Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Critical-Mineral Upgrading Across Project Stages: A Comparative Framework for Industrial Policy

Martin Kiselicki

martin.kiselicki@eccf.ukim.edu.mk

Faculty of Economics - Skopje, Ss. Cyril and Methodius University in Skopje

Nils Haneklaus

Research Lab for Global Futures and Complex Systems, University for Continuing Education Krems

Sasho Josimovski

Faculty of Economics - Skopje, Ss. Cyril and Methodius University in Skopje

Tea Josimovska

Institute of Economics - Skopje, Ss. Cyril and Methodius University in Skopje

Ana Josimovska Nikolov

Institute for Sociological, Political and Juridical Research, Ss. Cyril and Methodius University

Research Article

Keywords: critical minerals, industrial upgrading, lithium, copper, social licence, comparative case study

Posted Date: November 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11340896/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Mineral endowments, strategic designation and prospective processing capacity are often treated as evidence of industrial upgrading. They are not equivalent to realised production or domestic value capture. This article develops the Resource Upgrading Decision Matrix (RUDM) from a country diagnostic into a comparative, stage-gated typology of implementation constraints. A structured comparison of Serbia's Jadar lithium-borates project, Bolivia's Salar de Uyuni lithium industry and Peru's Las Bambas copper mine combines dated legal and corporate records, independent research and the World Bank's 2016–2025 governance series. The cases distinguish proposed capacity from observed output and copper content in concentrate from domestic refining. Jadar shows the gap between strategic recognition and fully permitted production; Uyuni foregrounds technology validation, contracting and the scale-up of carbonate output; and Las Bambas shows that substantial concentrate production does not establish domestic refined-metal upgrading. The RUDM application identifies a distinct binding gate in each case: authorisation–legitimacy–finance, technical-commercial scale-up, and benefit-and-logistics. The contribution is a set of falsifiable policy-sequencing propositions, not an out-of-sample forecasting model. Before committing to downstream targets, policymakers should establish the condition that blocks the next project transition; once output is established, logistics, local benefits and processing economics require separate appraisal.

JEL classification: L72; O25; Q33; Q56.

1. Introduction

The industrial-policy appeal of critical minerals is readily stated: an economy supplying a sought-after input may seek to retain more value through refining, intermediate chemicals, equipment, manufacturing and domestic suppliers. Yet each link requires different capabilities and rests on a prior physical or institutional condition. A mineral occurrence is not an economic reserve; a spatial plan is not a mining permit; a battery-material plant's rated capacity is not its achieved output; copper in concentrate is not refined copper; and an agreement to develop a battery value chain is not an operating cell factory. Conflating these stages is more than a terminological error. It makes prospective rents appear realised and can direct policy at downstream processing when the binding obstacle is still upstream authorisation, production reliability, water governance, transport or the distribution of local impacts.

RUDM was introduced in a prior country-level mineral value-chain study (Author, 2026). The framework assesses four domains: economic feasibility, strategic importance, governance complexity, and sustainability and social licence. Together, they extend analysis beyond a narrow comparison of concentrate and refined-metal revenue. The original application does not establish whether the same configuration diagnoses divergent projects at different stages, whether similar policy instruments confront the same constraints, or how governments should sequence action when one condition blocks progress. This article addresses that follow-up question rather than replicating the prior case.

The cases represent **different observed stages**, rather than three observations of the same upgrading outcome. Serbia's Jadar project remains unbuilt even though the European Commission designated it strategically important and the Serbian Government restored its spatial plan. Bolivia has produced lithium carbonate, but a large geological resource, a nominal plant capacity and proposed direct lithium extraction (DLE) do not establish competitive scale-up or a domestic battery industry. Peru's Las Bambas supplies copper contained in concentrate at commercial scale; MMG reported 410,834 tonnes in 2025 (MMG, 2026b). This is neither physical concentrate mass nor domestically refined copper. The relevant upgrading question therefore concerns the steps after reliable extraction, rather than mine development alone.

Existing *Mineral Economics* studies sharpen this distinction. Östensson (2019) explains why resource endowment does not guarantee efficient downstream processing and cautions against poorly assessed export restrictions. Maiza-Larrarte and Claudio-Quiroga (2025) provide a detailed socio-economic assessment of Las Bambas in Apurímac, and Vivoda and Loginova (2025) analyse Jadar's security–cost–sustainability trilemma. The present contribution is an explicit cross-case mechanism that connects the RUDM domains to **stage-specific constraints and reversible policy choices**, with clear conditions under which the case classifications would change.

2. Literature and analytical framework

2.1 Upgrading is a sequence, not a synonym for extraction

Global-value-chain analysis distinguishes participation in production networks from changes in the tasks, knowledge and value retained by local firms. The ability to codify transactions, the complexity of the tasks and supplier capabilities influence chain governance (Gereffi et al., 2005). Access to a chain may create learning opportunities, but those opportunities depend on a domestic innovation system and the relationships through which firms can acquire capabilities (Pietrobelli & Rabellotti, 2011). A mineral shipment may finance infrastructure and public services while leaving chemical conversion, smelting or component production elsewhere. Conversely, imposing a local smelter can destroy value if power, scale, inputs, skills or logistics are inadequate. Östensson (2019) argues for evaluating these bottlenecks rather than assuming that coercive processing requirements make upgrading happen.

The analysis distinguishes five analytically separable stages: **resource identification** (a prospect or measured resource); **authorisation and finance** (completed project-specific approvals and investment decisions); **reliable commercial extraction** (observed mine output and route to market); **domestic transformation** (verified, competitive conversion or refining onshore); and **broader linkages** (documented supplier learning or manufacturing). These are not universal development rankings: domestic service capabilities can be valuable before smelting, and a small chemical pilot can exist without a large mine. The distinction prevents evidence about one stage from being mistaken for evidence about another. Policy success must be specified at the stage actually measured.

2.2 Strategic interest, institutions and contested development

Strategic status reflects the prospective relevance of supply to a wider market. It does not remove a domestic project's exposure to permitting, environmental obligations or local distributional conflict. The ability of states and firms to negotiate and implement agreements matters, but no single national index can substitute for observations of a local environmental procedure. The World Bank's Worldwide Governance Indicators (WGI) aggregate surveys and expert assessments, have measurement uncertainty, and are expressly intended as broad research indicators rather than definitive rankings (World Bank, 2026a, 2026b). The analysis uses the 2026 release's fixed-reference 0–100 *scores*, not percentile ranks, and retains its published 90% confidence intervals. Even an unambiguous national difference cannot establish a project's social licence or the legal validity of a particular permit.

Company–community conflict can translate perceived environmental and social risk into project costs, delays and institutional change. Franks et al. (2014) document this mechanism with case evidence and practitioner interviews rather than a universal numerical rule. Moffat and Zhang (2014) find that trust and engagement matter for acceptance in an Australian mining setting; transferring a numeric threshold from that setting to Serbia, Bolivia or Peru would be unjustified. In the cases here, objections must be described by the specific affected parties, procedure and disputed impact. Conversely, a company assurance is evidence that a company made an assertion, not proof of approved or safe performance.

2.3 An extension of the RUDM with explicit gates

The four RUDM domains are **ex ante questions**, not interchangeable points on a single risk scale. *Economic feasibility* asks what output and process can actually be financed and operated at a specified date and market price. *Strategic importance* asks which product and market might benefit and who captures that value. *Governance complexity* asks who can authorise, negotiate, monitor and enforce a viable arrangement. *Sustainability and social licence* asks which environmental and distributive impacts are examined with affected parties and whether procedures and outcomes remain contestable. The same governance fact may bear on more than one domain; it should not be double-counted as a spurious precise score.

The extension is **conditional sequencing**. Where resource potential and strategic interest are high but environmental review and consent are unresolved, the first intervention should not be construction or a downstream plant. Where chemistry and finance remain unproved at commercial scale, pilot operation and independent audit precede claims of industrial transformation. Where a mine already produces concentrate, the economics of domestic processing require separate testing alongside the production corridor, fiscal distribution and local supplier base. These propositions are conditional hypotheses. An authorised Jadar project with sustained local agreement, a competitive Uyuni process with verified capability transfer, or locally accepted Las Bambas exports with extensive independently measured linkages would revise the case classifications.

