India's hunt for rare earth elements (REEs) and critical minerals-A comprehensive review

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***Abstract*—Rare earth elements and critical minerals are very important for modern industries. China has the largest reserves of rare earth elements or critical minerals, and also has the largest refining capacity to mine and refine these minerals. This gives China a monopoly over the market. India has reserves of these minerals but lacks production and refining capability. India's dependency on importing these minerals from outside makes the supply chain vulnerable. The WTO rare earth dispute is an example of how countries protect their trade rights. India is now focusing on partnerships and tie-ups overseas to secure its supplies. This review also examines the environmental issues that mining imposes on nature, like pollution and habitat loss. It also covers its 'recycling potential',i.e, by recycling the old electronics and batteries, their value can be used again. India is now emphasizing developing better R&D and better extraction and recycling technologies for and government initiatives like the National Critical Minerals Mission are helping them. India aims to reduce its import dependency and develop future strategies to secure its supply chain.**

***Index Terms*—Critical Minerals (CMs), Rare Earth Elements (REEs), China Dominance, Supply Chain Vulnerability, WTO Rare Earths Dispute (2012–14), India's Reserves (6–8 MT, ~6%), Import Dependency (~80%), National Critical Minerals Mission (NCMM), Circular Economy, Recycling (PLI Scheme – 40 KT/year), Innovation & R&D (1000 Patents, 7 Centres),International Partnerships (26 Overseas Projects), Rare-Earth Magnets (Imports from China), Self-Reliance / Atmanirbhar Bharat, Energy Transition & Net Zero 2070**

I. INTRODUCTION

Rare earth elements like lithium, nickel, cobalt, graphite, etc. are very essential minerals for modern technology (like electronic vehicles, semiconductors, wind turbines, defense systems, etc.). Despite being abundant in Earth's crust, Rare earths are present in low concentrations, which makes their separation and extraction challenging and costly. These elements are used in high-strength magnets, catalysts, batteries, and electronics. As advanced technology, high-tech manufacturing, and clean and sustainable energy are in great demand, this has increased the importance of Rare Earths. REEs are also referred to as the 'new oil' of the global economy. China has historically led the production of these minerals and, as of 2023, produced around two-thirds (2/3) of the REEs. China's monopoly over rare earths and crucial minerals made the market very concentrated and increased the threat to other countries like India. Because if China changes its policies, trade quotas, and restrictions, it will affect the whole market.

II. REVIEW LITERATURE

Chandrashekar, S., Strategic Analysis, 2021.
Contributed insights into the geopolitical implications of rare earth elements, emphasizing India's strategic vulnerabilities due to reliance on imports and the necessity for securing diversified supply chains for national security and technological self-reliance.
Panda, S. K., Journal of Defence Studies, 2022.
Focused on the critical role of REEs and other strategic minerals in defense technologies and the broader implications for India's military preparedness and indigenous defense manufacturing capabilities.
Singh, R. K., et al., Journal of Geological Society of India, 2018.
Provided geological assessments and identified potential domestic reserves of rare earth elements,

particularly in monazite sands and carbonatite complexes across various Indian states, contributing to the understanding of India's indigenous resource base.
Kumar, A., & Tripathi, S., Mineral Economics, 2020.
Analyzed India's mineral policies and regulatory frameworks concerning critical minerals, offering a critique of their effectiveness in attracting investment and facilitating exploration and exploitation, and suggesting improvements for a more conducive environment.
Gupta, A., & Sharma, M., Hydrometallurgy, 2019.
Researched advanced hydrometallurgical techniques for the extraction and separation of rare earth elements, addressing the technological challenges and opportunities for developing indigenous processing capabilities in India.

Ahmed, Z. K., & Mehta, B. (2023) This study emphasizes the influence of web-based customer feedback upon consumer decision-making in the home furnishings sector. It emphasizes the growing potency of digital feedback mechanisms within the process of shaping purchase decisions. In import/export business, analysis of crossborder customer feedback via sentiment analysis using AI can provide rich insights into cross-border consumer preferences. Such data can allow exporters to modify product features, prices, and channels of distribution in real-time and thereby contribute to competitiveness in foreign markets.
Choudhary, P. D., & Madhwani, R. (2013) This research is looking into how world depressions influence tourism and hospitality sectors. Its implications reach the entire economy, foreign trade included, which gets hurt in world downturns. Now, AI software in predictive analytics and forecasting can assist importers as well as exporters to foresee market movements and pre-emptively modify supply chains. Thus, though the paper is centered on tourism, its conclusions echo the potential of AI to act as a shock absorber for import-export industries too.

