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Resources without Downstream Conversion: Explaining India's Rare Earth Paradox through Value-Chain Sequencing

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Abstract
India reports approximately 6.9 million tonnes of rare earth reserves and 2,900 tonnes of mine production in both 2023 and 2024, against world production of 390,000 tonnes (Survey, 2025, p. 149), a share of about 0.74 per cent. Existing scholarship explains the gap between Indian endowment and output through infrastructural, technological and institutional constraints, but appears not to establish at which stage of the chain the constraint binds. This
paper argues that India's rare earth deficit may be understood as a conversion deficit rather than an endowment deficit. It develops the Rare Earth Value-Chain Position Index (REVPI), a five-stage framework covering reserve
conversion, mining and extraction, separation and refining, metal and alloy production, and permanent magnet manufacturing. Each stage carries three indicators scored from zero to three, with the stage score set by its weakest indicator and a theoretical aggregate range of zero to 15. REVPI is proposed, not validated: no scores are assigned, because comparable cross-stage capacity data are not publicly auditable. Three documentary findings appear to follow: reserves and production are decoupled; the deterrents to conversion are economic and institutional rather than geological; and post-2022 India–United States engagement produced institutional access without documented conversion capability.

Keywords: rare earth elements; critical minerals; value-chain sequencing; downstream processing; industrial capability; resource endowment; economic statecraft; supply-chain resilience; India–United States relations; strategic minerals policy

1. Introduction

Rare earths may matter strategically less because they are geologically scarce than because the capability to separate them is concentrated. As of 2023, China processed roughly 85 per cent of all rare earth elements and nearly 99 per cent of heavy rare earth separation (Woods, 2025, p. 3); recycling covers less than one per cent of rare earths globally (Torta et al., 2024, p. 574). The October 2024 Rare Earth Regulation consolidated state control across mining, refining, smelting, distribution and export, adding quantitative controls and mandatory traceability; in April 2025, the Export Control Law was invoked against seven heavy rare earths, including dysprosium and terbium, and European spot prices for both

nearly tripled (Woods, 2025).

India's position appears puzzling. The U.S. Geological Survey reports Indian reserves of 6,900,000 tonnes and mine production of 2,900 tonnes in 2023 and 2,900 tonnes in 2024, against world production of 390,000 tonnes, a share of 0.74 per cent (Survey, 2025). Indian ore does not appear marginal: monazite beach sands in Odisha grade 56.75 per cent rare earth elements by weight, with ThO_2 at 10.18 weight per cent and UO_2 at 0.26 per cent (Ganguli & Cook, 2018, p. 6). Yet India depends almost entirely on imports for its rare earths (Zamariolli, 2021, p. 151), and meets its magnet requirement through processing in Japan, adding cost and delay (Chaturvedi et al., 2024).

Two readings are available: a resource problem, answered by exploration, or an industrial problem, answered by asking which stage fails; this paper adopts the second. RQ1 asks at which stage of the value chain India's principal weakness occurs, and how it relates to endowment. RQ2 asks what economic and institutional mechanisms explain the gap between endowment and downstream capability. RQ3 asks to what extent post-2022 engagement with the United States has altered institutional access, supply-chain cooperation, and documented conversion capability.

The contribution is threefold: treating value-chain position as an independent variable in economic statecraft rather than a description of network location; specifying a documentary instrument that confronts composite construction's contested steps of weighting, aggregation, and robustness (Greco et al., 2018); and suggesting that

institutional access and industrial capability may diverge within one bilateral relationship. The design is documentary and theory-testing: no interviews, surveys, or statistical modelling.

2. Literature Review and Theoretical Framework

Measurement of resource wealth appears to have moved from single ratios to multidimensional scoring (Lebdioui, 2021, p. 105638). The Multidimensional Indicator of Extractives-based Development weights six indicators on a zero-to-one scale, with the indicators chosen to reflect successive steps of the revenue-management policy chain that converts extracted commodities into developmental assets, and presents them as radar charts to avoid synthesis into a single number (Lebdioui, 2021, p. 9). Aggregation may thus be understood as an analytical, rather than a presentational, decision; because REVPI aggregates, it may need to justify its weighting and report sensitivity, where composite-index criticism concentrates (Greco et al., 2018).