3. Research design, sources and comparability

3.1 Questions and selection

Three research questions guide the comparison. **RQ1**: At what observable stage does each project or production system stand, and which RUDM domain is the immediate constraint on its next stage? **RQ2**: How do strategic designation, technical scale-up and operating output interact with governance and community-facing institutions across the cases? **RQ3**: Which policy actions are appropriate at each stage, and what observation would falsify each proposed pathway?

The study uses a structured, focused comparison of three **purposively selected** mineral systems. They vary in mineral and process chemistry, ownership arrangements, geography and realised output. The design develops mechanisms; it is neither a representative sample nor a controlled most-different-systems test. Two cases are lithium developments and one is an operating copper mine, while selection on visible industrial-policy debate may exaggerate the generality of conflict-related findings. The unit of analysis is the named **project or production system at a stated date**, not a country's entire mining industry. “Bolivia” denotes Uyuni/YLB-related lithium initiatives; “Peru” denotes Las Bambas and its logistics corridor. Country-level WGI observations are contextual covariates; company disclosures and government documents determine whether a mine is physically producing or a procedure has occurred.

3.2 Evidence hierarchy and outcome definitions

The time window combines the 2016–2025 WGI revised series and a dated review of project records available by **4 October 2026**. The review prioritises official law, court and ministry records for legal milestones; company annual reporting for measured output and stated capital plans; and independent peer-reviewed and civil-society studies for critiques and counterclaims. It distinguishes **resource** from economically demonstrated **reserve**, **planned annual capacity** from **observed annual production**, *copper metal content in concentrate* from total concentrate mass, and *commissioning* from commercial scale. Proposed impacts are attributed to their sponsor. Online Resource 1 provides the claim-level evidence protocol, coding rules, source dates, uncertainty notes and counterevidence for the three cases.

The analysis does **not** apply ordinal 1–5 RUDM scores because no pre-specified thresholds, raw-indicator dataset, uncertainty treatment or independent coding protocol supports their use. Averaging such scores would create an unsupported impression of measurement. Instead, Table 1 operationalises a dated, evidence-based assessment; a status of “not demonstrated” is not zero, and evidence of a procedural step is not evidence of completion of later steps.

Table 1
Observable evidence required for each RUDM domain

Domain	Positive evidence	Insufficient on its own	Remaining uncertainty
Economic feasibility	Achieved output, costs, finance, dated price	Resource, rated capacity, old forecast	Recovery, power, water, capital cost
Strategic importance	Official designation; product-specific buyer and local share	Mineral label or memorandum	Designation scope; where value accrues
Governance complexity	Exact permit/contract; monitor and implementer	Spatial plan or contract signature	Approval, enforcement, procurement
Sustainability/social licence	Complete review, baseline, participation and follow-up	Sponsor assurance or national WGI score	Cumulative effects; affected communities

The analysis uses *within-case chronologies* and cross-case pattern matching. It does not identify causal effects in the econometric sense. Alternative explanations include commodity prices and cost of capital, processing technology, national elections, foreign demand, mineral grade and transport geography. Figure 3 specifies the analytical decision rule; the remaining empirical figures provide **descriptive context**, not a quantitative estimate of how governance caused production. The reported WGI values retain the publication's 90% uncertainty intervals, and project-level production figures are traced to dated primary records. Because no harmonised Jadar–Uyuni–Las Bambas event dataset is available, the study does not estimate protest frequency or a causal conflict effect.

Online Resource 1, Fig. S1 reports the corresponding regulatory-quality and control-of-corruption series.

3.3 Transparency statement on generative AI assistance

Generative AI tools assisted with drafting, language revision and code development. They were not used to generate or alter empirical data, estimate unreported values or create synthetic figures. The authors are responsible for checking all sources, citations, data, analyses and final text, and for the integrity of the manuscript.

4. Results: RUDM as a non-compensatory stage-gate model

4.1 Decision rule: from four domains to an observable binding gate

The comparative result is produced in two steps. First, each system is classified by the **product stage actually observed** at the evidence cut-off: **P0** denotes no verified commercial product from the named system; **P1** denotes verified output without demonstrated sustained design-level or commercially viable

scale; and **P2** denotes established operating production at scale. A second designation distinguishes **D0**, no verified domestic transformation beyond extraction or concentration, from **D1**, verified domestic chemical or metallurgical transformation. These are factual classifications of product and process status, not rankings of national development.

Second, the four RUDM domains are tested against the **next transition actually under consideration**. For each domain, the evidence status is recorded as **established**, **partial/conditional**, or **not demonstrated**. *Established* means that the evidence required for the specific next transition is available at the stated date. *Partial/conditional* means that relevant evidence exists but a material condition remains unresolved. *Not demonstrated* means that the required evidence is absent, incomplete, or cannot be verified from the accessible record. A resource estimate, strategic designation, memorandum, spatial plan, signed contract, or nameplate capacity may be relevant evidence, but none automatically establishes a later-stage condition.

This is a **non-compensatory rule**. Strategic importance identifies why a project may merit public attention; it does not offset absent finance, uncompleted authorisation, unproven process performance or unresolved environmental and distributive evidence. A project is not ready for its next upgrading commitment until the conditions relevant to that transition are established. The **binding gate** is the earliest unresolved condition or, where the record shows interdependence, the jointly unresolved bundle of conditions that prevents a credible next-stage decision. The rule does not assume that one RUDM domain is universally dominant, and it does not infer a causal effect from a status classification.

4.2 First result: the cases occupy different observed product stages

Table 2 *reports the observed production and transformation outcomes. The comparison does not show three countries with a common "value-chain gap." It shows three systems at different points in a sequence: Jadar has not produced a verified commercial product; Uyuni has produced lithium carbonate but has not demonstrated sustained design-level operation; and Las Bambas has demonstrated high-volume copper-concentrate production without verified project-level refining. This distinction is the empirical starting point for the RUDM application.*

Table 2
Observed production and domestic-transformation stage at the October 2026 cut-off

System	Observed production class	Transformation class	Decisive dated evidence	Immediate next transition
Jadar, Serbia	**P0** — no verified commercial product	**D0** — no verified domestic mineral transformation	2021 sponsor plan for 58,000 t/y battery-grade lithium carbonate was conditional; 2025 EU strategic extraction designation; Rio Tinto reported care and maintenance in 2026; no output	P0 → P1: authorise, finance, construct and produce under credible safeguards
Uyuni/YLB, Bolivia	**P1** — verified lithium-carbonate output, but sustained design-level operation not demonstrated	**D1 at limited scale** — verified carbonate production	2,462 t Li_2CO_3 produced in 2025 versus YLB's 3,500 t plan and the plant's 15,000 t/y nameplate	P1 → sustained scale: demonstrate repeatable technical-commercial operation
Las Bambas, Peru	**P2** — established mine and concentrator production	**D0 for project-level refining** — no verified refined-copper output from the project	410,834 t copper metal contained in concentrate in 2025; no documented project refinery	P2/D0 → D1 and broader linkages: determine whether domestic transformation is viable and socially supported

Notes: P0 = no verified commercial product; P1 = verified product without demonstrated sustained design-level or commercially viable scale; P2 = established production at scale; D0 = no verified transformation beyond extraction/concentration; D1 = verified domestic chemical or metallurgical transformation. Sources: Rio Tinto (2021, 2026); European Commission (2025); Ministry of Hydrocarbons and Energies (2023); YLB (2026a); MMG (2026b). No direct cross-mineral tonnage comparison is implied.

The classification establishes the first substantive finding. Jadar's strategic relevance does not change P0 status. Uyuni's large lithium resource and prospective DLE agreements do not change the P1 classification of the currently observed carbonate operation. Las Bambas' high P2 output does not change its D0 status for project-level copper refining. The policy question is therefore different in each case: whether to advance a proposed project, how to establish scalable chemical production, or whether and how to extend an operating concentrate-export chain.

