues by mining stage and typical mitigation options

Mining stage	Main environmental issues	Typical mitigation/management measures
Exploration	Soil disturbance, access roads, small-scale pits	Minimizing footprint, seasonal access planning, reclamation of drill pads
Mining (open-pit, dredging)	Sedimentation, deforestation, erosion, habitat loss	Progressive rehabilitation, sediment traps, reforestation, road management
Ore processing	Tailings, chemical leachates, reagent use, NORM	Filtered/paste tailings, reagent recycling, effluent treatment, NORM handling protocols
Waste storage	TSF stability, seepage,	Engineered liners, seepage collection

	tailings breach risk	systems, monitoring, emergency action plans
Closure & post-closure	Long-term water quality, land-use conversion	Financial assurance, long-term monitoring, adaptive management, community oversight

Vietnam has begun promoting sustainable mining through policies encouraging cleaner production, environmental management systems and corporate social responsibility. State-supported pilot projects and international cooperation (e.g., with development partners) aim to introduce modern beneficiation and processing methods that reduce chemical usage and waste. A good example of reasonable environmental management is Nui Phao polymetallic project in Thai Nguyen province, where Masan High-Tech Materials (MHT) of Masan Group is major developer (Masan High-tech Materials, 2025). The main products are tungsten, copper, lead-zinc, fluorite and by-product rare metals. Mining technique is open-pit operation with on-site flotation and hydrometallurgical circuits and the commercial operation began around 2013-2014. The environmental management procedures for wastewater are multi-stage treatment-sedimentation, neutralization and polishing-prior to controlled discharge. Typical treated effluent parameters reported in public summaries met national discharge standards for pH, suspended solids and many metals; occasional spikes were reported during heavy rainfall events in early operation years. Tailings from mining activities are engineered TSF with seepage control, the tailing dams are periodic geotechnical monitoring and tailings reprocessing potential evaluated for residual values. Resettlement and livelihood restoration programs were also implemented for directly affected households, ongoing community grievance mechanisms instituted by operator. Site-level environmental data show surface water near discharge with average pH ~6.8-7.5, elements of Cu, Pb, Zn are typically below national discharge limits in routine sampling, occasional exceedances historically linked to extreme weather and operational incidents. Groundwater monitoring show values within baseline variability for most parameters in publicly available summaries. Key finding in this specific example is large-scale developer capacity enabled adherence to higher standards and investment in mitigation; continuous monitoring and public reporting improved stakeholder trust but highlighted need for strengthened contingency planning for extreme weather.

Cleaner technologies include closed-circuit water systems, reagent recovery and recycling, advanced filtration and solid-liquid separation (e.g., high-rate thickeners, filter presses), hydrocyclones and gravity separation to reduce downstream chemical processing. For hydrometallurgical processes, optimized leach chemistries, solvent extraction with secondary treatment to recover reagents and improved tailings dewatering are relevant. Regulations require mine closure planning, progressive rehabilitation during operations and post-closure land use strategies (agriculture, forestry, recreation). Successful rehabilitation requires restoring soil structure, replacing topsoil, re-establishing native vegetation, stabilizing slopes and ensuring long-term water quality. Tailings reprocessing, where economically feasible, can reduce footprint and recover value. On waste management and tailings treatment, proper classification, containment and treatment of mining wastes are essential. Engineered tailings storage facilities (TSFs) with liners, seepage control, monitoring networks and emergency action plans reduce failure risk. Emerging approaches include paste tailings and filtered tailings to lower water content and improve stability. Management of potentially radioactive materials

(e.g., monazite residues containing thorium) requires specialized handling, regulatory oversight and long-term stewardship. Water use efficiency and closed-loop systems reduce freshwater abstractions and effluent volumes. Constructed wetlands, sedimentation ponds and multi-stage treatment systems (neutralization, precipitation, adsorption, membrane filtration) can treat mining effluents. Groundwater monitoring and hydrogeological assessments inform sustainable extraction and prevent aquifer contamination.

3.3. Challenges and opportunities for sustainable mining of critical minerals in Vietnam

The main environmental issues in mining activities relating to critical minerals in Vietnam are water contamination, tailings management, radioactive residues, biodiversity loss and social impacts-require integrated mitigation (Haque et al., 2014; International Atomic Energy Agency, 2022). Efforts to mitigate these include EIAs, adoption of best available techniques, stricter monitoring and rehabilitation obligations. However, implementation varies and requires scaling. While regulations and specific mitigation measures exist, effectiveness is mixed, in some large-scale projects implement international standards, but many smaller operations lack capacity for compliance. Monitoring data gaps, inconsistent enforcement and financial constraints hinder full effectiveness. International experience shows that integrating rigorous EIA procedures, strong financial assurance for closure, community participation, transparent permitting, independent monitoring and adoption of improved tailings technologies significantly reduce environmental and social risks.

On technological and financial constraints, high upfront capital required for modern processing, tailings technologies and water treatment can deter adoption, especially for small operators. Limited domestic capacity for advanced metallurgical processing and scarcity of specialized contractors is a constraint. Financing mechanisms and incentives are needed to accelerate technology uptake. However, governance issues are transparent licensing, public disclosure of EIAs and monitoring results, anti-corruption measures and open grievance mechanisms strengthen accountability (Zapp et al., 2022; Wang et al., 2024). Currently, opacity in some decision-making processes and limited civil society access to information weaken governance.

The potential for green technologies is relatively high as opportunities exist to integrate circular economy principles, such as recycling of end-of-life products to reduce primary extraction, reprocessing of tailings to recover residual values, reagent recycling and more efficient material flows. Developing domestic downstream processing for batteries or magnets could add value, provided environmental safeguards are in place.

4. Conclusion

Vietnam holds meaningful potential for contributing to global supplies of rare earths and other critical minerals, but current mining and processing practices pose significant environmental and social risks. Existing legal frameworks provide a foundation but require updating, stronger enforcement and targeted measures to address the unique challenges of REE and critical mineral extraction, such as radioactive residues, complex tailings chemistry, etc. Technological, financial, governance and community-engagement barriers clearly constrain the transition to sustainable mining.

To strengthen the environmental regulations, we need to update mining and environmental regulations to include specific standards for REE and critical mineral processing that handling of radioactive residues, tailings dewatering standards, closure bonding. Stricter permitting should be implemented to demonstrated technical capacity and financial guarantees

for closure and long-term monitoring. A sustainable future requires integrated policy action: modernize regulations tailored to REE and critical mineral risks; mandate financial assurance and long-term monitoring; incentivize cleaner technologies; enhance transparency and community participation; and build institutional and technical capacity. Encouraging circular economy strategies and downstream value addition, under strong environmental safeguards, will maximize economic benefits while reducing ecological footprints.

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