A second strand treats resilience as dependent not only on physical disruption but on dynamic societal and geopolitical factors, including environmental regulation, speculative markets, and export bans (Mancheri et al., 2018).Since 1990, over the course of 261 cases, the main impetus for resource-nationalist intervention seems to be the increase in mineral prices, although ideology, institutional quality, social climate and economic dependence have non-trivial roles. Recurring interventions include banning foreign capital from local smelting and processing, and prohibiting raw ore exports (Xu et al., 2024). Studies of export restrictions for downstream processing have likewise found little or no evidence of success for these coercive measures—and highlight the need for appropriate industrial policies to address bottlenecks (Östensson, 2019, p. 205). The 2024 Chinese regulation may add an informational layer by providing the state with internal visibility while limiting transparency for foreign markets (Woods, 2025). What this literature appears to under-specify is the response capacity of exposed states: one that cannot separate ore faces a different menu from one that cannot mine it, because separation capacity cannot be substituted in the short run by new deposits. India-specific scholarship is largely

diagnostic: extraction is energy-intensive and produces radioactive and hazardous by-products (Patil et al., 2022, p. 56); India has limited
downstream processing infrastructure and technological capacity (Singh & Srivastava, 2025); and China processes nearly 99 per cent of heavy rare earth separation (Woods, 2025, p. 3). Only a small share of India's land has been assessed through geochemical and geophysical surveys (Chaturvedi et al., 2024, p. 112522), and programme-level
accounts document the sector's institutional history (Kain et al., 2022). The gap is specific: existing work appears to explain availability, processing
concentration and industrial constraint, but appears to offer no stage-specific framework for where resource-to-industry conversion is constrained, and appears unable to separate upstream from downstream causation.

Three propositions follow. P1: where reserve endowment is high but production share low, the binding constraint may lie downstream of extraction. P2: the pattern may be better explained by the economics and institutional organisation of downstream processing than by resource volume alone. P3: partnership with a chokepoint-averse power may produce institutional access and opportunities for source diversification without necessarily producing documented domestic conversion capability.

3. Research Design and Methods: The REVPI Framework

The study is documentary and theory-testing, combining a stage-wise assessment with a chronology of bilateral instruments and treating China's documented integrated chain (Woods, 2025) as an external benchmark, not a scored comparator. No index scores are assigned because cross-stage indicators of comparable quality do not appear to be publicly auditable for India; REVPI is applied descriptively.

Five stages are defined: reserve conversion, turning geological inventory into a currently classified, auditable reserve base; mining and extraction, the recovery of concentrate; separation and refining, the production of individual oxides at commercial specification; metal and alloy production, the conversion of oxides into metals and magnet alloys; and permanent magnet manufacturing, finished magnets including alloy-to-magnet integration.

Figure 1. India's Rare Earth Value Chain: Five-Stage Analytical Framework

Each stage carries three indicators, each scored on a four-level scale where 0 denotes absence, 1 denotes pilot, laboratory, or externally dependent activity, 2 denotes partial domestic capability, and 3 denotes commercial domestic capability at specification. The stage score is the minimum of its three indicator scores, under weakest-link logic: a stage cannot be rated above its own binding constraint, since separating one element at specification while importing the rest is not a functioning separation stage, and average scores would conceal the asymmetry the framework exists to detect. The aggregate is the unweighted sum of the five stage scores, with a range of 0–15; equal weights are a transparency decision, not an empirical finding. A stage is scored only where two independent published sources support each indicator; otherwise it is recorded as unscored with the reasonstated, and aggregates are reported as partial sums. Conflicting sources take the lower value. Future scoring should report rank stability across equal, principal-component and expert-elicited weights following the ten-step sequence in Organisation for Economic Co-operation and Development (OECD) and Joint Research Centre (JRC) guidance (OECD & Union, 2008; Roszkowska & Filipowicz-Chomko, 2020, p. 300); no such validation has been performed here. Data come from the U.S. Geological Survey (Survey, 2025), the geological literature (Ganguli & Cook, 2018), the policy record (Kain et al., 2022), and official and institutional

sources (Akhtar & Kronstadt, 2025; Barlock et al., 2024; Victor, 2023). The design cannot establish causal direction between institutional arrangements and output, and bilateral coverage ends in March 2024.