4.3 Second result: strategic relevance is not a substitute for a stage-relevant RUDM condition

Table 3 *applies the four RUDM domains to the next transition identified in* Table 2. *The coding does not collapse evidence into a composite score. It records the condition of each domain and identifies the specific unresolved evidence that prevents progression. Where more than one condition is unresolved, the result is a joint gate rather than a spurious single-cause attribution.*

Table 3
Cross-case RUDM evidence matrix and binding-gate result

System and transition	Economic feasibility	Strategic importance	Governance complexity	Sustainability and social licence	Binding-gate result
Jadar: P0 → P1	**Not demonstrated**: no final investment decision, construction or output	**Established**: EU strategic extraction designation; no manufacturing evidence	**Not demonstrated**: plan and EIA scoping, not final authorisation	**Not demonstrated**: no integrated assessment and trusted implementation process	**Joint authorisation–legitimacy–finance gate**
Uyuni: P1 → sustained scale	**Partial**: output exists; audited recovery, cost, uptime and quality are not established	**Established**: strategic resource and state priority; no realised value-capture proof	**Partial**: DLE arrangements conditional; terms and performance not fully public	**Not demonstrated**: basin-specific water, waste and affected-party monitoring incomplete	**Technical-commercial scale-up gate with accountability conditions**
Las Bambas: P2/D0 → D1 and broader linkages	**P2 established; D1 not demonstrated**: no refinery economics, energy, emissions or finance case	**Established**: major copper supply; no domestic value-capture proof	**Partial**: corridor and benefit-accountability evidence remains material	**Partial**: unresolved grievances and route-level conditions	**Benefit-and-logistics gate; then separate refining appraisal**

Notes: Status applies only to the stated next transition. "Not demonstrated" means that the evidence required for a credible next-stage decision is not established in the accessible record; it does not mean that the underlying activity is impossible or has zero value. Sources: Government of Serbia (2022); Constitutional Court of Serbia (2024); Ministry of Environmental Protection of Serbia (2024); Rio Tinto (2021, 2024, 2026); European Commission (2024, 2025); YLB (2024, 2025, 2026a, 2026b, 2026c); Chamber of Deputies of Bolivia (2025a, 2025b, 2026); Ministry of Hydrocarbons and Energies (2023); MMG (2022a, 2023b, 2025a, 2026a, 2026b, 2026c); Defensoría del Pueblo (2022, 2026); MEF (n.d.).

The matrix produces the paper's second finding: **all three systems possess strategic relevance, but strategic relevance does not remove their binding gate.** Jadar cannot move from P0 to P1 merely because it has EU recognition. Uyuni cannot move from P1 to reliable scale merely because it has a large resource and planned DLE capacity. Las Bambas cannot be classified as domestically upgraded merely because it produces large volumes of copper in concentrate. In each case, the relevant constraint is identified by the missing stage-specific evidence rather than by the project's mineral label or national governance rank.

National WGI observations contextualise, but do not generate, this result. In the 2025 fixed-reference series, regulatory-quality scores are approximately 56.5 for Serbia, 34.5 for Bolivia and 57.6 for Peru; government-effectiveness scores are approximately 53.0, 39.7 and 49.4; and control-of-corruption scores

are approximately 35.9, 24.1 and 32.8, with published 90% confidence intervals (World Bank, 2026a). These values may inform the national setting, but neither the confidence intervals nor the absolute scores establish a project permit, a brine recovery rate, a corridor agreement or local consent. Removing WGI from the matrix would not alter any P0/P1/P2 or D0/D1 classification.

4.4 Case evidence underpinning the three binding gates

4.4.1 Jadar: a joint authorisation–legitimacy–finance gate

Jadar has prospective economic significance, but the conditions needed to cross from P0 to P1 remain unestablished. The proposed integrated lithium-borates project is geographically relevant to the European automotive market. In July 2021, Rio Tinto announced a US$2.4 billion funding commitment, explicitly conditional on approvals, and projected approximately 58,000 t/y of battery-grade lithium carbonate after ramp-up, alongside boric acid and sodium sulphate (Rio Tinto, 2021). These figures are sponsor assumptions, not observed output, a final investment decision or a current independently confirmed capital requirement.

The legal record establishes process activity but not a completed mine authorisation. The Serbian Government annulled the regulation underpinning the special-purpose spatial plan in January 2022 amid environmental protest; the Constitutional Court declared the termination regulation unlawful and unconstitutional in July 2024; and the spatial plan was subsequently restored (Government of Serbia, 2022; Constitutional Court of Serbia, 2024). These acts do not themselves establish environmental, construction, exploitation or operating permission. The Ministry of Environmental Protection's November 2024 decision set the scope and content of an EIA study for the underground-mine component, rather than approving a completed integrated assessment (Ministry of Environmental Protection of Serbia, 2024). Rio Tinto's own 2021 release identified exploitation licensing and EIA approval as future conditions.

The sustainability and social-licence domain is also unresolved for the next transition. Rio Tinto stated that draft impact studies had been released and that safe implementation could be possible (Rio Tinto, 2024). A RERI legal opinion criticised the segmentation of assessment across the mine, processing, waste, transport and water elements (RERI, 2024). Survey and mobilisation research documents concerns about environmental impacts, livelihoods, landscape, participation and changing project plans (Ivanović et al., 2023; Stuehlen & Anderl, 2024). These sources do not establish a numerical social-licence score or a universal local view; they establish that a comprehensive and trusted public process remains necessary. The EU's 2025 strategic-project designation confirms strategic relevance, not Serbian authorisation, consent, or domestic value added (European Commission, 2025; European Union, 2024).

The current corporate status reinforces the P0 classification. Rio Tinto reported in October 2026 that it was transitioning Jadar to care and maintenance, citing capital discipline and prioritisation of nearer-term projects (Rio Tinto, 2026). This status neither resolves the project's contested environmental and procedural questions nor proves that they alone caused the pause. It means, however, that a downstream

battery or chemical-policy commitment has no established upstream operating base. Jadar's binding gate is consequently a jointly unresolved authorisation–legitimacy–finance bundle. The classification would change if an integrated assessment, legally complete approvals, credible affected-party arrangements, renewed finance, construction and verified product output became observable.

4.4.2 Uyuni: a technical-commercial scale-up gate with governance and environmental conditions

Uyuni demonstrates why observed output must be separated from industrial ambition. USGS reports 23 million tonnes of measured and indicated lithium resources for Bolivia, expressed as elemental lithium, while YLB reports 21 million tonnes of certified Uyuni resources (USGS, 2026; YLB, 2026c). The estimates differ in geographical and classification scope. Neither is an economic reserve, a recovery estimate, an annual carbonate output, or evidence of competitive processing. Large resource estimates and national strategic priority support the strategic domain, but they do not satisfy the economic conditions for P1-to-scale transition.

The production record establishes P1 and limited D1, not sustained design-level operation. YLB reported 948.48 tonnes of technical-grade lithium carbonate from a pilot plant in 2023. The Llipi industrial plant was inaugurated in December 2023, with a reported 15,000 t/y nameplate (YLB, 2024; Ministry of Hydrocarbons and Energies, 2023). Reported production was 2,064.46 tonnes in 2024 and 2,462 tonnes in 2025, compared with YLB's own 2025 production plan of 3,500 tonnes (YLB, 2025, 2026a). YLB attributes the shortfall to feed concentration, input and fuel availability, and maintenance. Reported 2025 sales exceeded current-year output, so sales cannot be treated as production without a stock explanation. These observations establish a real carbonate operation, but not reliable operation at design capacity or demonstrated commercial viability.

Technical-process evidence explains why production data cannot be replaced by a resource argument. Uyuni brines exhibit spatial variation in lithium, magnesium and sulphate; experimental evaporation work found lithium concentration to rise and then fall as lithium sulphate precipitated under the tested conditions; and process studies identify impurity-removal demands (Ericksen et al., 1978; An et al., 2012; Ogawa et al., 2014). These sources do not prove that any particular DLE process is infeasible. They do establish why representative-brine recovery, reagent demand, water balance, energy use and product specifications must be demonstrated before treating a prospective technology partnership as commercial scale-up.