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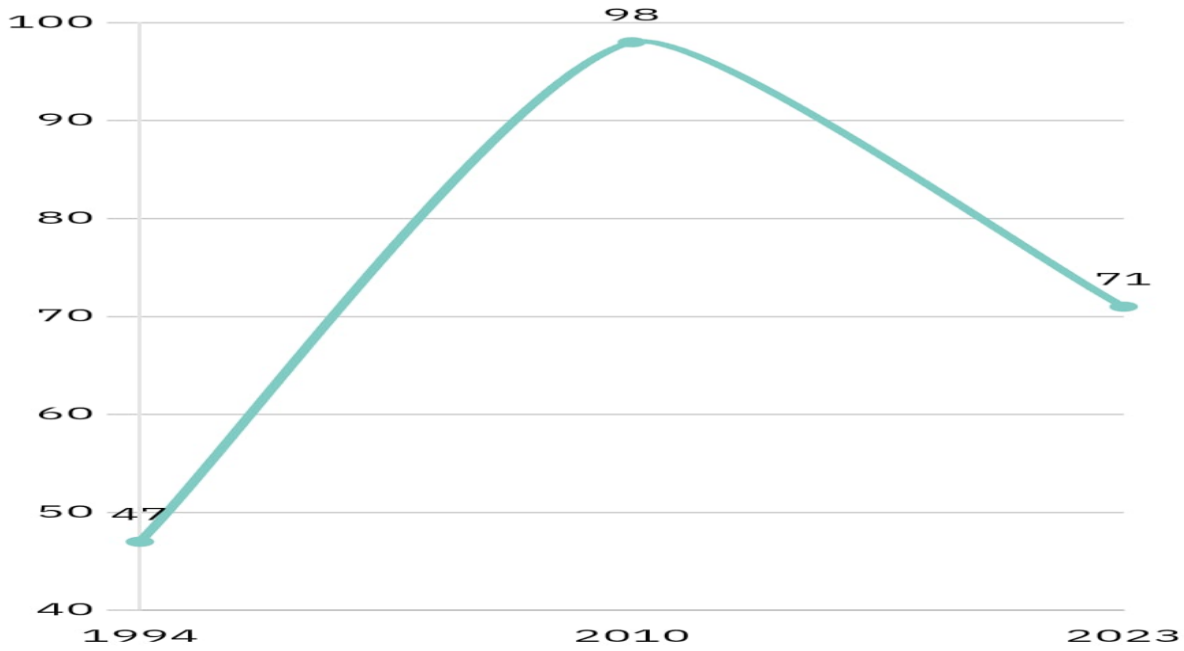
Dave, K. K., & Paliwal, R. (2016). A study on consumer perception on malted health food drinks in Udaipur ciy explores consumer perceptions and behavior in a specific kind of FMCG category. Its conclusion reflects how local palates influence market success. In import-export, world consumer food and beverage preferences can be predicted through AI-driven market analysis, allowing exporters to access the appropriate markets with the appropriate products. Hence, market research on consumer attitudes, linked with AI tools, is critical in handling world product acceptance.

Sharma, R., Dadhich, M., & Chauhan, K. (2022). The pandemic effect analysis of financial indicators of the selected BSE listed firms: an in-depth analysis provides a comprehensive view of how COVID-19 interrupted financial performance of leading companies. It reflects the need for robust systems that can handle external shocks. In import and export firms, AI-based financial modeling may help in forecasting risks, handling disruption in supply chains, and optimizing the use of resources during crises. The findings corroborate the relevance of AI in formulating adaptive approaches to international trade in uncertain situations.