4. Outcome

4.1 P1 appears supported: reserves and production are decoupled. India's share of world mine production is 0.74 per cent (Survey, 2025), while Odisha monazite grades 56.75 per cent rare earth elements by weight (Ganguli &Cook, 2018). Thorium may be part of the explanation rather than a footnote: monazite can contain 0–12 per cent thorium by weight, rendering tailings potentially radioactive (Ganguli & Cook, 2018, p. 6)

4.2 P2 supported: conversion appears to be deterred by economics and institutions. Separation appears to be capital-intensive, energy-intensive, and productive of toxic by-products (Babu et al., 2024, p. 356). Monazite is a prescribed substance containing uranium and thorium for the atomic energy programme, and Indian Rare Earths was mandated to extract those elements for the Department of Atomic Energy and supply rare earths in liberated and marketable form (Kain et al., 2022). Rare earths were accordingly kept in the open category, free from a licence regime or restriction (Kain et al., 2022): the restraint therefore appears to have been economic rather than a licensing prohibition. The same account explains non-entry: low profits, consumption confined to selective global pockets, no domestic market, long gestation, non-availability of industry-scalable technology, and lack of instant returns (Kain et al., 2022). Export dependence appears to have followed: because the domestic market had been limited since inception, mixed rare earth chloride went to Japan and later to the United States, Europe, and Brazil; cracking halted in 2004 and resumed at OSCOM as a deemed export to a Japanese-owned subsidiary in a special economic zone (Kain et al., 2022, p. 305). Even Nd–Pr oxide exports to Japan and Vietnam go abroad for fine-tuning to magnet grade (Kain et al., 2022), and the magnet requirement is met through Japanese processing at extra cost and delay (Chaturvedi et al., 2024).

Figure 2. India's Rare Earth Paradox: From Resource Endowment to Industrial Capability (documented capability versus evidence gap; no numerical values assigned)

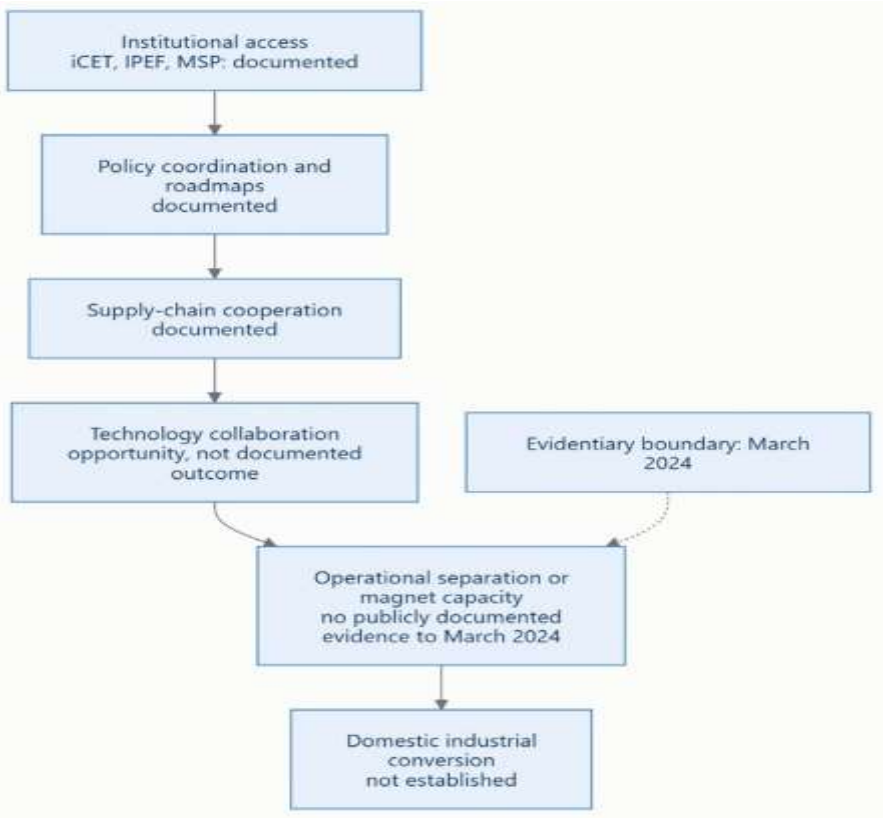


4.3 Product-level disaggregation. Full import dependence is documented at the level of rare earth elements as a category, alongside the 94 per cent Chinese share of global heavy rare earth supply (Chaturvedi et al., 2024), whereas at the product level India appears to produce and export light rare earth intermediates while importing heavy rare earths, metals, alloys, and finished magnets (Goyal et al., 2026; Kain et al., 2022, p. 300). India appears to export the low-value end of its own chain and to import the high-value end.