The proposed DLE arrangements remain conditional rather than observed plants. The Uranium One proposal is associated with 14,000 t/y of battery-grade carbonate, while the CBC arrangement concerns two proposed plants with combined 35,000 t/y capacity (Chamber of Deputies of Bolivia, 2025a, 2025b; YLB, 2025). In its 2026 plan, YLB described execution as conditional on judicial and legislative steps, and the relevant approval bills were archived by the Chamber (Chamber of Deputies of Bolivia, 2026; YLB, 2026b). The accessible record does not verify commercial DLE operation. Law 928 and the constitutional framework establish state direction and consultation principles, but they do not disclose the project-

specific allocation of risk, performance obligation, procurement, benefit or recovery terms (Gaceta Oficial de Bolivia, 2009, 2017).

The binding gate is technical-commercial scale-up coupled to contract and environmental accountability. Before a new DLE or downstream commitment, the relevant evidence includes independently auditable recovery and uptime, representative brine and water balances, product quality, disclosed contracts and approval status, and affected-party monitoring (Vera et al., 2023; Williams & Vengosh, 2025). Sustained, independently verified large-scale output at stated specifications and costs, operative agreements, and credible environmental and benefit arrangements would change the classification.

4.4.3 Las Bambas: a benefit-and-logistics gate before any refining claim

Las Bambas is the P2 contrast case: it demonstrates that reliable extraction and concentration do not by themselves demonstrate domestic refining or broad-based upgrading. MMG reports a sequence of mining, crushing, grinding, flotation and filtration, followed by shipment of concentrate. In 2025 it reported 1,375,890 tonnes of physical concentrate at 29.9% copper grade containing 410,834 tonnes of copper; its annual results separately report 390,580 tonnes of payable copper in products sold (MMG, 2026a, 2026b). Copper metal contained in concentrate is neither physical concentrate mass nor refined cathode. No cited project record establishes a Las Bambas smelter, electrorefinery or cathode facility.

The production record confirms P2. Reported contained copper was 290,097 tonnes in 2021, 254,836 tonnes in 2022, 302,033 tonnes in 2023, 322,912 tonnes in 2024 and 410,834 tonnes in 2025 (MMG, 2022a, 2023a, 2025a, 2026b). This improvement does not establish D1. A refinery would require its own feed, power, water, sulphur/emissions controls, technology, capital, market and consent case. The RUDM economic domain is therefore established for the existing concentrate operation but not for a hypothetical downstream refinery.

The governance and sustainability domains remain partial rather than absent. MMG attributes 52 days of full operational cessation in April–June 2022 to site conflict and reports 173 days of concentrate-transport disruption during the year; the measures describe different exposures and must not be added to claim a 225-day mine closure (MMG, 2023b). The mine restarted after affected communities suspended protests and entered government-led dialogue (MMG, 2022b). The Defensoría independently recorded injuries in a late-April confrontation (Defensoría del Pueblo, 2022). More stable transport and higher output after 2023 do not erase a route-level governance agenda: the March 2026 Defensoría register listed relevant active cases but no events that month, while a distinct August 2026 safety incident temporarily suspended activity and must not be misclassified as a community blockade (Defensoría del Pueblo, 2026; MMG, 2026c, 2026d, 2026e).

The road–rail corridor makes the distributional issue wider than the mine site. Concentrate travels by road to a rail transfer point and then to Matarani; Maiza-Larrarte and Claudio-Quiroga (2025) report approximately 438 km of truck movement before rail transit. MMG describes a bimodal export chain, not

domestic smelting (MMG, 2025a). Mining canon is 50% of income tax received from mining right-holders, distributed territorially; it is not 50% of sales, profits, export revenue, all taxes or a project-specific community-payment figure (MEF, n.d.). The accessible record does not allow a causal project-by-project allocation of benefit to individual corridor communities.

Las Bambas has a benefit-and-logistics gate before any assertion of broader upgrading, followed by a separate D1 feasibility test. The policy sequence begins with route monitoring, enforceable agreements, transparent fiscal-transfer execution, grievance resolution and local-supplier measurement. A domestic smelter or refinery can then be assessed on independent economic and environmental terms. Durable route cooperation and verified benefits, together with a financed, permitted and operating domestic refining facility that demonstrates measurable value added, would change the classification.

4.5 Third result: a binding-gate typology, not three country stories

The non-compensatory application produces a three-part **binding-gate typology**. The typology is not a country ranking and does not claim exhaustive global categories. It identifies the policy error that follows from mistaking one type for another: treating strategic designation as production readiness, prospective capacity as scalable performance, or concentrate exports as domestic transformation.

Table 4
Stage-gated typology derived from the RUDM evidence matrix

Type	Empirical exemplar	RUDM pattern	Immediate policy error to avoid	Appropriate next sequence
Contested pre-production strategic project	Jadar	Strategic relevance established; economic, governance and sustainability conditions for P0 → P1 not established	Mandating downstream manufacturing or assuming strategic designation equals project readiness	Complete integrated authorisation, credible participation and safeguards, updated finance, then assess production and transformation
Under-scaled chemical producer with prospective technology partnerships	Uyuni	Strategic relevance established; P1/D1 exists, but economic, governance and sustainability conditions for sustained scale remain partial or unestablished	Treating resource size, nameplate capacity or proposed DLE capacity as proven industrial performance	Demonstrate recovery, costs, uptime, quality, water/waste performance and accountable contracts before expansion
Producing concentrate exporter with a benefit-and-logistics gate	Las Bambas	P2 extraction established; refinery economics not established; governance and sustainability conditions for route-level benefits remain partial	Assuming mine output proves refined-metal upgrading or automatically justifies a smelter	Secure route and benefit institutions; measure supplier linkages; separately appraise refining economics, emissions and consent

The typology produces the paper's third finding: **the appropriate industrial-policy instrument depends on the stage and binding gate, not on the mineral's strategic label alone.** A government confronting Jadar should not start with downstream targets. A government confronting Uyuni should not equate further contracting with demonstrated chemical scale-up. A government confronting Las Bambas should not interpret high concentrate output as sufficient evidence for a domestic refinery. The RUDM is operational because it identifies what must be established before a later-stage intervention can be credibly evaluated.

5. Discussion: contribution, policy sequencing and boundary conditions

5.1 Contribution: from diagnostic profile to stage-gated decision rule

The paper makes a specific advance over a diagnostic RUDM application: it transforms the framework from a profile of conditions into a **stage-gated decision rule**. The original four domains remain necessary,

but averaging them would obscure the sequence of implementation. A highly strategic project with unresolved authorisation is not equivalent to a high-output mine with contested benefit distribution, even if both appear attractive on a strategic-mineral map.

The non-compensatory rule addresses a limitation of composite scoring. In a conventional composite score, high strategic importance might mathematically offset a low social-licence or governance score. That is misleading when the lower-scoring domain is a prerequisite: strategic designation cannot substitute for a legal permit; a resource estimate cannot substitute for an audited recovery rate; and high copper output cannot substitute for a refinery business case or durable corridor arrangements. RUDM therefore identifies **conditions that must be satisfied sequentially**, rather than averaging favourable and unfavourable features.

The three cases also show why the unit of analysis must be the project or production system rather than a national mineral sector. Serbia may host other minerals and manufacturing capabilities, but Jadar remains P0 at the stated cut-off. Bolivia's national resource endowment does not establish the performance of a particular Uyuni process route. Peru's copper exports do not establish value capture at Las Bambas or in corridor communities. National governance indicators help contextualise these cases, but project records determine the observed stage and binding gate.