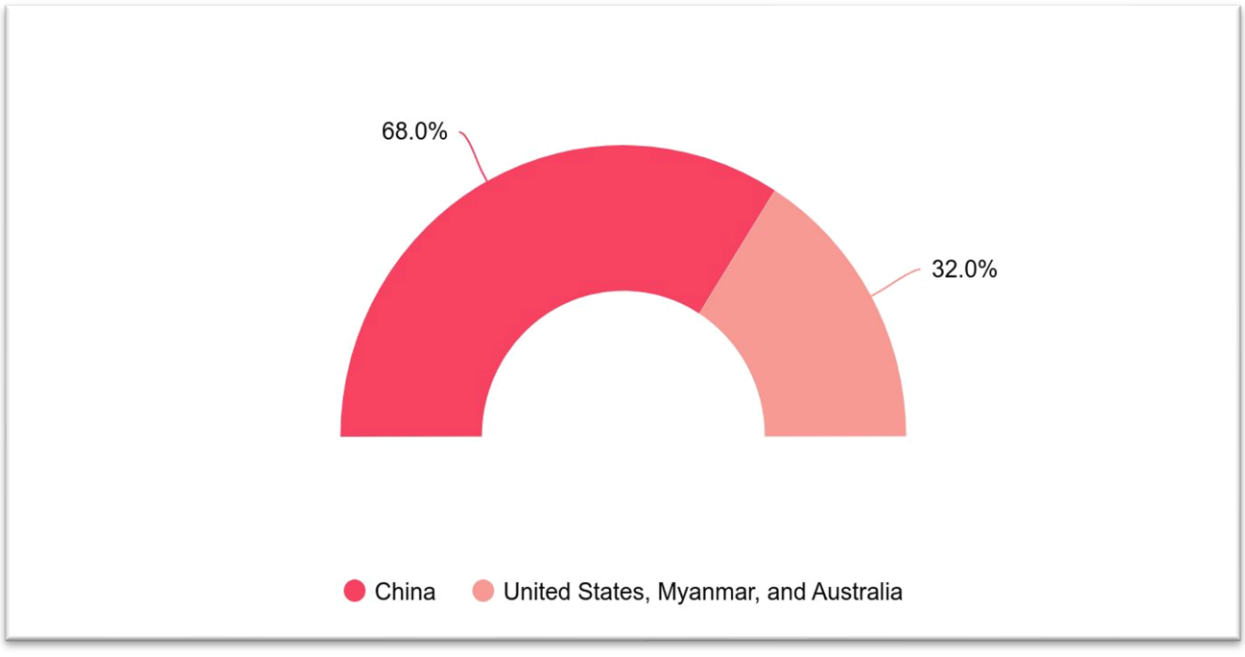
Mehta, A., & Hiran, D. (2023). Change management practice in medium size business organizations of small cities study emphasizes change management practice within mid-sized organizations, particularly in smaller cities. It argues that business continuity requires flexibility and systematic approaches. For import-export, AI facilitatesb smoother change management by offering real-time information, automating rules, and streamlining supply chains. The observations of the paper align with how AI can guide small and medium enterprises (SMEs) in smaller cities to participate confidently in global trade networks.

Global Production and Concentration
Global production of rare earth elements or critical minerals is concentrated in the hands of only a few

countries. As shown in fig 1, In 1994, China held around 47% of the world's rare earth oxide production. By 2010, these shares increased to around 98%. But by 2018, China's share had declined to 71%. In 2023, China still produces around two-thirds of the world's rare earth production. Other countries like the United States, Myanmar, and Australia together contribute to the remaining production as shown in fig 2. Similar trends are also seen in other minerals like lithium, nickel, and cobalt. When a dominant supplier like China imposes restrictions on its exports or quotas, it can disrupt the global supply chain.



(fig 1)



(Fig 2)

In the 2010s, China imposed export quotas on rare earths and related metals to conserve its resources. In 2012, the United States, the European Union, and Japan challenged these quotas at the WTO. They argued that the restriction is against China's trade commitment. The WTO appellate body gave a judgment against China, stating the quotas were unjustified. These quotas were lifted by China by 2015. This case signifies that REEs are not just minerals, but also strategic trade tools, influencing other countries to reduce dependency on a single supplier (China). The United States established the National Defense Stockpile of critical minerals; the European Union passed the Critical Raw Materials Act; the Quad (US, Japan, Australia, India) announced the 2015 critical minerals initiative to support mining and processing projects. China has used restrictions on other elements like germanium and gallium, even after the WTO case, to impose influence. Strategic policies and plans are shaping the supply chain greatly; therefore, international trade in essential minerals has become more tense and geopolitical.