4.4 A measurement caveat. Reported figures are not commensurable and should not be reconciled arithmetically:11.93 million tonnes of monazite reserves (Ganguli & Cook, 2018) and 6.9 million tonnes of rare earth reserves (Survey, 2025) describe different quantities under different conventions, and rare earth element grade is not interchangeable with oxide grade (Ganguli & Cook, 2018, p. 9), so a regional grade applied nationally would not establish contained oxide reserves. REVPI therefore scores reserve conversion on inventory currency and classification basis rather than tonnage. 4.5 P3

supported in qualified form. Critical minerals were embedded in the Initiative on Critical and Emerging Technologies (iCET) at its launch (Akhtar & Kronstadt, 2025), and India is a partner in the Indo-Pacific Economic Framework (IPEF), with the IPEF Supply Chain Agreement entering into force on 24 February 2024 (Barlock et al., 2024). Minerals Security Partnership (MSP) membership shifted: the June 2022 founding coalition excluded India (Victor, 2023), whereas a March 2024 departmental mapping lists India alongside both the MSP and IPEF (Barlock et al., 2024). Institutional access therefore appears to have improved between 2022 and 2024. Across the sources examined to March 2024, no publicly documented new operational separation, refining, or magnet-manufacturing capacity was identified, and the documented magnet route remained offshore (Chaturvedi et al., 2024). This qualification pertains to the examined public record, not to the existence of such activity.

Figure 3. India–US Critical Minerals Cooperation: Institutional Access and Domestic Conversion



5. Discussion

Three implications follow. First, sequencing may warrant inclusion among the variables of economic statecraft: network position may not, by itself, explain why a resource-rich state remains exposed, and endowment without separation may function as a cost rather than leverage. Second, India may extend rather than illustrate the resource-nationalism literature. That literature models intervention as a response to price and rent (Xu et al., 2024) and evaluates downstream promotion by its place within a coherent industrial policy (Östensson, 2019); India's constraint may be understood as the inverse, with no rent to capture, no export ban to defend, and a conversion industry that may not have formed because returns were slow and technology was not scalable domestically (Kain et al., 2022). The relevant state failure appears to be promotional, not extractive. Third, partnerships may reproduce asymmetry, since

cooperation at refining may be most difficult where partners' own firms are weakest. Methodologically, REVPI's contribution may be understood as a discipline rather than a score: it requires the analyst to state, stage by stage, what would count as evidence.

5.1 Policy implications. Six proposals are advanced; they should be read as recommendations rather than existing commitments. First, publish an auditable reserve and resource inventory separating resources from reserves, reporting grades by deposit, and stating its conversion basis. Second, direct industrial policy to the stages that bind rather than to extraction alone (Östensson, 2019, p. 205). Third, create domestic demand linkages, as non-entry is attributed to a dearth of demand and selective consumption worldwide (Kain et al., 2022); begin with assessing by demand and in-use and in-year. Fourth, embed capability conditions for processing partnerships, whose present Nd–Pr oxide exports may be insufficient toward magnet mineral-quality standards (Kain et al., 2022), and negotiate local localization milestones with minimum qualifying domestic magnet-grade material. Fifth, realign bilateral cooperation from forums to projects with tangible outputs (joint feasibility studies, pilot plants, supply chain mapping), as, while access appears to have been increasing, capability proof points may not have tracked (Chaturvedi et al., 2024, p. 112523; Sahoo, 2026, p.150). Sixth, build the data infrastructure REVPI requires: a defined indicator set, periodic reporting, source transparency, and independent verification, so that weighting and sensitivity testing become possible (Roszkowska & Filipowicz-Chomko, 2020).

6. Conclusion

India's rare earth problem appears to lie not in a shortage of rock but in the absence of commercially viable conversion between ore and magnet, driven by separation economics, a sector organised around monazite processing for its radioactive content, and a domestic market insufficiently large to sustain downstream entry (Kain et al., 2022, p. 305). The sequencing approach appears to locate the constraint where aggregate ratios may conceal it, and REVPI sets out what evidence could demonstrate a position at each stage; its significance is procedural and its validation outstanding, since no scores are assigned here. On India–United States cooperation, the findings are qualified: institutional access appears to have improved between 2022 and 2024, and no publicly documented conversion capability attributable to those instruments was identified within that window. Populating REVPI across a panel of resource-rich democracies, with reported weights and explicit treatment of missing data, could operationalize the framework as a measurement instrument. The conclusion could then establish reproducibility as a criterion, since a published weighting scheme would allow other analysts to contest the scores rather than merely accept or reject the framework as a whole.

Such a scheme would also enable readers to identify which judgments
drive the result, so that disagreement can be located at specific stages rather than dismissed in aggregate.

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