5.2 Policy sequencing implied by the binding-gate typology

Table 5 *translates the findings into a decision sequence. These are not investment recommendations, regulatory approval criteria, or numerical forecasts. They are minimum evidence requirements before moving from one class of policy commitment to the next. Their purpose is to prevent a downstream strategy from being used as a substitute for the upstream evidence that makes it feasible and legitimate.*

Table 5
Non-compensatory policy sequencing under the revised RUDM

Observed type and next decision	First policy task	Evidence required before the next commitment	Later-stage commitment that should not be presumed
P0 contested strategic project: authorise, redesign or defer?	Establish a comprehensive legal, environmental and participation process; update financial appraisal	Integrated accessible EIA covering mine, processing, water, waste and corridor; final permits; affected-party process; finance and construction evidence	Battery manufacturing, conversion capacity or other downstream mandates
P1 under-scaled chemical producer: expand, modify process or defer DLE?	Demonstrate actual technical-commercial performance and accountable contracting	Representative brine mass balance; audited recovery, uptime, quality and cost; water/reagent/waste monitoring; effective, disclosed agreements	Capacity claims based on resource size, nameplate or signed prospective contracts
P2/D0 concentrate producer: pursue linkages or assess refining?	Secure logistics and benefit evidence; conduct a separate refinery appraisal	Route-level monitoring and agreements; transparent fiscal-flow and investment-execution data; supplier metrics; feed, power, emissions, finance and market analysis	Smelter/refinery construction inferred from concentrate tonnes or national copper importance

The first implication is that **strategic policy must be stage-sensitive**. Strategic designation may justify public coordination, information provision, infrastructure planning or research support; it does not justify treating an unpermitted or technically unproven project as an operating supply-chain anchor. This distinction is particularly important where critical-mineral strategies are linked to battery, vehicle or energy-security objectives. Industrial policy that promises downstream spillovers before reliable upstream production can create a credibility gap and divert attention from the gate actually blocking progress.

The second implication is that **domestic transformation requires its own evidence threshold**. Uyuni demonstrates chemical transformation at limited scale, but its next question is stable technical-commercial performance. Las Bambas demonstrates extraction and concentration at scale, but no documented project-level refining. These are different pathways. Both require a specific appraisal of process chemistry, recovery, energy, water, emissions, capital, markets, skills, supplier capability and local consent. The existence of a mineral resource or a large mine can make such appraisal worthwhile; it cannot determine the conclusion in advance (Östensson, 2019; Pietrobelli & Rabellotti, 2011).

The third implication is that **governance and social licence should be treated as implementation conditions, not residual risks added after economic appraisal**. Jadar's case shows that an integrated, intelligible procedure and affected-party participation are part of whether a project can move beyond P0. At Uyuni, publicly accountable water, waste and contract terms are part of whether scale-up is credible. At Las Bambas, route-level distribution, public-investment execution and grievance institutions shape

whether production can remain reliable and create broader local linkages. This is consistent with evidence that extractive conflict can impose material costs, while avoiding a claim that any particular local grievance mechanically explains all production outcomes (Franks et al., 2014; Moffat & Zhang, 2014).

5.3 Rival explanations and robustness of the classifications

The typology does not support a universal claim that governance or social licence always dominates economics. Jadar's care-and-maintenance status has at least two live explanations: unresolved procedural and distributive questions, and Rio Tinto's stated capital discipline and prioritisation of nearer-term projects (Rio Tinto, 2026). The classification does not attribute the pause entirely to protest. It shows that, whatever the relative causal weight of those explanations, the evidence required to move from P0 to P1 is not established.

In Bolivia, state ownership is not a monocausal explanation for low throughput. YLB identifies feed concentration, fuel and input supply, and maintenance as proximate operational problems (YLB, 2026a). Process chemistry makes a technical constraint plausible (An et al., 2012; Ogawa et al., 2014), while the status of contracts and approvals introduces governance conditions. A technically successful, independently audited public operation could therefore alter the P1 classification without an ownership change. Conversely, a private technology partner would not solve an unrepresentative-brine or water-accountability problem merely through a signed agreement.

At Las Bambas, the 2022 cessation links conflict and output, but it does not explain every annual production movement. MMG reports materially higher ore mined, ore milled and recovery in 2025, as well as more stable operating conditions (MMG, 2026b). The classification nevertheless survives the 2022–2025 shift because it does not label the mine permanently blockaded. It records P2 production and identifies the separate evidence still needed for a durable benefit-and-logistics pathway and any D1 refining decision.

The classifications also withstand reasonable proxy and date changes. Jadar's restored spatial plan and EU designation do not change the absence of output at the 2026 cut-off. Uyuni's move from pilot-dominant 2023 production to 2025 industrial-plant output changes the case from P0 to P1, but not to sustained-scale operation. Las Bambas' 2025 recovery prevents a "currently blockaded" label, but does not demonstrate domestic refining or resolve route-level benefit questions. Replacing WGI government effectiveness with regulatory quality, or omitting WGI entirely, does not alter these product-stage and gate classifications because they rest on project-level legal and operational records rather than index thresholds.

5.4 Limits and route to a stronger test

The analysis is a structured, focused comparison rather than a representative sample or a causal evaluation. The cases differ in commodity, chemistry, national political systems, capital intensity, ownership arrangements and project stage. Their selection for visible industrial-policy debate makes

success stories less likely to appear. The study does not estimate trade values, value-added multipliers, mine-specific fiscal returns, protest counts, causal effects or a weighted RUDM score where no consistent source dataset exists. A public-company report is reliable for what the company reported, not independent confirmation of forward-looking claims; YLB reporting does not disclose all cost and recovery information required to establish DLE viability.

This non-compensatory implementation is an analytical application, not external validation. A stronger test would code a larger project sample at a common decision point, use independent coders and an adjudication protocol, report missingness and alternative classifications, and observe longitudinal outcomes such as time to first production, reliable operation, domestic transformation or project failure. That design could test whether an RUDM profile measured before a decision is associated with later outcomes after accounting for commodity prices, technology and deposit characteristics. With three retrospective cases, the paper establishes a mechanism and falsifiable policy propositions rather than a validated forecasting instrument.

6. Conclusion

This paper applies RUDM as a **non-compensatory stage-gate model**. Its first finding is that the systems occupy different observed product stages: Jadar is P0/D0, with no verified commercial product or domestic transformation; Uyuni is P1/D1 at limited scale, with verified lithium-carbonate output but no demonstrated sustained design-level operation; and Las Bambas is P2/D0, with established copper-concentrate production but no verified project-level refining. These are not three versions of the same value-chain gap.

The second finding is that strategic relevance does not compensate for an unmet stage-relevant condition. Jadar's EU designation does not establish an authorised, financeable and legitimate P0-to-P1 pathway. Uyuni's resource scale and prospective DLE capacity do not establish repeatable technical-commercial operation. Las Bambas' high copper-in-concentrate output does not establish D1 transformation or a viable refinery. The RUDM evidence matrix consequently identifies different binding gates: a joint authorisation–legitimacy–finance gate at Jadar; a technical-commercial scale-up gate coupled to environmental and contract-accountability conditions at Uyuni; and a benefit-and-logistics gate at Las Bambas, followed by a separate refining appraisal.

The third finding is a policy-sequencing rule. Industrial policy should first resolve the evidence gap blocking the **next** transition, rather than apply a later-stage intervention because a mineral is strategically important. For Jadar, the relevant task is a comprehensive, credible authorisation and participation process together with updated financing. For Uyuni, it is auditable recovery, cost, uptime, water/waste and contract evidence. For Las Bambas, it is route-level benefit and logistics institutions plus an independent economic, environmental and social case for refining. Each diagnosis is falsifiable by a stated future observation.

The contribution is therefore a comparative extension of the prior RUDM study (Author, 2026): RUDM moves from a diagnostic profile to a **stage-gated decision rule** that prevents high strategic scores from masking prerequisites that remain unestablished. The three cases do not validate a universal predictive model, but they demonstrate why policy advice must distinguish a resource from a reserve, a strategic designation from an operating mine, nameplate from sustained output, and concentrate production from domestic transformation. A larger independently coded project sample is required to test the typology's wider predictive relevance.

Declarations

Author Contribution

MK and NH conceived the study and designed the comparative extension of the Resource Upgrading Decision Matrix. MK led the literature review, evidence collection, data curation, formal analysis, figure preparation and drafting of the manuscript. NH co-led the theoretical framing, methodological design and interpretation of the findings, and critically revised the manuscript. SJ contributed to the economic and industrial-policy analysis and reviewed the manuscript. TJ contributed to the comparative case-study research, source validation and manuscript review. AJN contributed to the governance and social-license analysis, interpretation and manuscript review. All authors reviewed and approved the final manuscript and agree to be accountable for the work.