India's critical mineral situation

India has significant deposits of REEs or critical minerals, like coastal monazite sands contain rare earths and thorium. India holds around 6-8 million tonnes of rare earth reserves. This means around 6% of global resources are held by India. Despite this, India produces only around 1% of global rare earth reserves. This is because India lacks good refining capability (production level < potential). India is highly dependent on imports for most critical minerals. India is almost entirely dependent on the import of minerals like Lithium, nickel, cobalt, and germanium. 80% of critical minerals demand is met through imports. In 2024-25, India imported about 53700 tonnes of rare earth magnets (essential for industries, defense, electronics, etc.), the majority came from China. This shows that India is heavily dependent on foreign countries for supplies, which puts India at high risk of supply shocks (export bans, fluctuations in supply) and price volatility (global prices rise due to supply cuts) .

India's new policies reflect that India has started to address mineral dependencies and ecological concerns and risks. The NCMM – National Critical Minerals Mission plays a central role. Under NCMM, the government has allocated Rs 100 crore funding for pilot projects, focusing on recovering valuable metals from mine tailings, flu ash, red mud, and other industrial byproducts. This is a circular economy approach targeted at reducing waste. On new projects, strict mining rules were imposed. This includes necessary evaluation impacts and developing exclusive zones in delicate coastal areas. Despite this, India struggles to balance monetary needs with public health and environmental protection. Mining waste must be handled effectively to ensure that clean energy technologies don't create new hidden ecological crises by taking measures like sustainable tailings storage, sewage treatment, and recycling e-waste and electronics.

Innovation in Recycling & Technology (India's Mineral Strategy)

By focusing on the NCMM (National Critical Minerals Mission), India has set a goal of 1000 new patents. By 2030, areas like exploration, extraction, processing, and recycling of critical minerals will be covered. To develop new technologies in mining and mineral sciences, special research centres will be set up. Rs120 million grants for startups and R&D institutes in mining and processing were announced by the Mines Ministry in late 2023. For scientific and technological development, an additional Rs 200 million was allocated. Integrating AI in exploration and earth physics (geophysics) to find the deposits of minerals. Reduce Environmental damage by developing eco-friendly refining methods and implementing better technologies for separating metals and recycling to make the process more efficient.

India launched a Rs 1500 crore Production-Linked Incentive (PLI) scheme to set up recycling facilities. This mainly focuses on batteries, electronics, and magnet waste and targets to recover 40 kilotons of critical minerals per year. Ongoing research and development projects to extract lithium and rare earths from e-waste and industrial scrap. International collaborations help transfer technology. Toyotsu RE India is an example of a joint venture with Japan, which supports domestic magnet production using advanced Japanese processes. Patents and investment policies are being used to build Indigenous Capabilities in critical technologies. From advanced

separation chemistry to material substitution (like making an electronic vehicle without using rare-earth magnets) to make India self-reliant in minerals, reduce import dependence, and ensure sustainable resource use.

Future strategy: National Critical Minerals Mission (NCMM,2024-2031)

India's NCMM targets domestic projects, overseas tie-ups, recycling patents, and R&D centers 1200 1200the NCMM has set a target of funding over 1200 exploration projects in the next 7 years. These projects focus on REEs like lithium, cobalt, nickel, and other strategic minerals. Over 100 mineral blocks will be auctioned, inviting both private players and PSUs' advanced technologies, like AI-driven geophysics, satellite imaging, and geochemical surveys, which will be used to speed up discovery. The goal is to shift India from being imoport-0dependent to becoming a serious global producer

India knows domestic reserves are limited, so NCMM has a strong focus on international tie-ups.

Through state-owned PSUs and joint ventures, at least 26 minerals projects will be funded overseas with friendly nations. Like lithium from Argentina, Chile, and Australia; cobalt and copper from African nations like the Democratic Republic of Congo (DRC); earth and nickel from Australia.

India has already signed bilateral mineral agreements with Australia, Argentina, and Mongolia. This strategy ensures supplier diversification and reduces over-reliance on China, which currently dominates critical minerals export

The NCMM strongly emphasizes recycling as a 'secondary mine'. India plans to establish large-scale recycling facilities under the PLI scheme, to recover several hundred kilotons /year of minerals from-

- Spent batteries (lithium, cobalt, and nickel)
- E-waste (REEs, gallium, germanium)
- Industrial scrap (for aluminum, copper, and rare magnets)

By 2031, India aims to recover 40 kilotons of minerals per year from recycling. This will reduce waste imports, cut down environmental harm, and address issues with are sustainable domestic supply.