Data Availability

The evidence protocol and coding register are available in Online Resource 1. Aggregate data extracts and analytical code used to reproduce the figures are available in Online Resource 2. Worldwide Governance Indicators estimates are publicly available from the World Bank. Project-level production, legal and corporate data were compiled from the publicly accessible official sources cited in the manuscript and reference list.

References

1. An JW, Kang DJ, Tran KT, Kim MJ, Lim T, Tran T (2012) Recovery of lithium from Uyuni salar brine. Hydrometallurgy 117–118:64–70. https://doi.org/10.1016/j.hydromet.2012.02.008
2. Author (2026) [Details omitted for double-anonymous review]
3. Chamber of Deputies of Bolivia (2025a) *Proyecto de Ley PL 170/2024–2025: Aprobación del contrato de asociación accidental YLB–Uranium One* [Approval bill]. https://diputados.gob.bo/wp-content/uploads/2025/01/PL-170-2024-2025.pdf
4. Chamber of Deputies of Bolivia (2025b) Proyecto de Ley PL 197/2024–2025: Contrato YLB–Hong Kong CBC [Approval bill]. https://diputados.gob.bo/wp-content/uploads/2025/01/PL-197-2024-2025.pdf

5. Chamber of Deputies of Bolivia (2026) *Proyectos de ley archivados* [Archived bills; accessed October 4, 2026]. https://diputados.gob.bo/proyectos-de-ley-archivados/
6. Constitutional Court of Serbia (2024), July 11 *Saopštenje sa 9. sednice Ustavnog suda: predmet IUo-39/2022* [Court session communiqué on the Jadar regulation]. https://ustavni.sud.rs/sednice-suda/saopstenja-sa-sednice-suda/saopstenje-sa-9-sednice-ustavnog-suda-odrzane
7. Defensoría del Pueblo (2022), April 28 *Conflicto en Las Bambas: Defensoría del Pueblo exige cese inmediato de la violencia en Challhuahuacho y Coyllurqui*. https://www.defensoria.gob.pe/conflicto-en-las-bambas-defensoria-del-pueblo-exige-cese-inmediato-de-la-violencia-en-challhuahuacho-y-coyllurqui/
8. Defensoría del Pueblo (2026) *Reporte de conflictos sociales n.º 265: Marzo de 2026*. https://www.defensoria.gob.pe/wp-content/uploads/2026/04/Reporte-de-Conflictos-Sociales-n-265-VF.pdf
9. Ericksen GE, Vine JD, Ballón AR (1978) Chemical composition and distribution of lithium-rich brines in Salar de Uyuni and nearby salars in southwestern Bolivia. Energy 3(3):355–363. https://doi.org/10.1016/0360-5442(78)90032-4
10. European Commission (2024), July 19 *EU and Serbia sign strategic partnership on sustainable raw materials, battery value chains and electric vehicles*. https://ec.europa.eu/commission/presscorner/detail/en/ip_24_3922
11. European Commission (2025) *Annex to Commission decision on strategic projects under the Critical Raw Materials Act* [Jadar designation; decision C(2025) 3491]. https://single-market-economy.ec.europa.eu/document/download/60c576a5-435e-43e6-83de-c81f3652259b_en?filename=C_2025_3491_1_EN_annexe_acte_autonome_part1_v3.pdf
12. European Union (2024) Regulation (EU) 2024/1252 establishing a framework for ensuring a secure and sustainable supply of critical raw materials. Official J Eur Union. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32024R1252
13. Franks DM, Davis R, Bebbington AJ, Ali SH, Kemp D, Scurrah M (2014) Conflict translates environmental and social risk into business costs. *Proceedings of the National Academy of Sciences, 111*(21), 7576–7581. https://doi.org/10.1073/pnas.1405135111
14. Gaceta Oficial de Bolivia (2009), February 7 *Constitución Política del Estado*. http://www.gacetaoficialdebolivia.gob.bo/app/webroot/archivos/CONSTITUCION.pdf
15. Gaceta Oficial de Bolivia (2017), April 27 *Ley N° 928: Ley de la Empresa Pública Nacional Estratégica de Yacimientos de Litio Bolivianos – YLB*. http://www.gacetaoficialdebolivia.gob.bo/normas/verGratis_gob/155250
16. Gereffi G, Humphrey J, Sturgeon T (2005) The governance of global value chains. Rev Int Polit Econ 12(1):78–104. https://doi.org/10.1080/09692290500049805
17. Government of Serbia (2022), January 20 *Government revokes spatial plan for Jadar*. https://www.srbija.gov.rs/vest/en/183853/government-revokes-spatial-plan-for-jadar.php

18. Ivanović S, Tomićević-Dubljević J, Bjedov I, Đorđević I, Živojinović I (2023) Cultural landscape management in context: Local communities' perceptions under Jadar mineral extraction project in Serbia. Extractive Industries Soc 16:101361. https://doi.org/10.1016/j.exis.2023.101361
19. Maiza-Larrarte A, Claudio-Quiroga G (2025) The impact of Las Bambas megamine on development in Apurímac, Peru. Mineral Econ 38:569–583. https://doi.org/10.1007/s13563-025-00506-w
20. Ministry of Economy and Finance [MEF]. (n.d.). Canon minero: Base legal y aspectos metodológicos. Government of, Peru https://www.mef.gob.pe/es/transferencias-a-gobierno-nacional-regional-y-locales/base-legal-y-aspectos-metodologicos/canon
21. Ministry of Environmental Protection of Serbia (2024) *Rešenje kojim se nosiocu projekta Rio Sava Exploration d.o.o. određuje obim i sadržaj studije o proceni uticaja* [EIA study scoping decision, November 21]. https://old.ekologija.gov.rs/lat/obavestenja/procena-uticaja-na-zivotnu-sredinu/doneta-resenja-i-zakljucci/resenje-o-odredjivanje-obima-i-sadrzaja/resenje-kojim-se-nosiocu-projekta-rio-sava-exploratlon-doo-beograd-odreduje-obim-i-sadrzaj-studije-o-proceni-uticaja-na-zivotnu-sredinu
22. Ministry of Hydrocarbons and Energies (2023), December 17 *Planta de carbonato de litio alcanzará su máxima capacidad de producción en 2025* [Company-design capacity statement, not outcome]. Government of Bolivia. https://www.hidrocarburos.gob.bo/2023/12/17/planta-de-carbonato-de-litio-alcanzara-su-maxima-capacidad-de-produccion-en-2025/
23. MMG. (2022a), January 25 *Solid result amid a challenging quarter, set for growth* [2021 fourth-quarter production release]. https://www.mmg.com/investors/reports-and-presentations/solid-result-amid-a-challenging-quarter-set-for-growth/
24. MMG (2022b), July 25 *Second quarter production report for the period ended 30 June 2022*. https://www.mmg.com/content/uploads/2022/07/e_2022-07-25_2QTR-Production-Report.pdf
25. MMG (2023a), January 31 *2022 fourth quarter production result*. https://www.mmg.com/investors/reports-and-presentations/2022-fourth-quarter-production-result/
26. MMG (2023b), March 7 *Announcement on annual results for the year ended 31 December 2022*. https://www.mmg.com/content/uploads/2023/03/e_2023-03-07_2022-Annual-Results.pdf
27. MMG (2025a) *Annual report 2024*. https://www.mmg.com/content/uploads/2025/04/MMG_Annual-Report-2024.pdf
28. MMG (2026a), January 22 *Fourth quarter production report for the period ended 31 December 2025*. https://www.mmg.com/content/uploads/2026/01/e_2026-01-22_4QTR-Production-Report.pdf
29. MMG (2026b), March 3 *Announcement on annual results for the year ended 31 December 2025*. https://www.mmg.com/content/uploads/2026/03/e_2026-03-03_2025-Annual-Results.pdf
30. MMG (2026c), July 21 *Second quarter production report for the period ended 30 June 2026*. https://www.mmg.com/content/uploads/2026/07/e_2026-07-21_2QTR-Production-Report.pdf
31. MMG (2026d), August 19 *Voluntary announcement: Fatal incident at Las Bambas*. https://www.mmg.com/content/uploads/2026/08/e_2026-08-19_Voluntary-LB-Fatalities.pdf

32. MMG (2026e), August 24 *Voluntary announcement: Las Bambas mine and process plant recommence operations*. https://www.mmg.com/content/uploads/2026/08/e_2026-08-24_Voluntary-Announcement.pdf
33. Moffat K, Zhang A (2014) The paths to social licence to operate: An integrative model explaining community acceptance of mining. Resour Policy 39:61–70. https://doi.org/10.1016/j.resourpol.2013.11.003
34. Ogawa Y, Koibuchi H, Suto K, Inoue C (2014) Effects of the chemical compositions of Salars de Uyuni and Atacama brines on lithium concentration during evaporation. Resour Geol 64(2):91–101. https://doi.org/10.1111/rge.12030
35. Östensson O (2019) Promoting downstream processing: Resource nationalism or industrial policy? Mineral Econ 32:205–212. https://doi.org/10.1007/s13563-019-00170-x
36. Pietrobelli C, Rabellotti R (2011) Global value chains meet innovation systems: Are there learning opportunities for developing countries? World Dev 39(7):1261–1269. https://doi.org/10.1016/j.worlddev.2010.05.013
37. Renewables and Environmental Regulatory Institute [RERI] (2024) *Opinion on the scoping request for the Jadar project environmental impact assessment*. https://reri.org.rs/wp-content/uploads/2024/10/RERI-Opinion-on-scoping-request-EIA-RioTinto-Jadar-project.pdf
38. Rio Tinto (2021), July 27 *Rio Tinto commits funding for Jadar lithium project*. https://www.riotinto.com/en/news/releases/2021/rio-tinto-commits-funding-for-jadar-lithium-project
39. Rio Tinto (2024) *Second quarter operations review* [Company account of the draft Jadar EIA]. https://www.riotinto.com/-/media/content/documents/invest/financial-news-and-performance/production/2024/2024-2qor-pdf.pdf?rev=ee1cbb46e4e4473cb77c8a495ea284c4
40. Rio Tinto (2026) *Jadar: Current project status* [Living webpage; accessed October 4, 2026]. https://www.riotinto.com/en/operations/europe-me/jadar
41. Stuehlen C, Anderl F (2024) Transnational companies in environmental conflicts: Rio Tinto, anti-mining resistance in Serbia, and the contradictions of Europeanization. Z für Friedens- und Konfliktforschung 13:243–268. https://doi.org/10.1007/s42597-024-00114-5
42. U.S. Geological Survey [USGS] (2026) *Mineral commodity summaries 2026: Lithium* [Resource table; elemental lithium units]. https://pubs.usgs.gov/periodicals/mcs2026/mcs2026-lithium.pdf
43. Vera ML, Torres WR, Galli CI, Chagnes A, Flexer V (2023) Environmental impact of direct lithium extraction from brines. Nat Reviews Earth Environ 4:149–165. https://doi.org/10.1038/s43017-022-00387-5
44. Vivoda V, Loginova J (2025) Lithium at the crossroads: Geopolitical, economic, and socio-environmental complexities of the Jadar project in Serbia. Mineral Econ 38:665–681. https://doi.org/10.1007/s13563-025-00517-7
45. Williams GDZ, Vengosh A (2025) Quality of wastewater from lithium-brine mining. Environ Sci Technol Lett 12(2):151–157. https://doi.org/10.1021/acs.estlett.4c01124

46. World Bank (2026a) *Worldwide Governance Indicators 2026 update: Governance estimates and scores, 1996–2025* [Dataset; downloaded October 4, 2026]. https://www.worldbank.org/en/publication/worldwide-governance-indicators
47. World Bank (2026b) *Worldwide Governance Indicators: Usage advisory*. https://www.worldbank.org/en/publication/worldwide-governance-indicators/usage-advisory
48. Yacimientos de Litio Bolivianos [YLB] (2024) *Presentación oficial: Rendición pública de cuentas final 2023* [2023 pilot-plant production]. https://www.ylb.gob.bo/wp-content/uploads/2025/09/PRESENTACION-OFICIAL-RPC-FINAL-2023-YLB.pdf
49. Yacimientos de Litio Bolivianos [YLB] (2025) *Rendición pública de cuentas final 2024* [2024 reported production and DLE contract descriptions]. https://www.ylb.gob.bo/wp-content/uploads/2025/09/RENDICION-PUBLICA-DE-CUENTAS-FINAL-2024_0.pdf
50. Yacimientos de Litio Bolivianos [YLB] (2026a) *Rendición pública de cuentas final 2025* [2025 industrial-plant actual versus planned output]. https://www.ylb.gob.bo/wp-content/uploads/2026/03/Informe_de_RPCF_2025_Publicado.pdf
51. Yacimientos de Litio Bolivianos [YLB] (2026b) *Rendición pública de cuentas inicial 2026* [Future production plan and project conditions]. https://www.ylb.gob.bo/wp-content/uploads/2026/04/Informe_de_RPCI_2026_Publicado.pdf
52. Yacimientos de Litio Bolivianos [YLB] (2026c), May 15 *YLB avanza en la certificación internacional de recursos* [Uyuni lithium resources]. https://www.ylb.gob.bo/index.php/nota_prensa/ylb-avanza-en-la-certificacion-internacional-de-recursos/

Figures

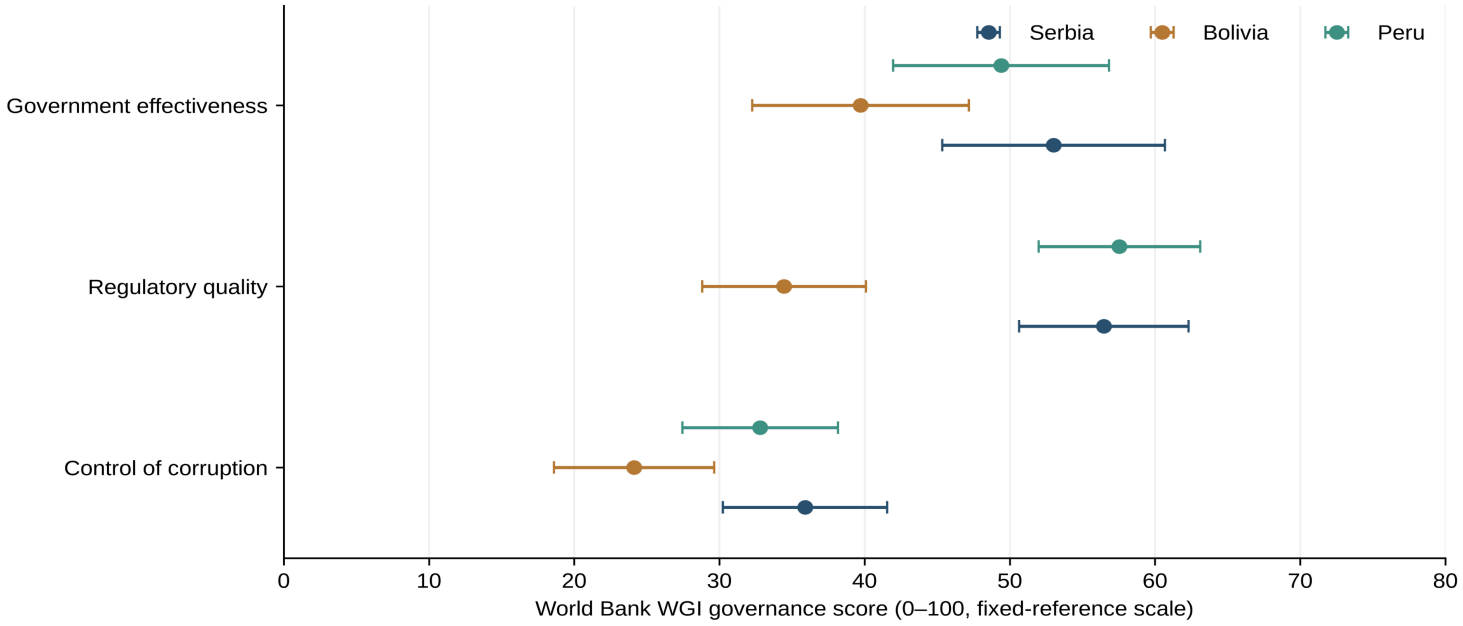


Figure 1

Three 2025 national WGI scores with 90% confidence intervals. Source: World Bank (2026a); authors' calculations. Fixed-reference scores are not percentile ranks or project-level probabilities