The government is investing heavily in science & technology for critical minerals. NCMM targets 1000 patents by 2030 in areas like-

- new exploration technologies
- environmentally friendly processing methods
- advanced recycling techniques
- material substitution (example: EV motors without REE magnets)

At least 7 centres of excellence will be set up to lead research. Funding – Rs120 million grant for startups and R&D institutes, and Rs200 million for scientific and technological development, international collaborations (example Japan and Australia) will also help transfer cutting-edge technology

The strategic vision of the NCMM is not just about minerals, but also India's future industrial security. Targets include-

- building a self-reliance supply chain for EVs, batteries, solar panels, semiconductors, and defensive equipment.
- reducing import dependency (India's currency imports over 80% of critical minerals)
- ensuring energy transition goals (net zero by 2070) are not disrupted by mineral shortages

the mission plans domestic mining + overseas sourcing + recycling + innovation into a balanced national strategy

III. CONCLUSION

India is at a pivot point in the global rare-earth and critical-mineral scenario. Its large reserves are a strategic resource, but bringing value from them involves bridging technology, regulatory, and environmental challenges. The nation's almost complete reliance on imports (particularly from China) is perilous; as one commentator observed, India is "underprepared" to confront the looming mineral pinch. The measures launched – from the NCMM's ambitious targets to recycling rewards and global alliances – reflect a definite determination to alter this. If implemented successfully, India can be self-reliant in critical minerals and can dominate the market globally. By implementing strict steps towards ecological concerns, steady investments in technologies and research, and development, we can succeed in our goals. Last but not least, it is the procurement of the rare earth and other strategic minerals that will decide India's destiny for clean energy, defence, and high-tech industry. If India coordinates its policy, industry, and scientific effort, it can make its own "new oil" – strategic minerals – fuel long-term and sustainable growth.

REFERENCES

[1] Ahmed, Z. K., & Mehta, B. (2023) This study emphasizes the influence of web-based customer feedback upon consumer decision-making in the home furnishings sector. It emphasizes the growing potency of digital feedback mechanisms within the process of shaping purchase decisions. In import/export business, analysis of crossborder customer feedback via sentiment analysis using AI can provide rich insights into cross-border consumer preferences. Such data can allow exporters to modify product features, prices, and channels of distribution in real-time and thereby contribute to competitiveness in foreign markets.

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[3] Chaplot, D., Ranawat, P., Yadav, A., & Soni, K. (2023). Customer relationship management (CRM) in the era of data analytics research includes the development of CRM with data analytics as a method of showcasing how businesses utilize data in order to establish better connections with customers. Extending this to global trade, AI-driven CRM can help import-export businesses manage cross-border client relationships, track cultural buying habits, and predict future customer demands. By integrating AI with CRM, businesses will be able to achieve loyalty and international market penetration, which is well-suited for globalized digital trade practices.

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[8] Rare earths trade dispute, Wikipedia (wiki entry on the WTO case; accessed 2025).

[9] Press Information Bureau, Govt. of India, “National Critical Minerals Mission (NCMM)” (Press Note, Jan. 2025).

[10] Sachdeva, Michael, S. and Golchha, A., “Building critical mineral stockpiles: A key priority for India”, IEEFA (June 2025).

[11] “The New Oil: Critical And Rare Earth Minerals, Their Emerging Geopolitics And India’s Strategic Crossroads”, IMPRI Report (2024).

[12]] Zadeh, J., “India’s Path to Critical Minerals Self-Sufficiency: Strategies and Challenges”, DiscoveryAlert (Aug 21, 2025).

[13] Exim Bank India, “India’s Hunt for Critical Minerals”, Working Paper (2024).

[14] Ives, M., “Boom in Mining Rare Earths Poses Mounting Toxic Risks”, Yale Environment 360 (Jan. 28, 2013).
[15] Harvard International Review, “Not So ‘Green’ Technology: The Complicated Legacy of Rare Earth Mining” (Aug. 12, 2021).
[16] Ritchie, H. & Rosado, P., “Which countries have the critical minerals needed for the energy transition?”, OurWorldInData (2024).Nexdigm Research, “India Rare Earth Elements Market Report” (2024).