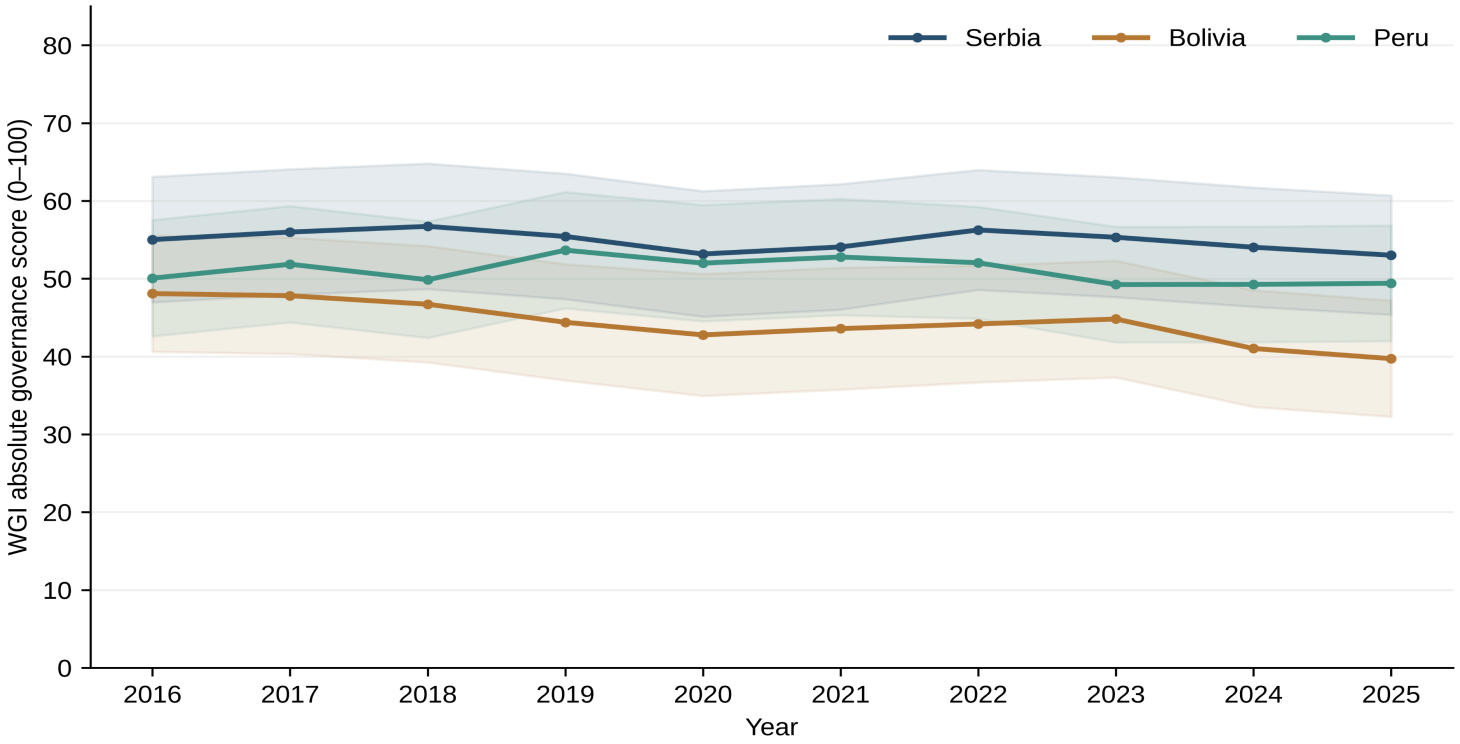


Figure 2

Government-effectiveness scores for 2016–2025. Bands show published 90% confidence intervals. Source: World Bank (2026a); authors' calculations. Changes near or within uncertainty bands are not interpreted as project effects

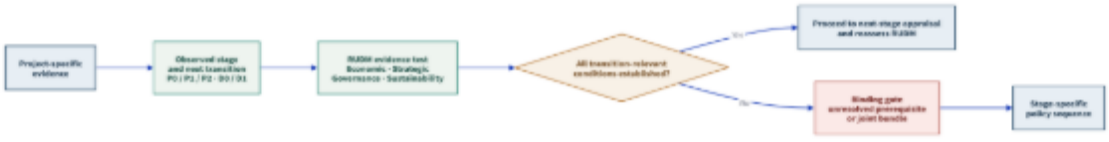


Figure 3

Non-compensatory RUDM rule: the observed stage determines the next transition; unresolved stage-relevant evidence identifies the binding gate and policy sequence. Source: authors' synthesis

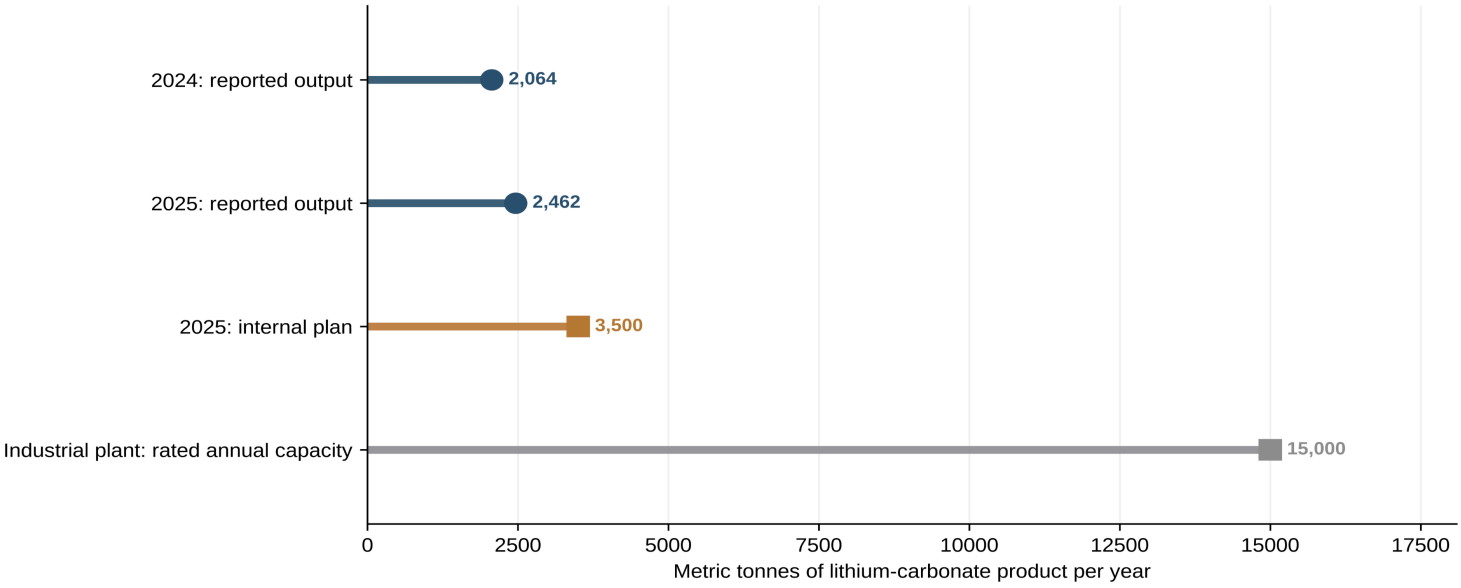


Figure 4

YLB annual lithium-carbonate product output for 2024–2025, YLB's internal 2025 plan and the Ministry's 2023 industrial-plant nameplate. These categories are deliberately distinguished rather than treated as equivalent observed outcomes. Sources: Ministry of Hydrocarbons and Energies (2023) and YLB (2025, 2026a); authors' compilation. The figure does not estimate plant utilisation

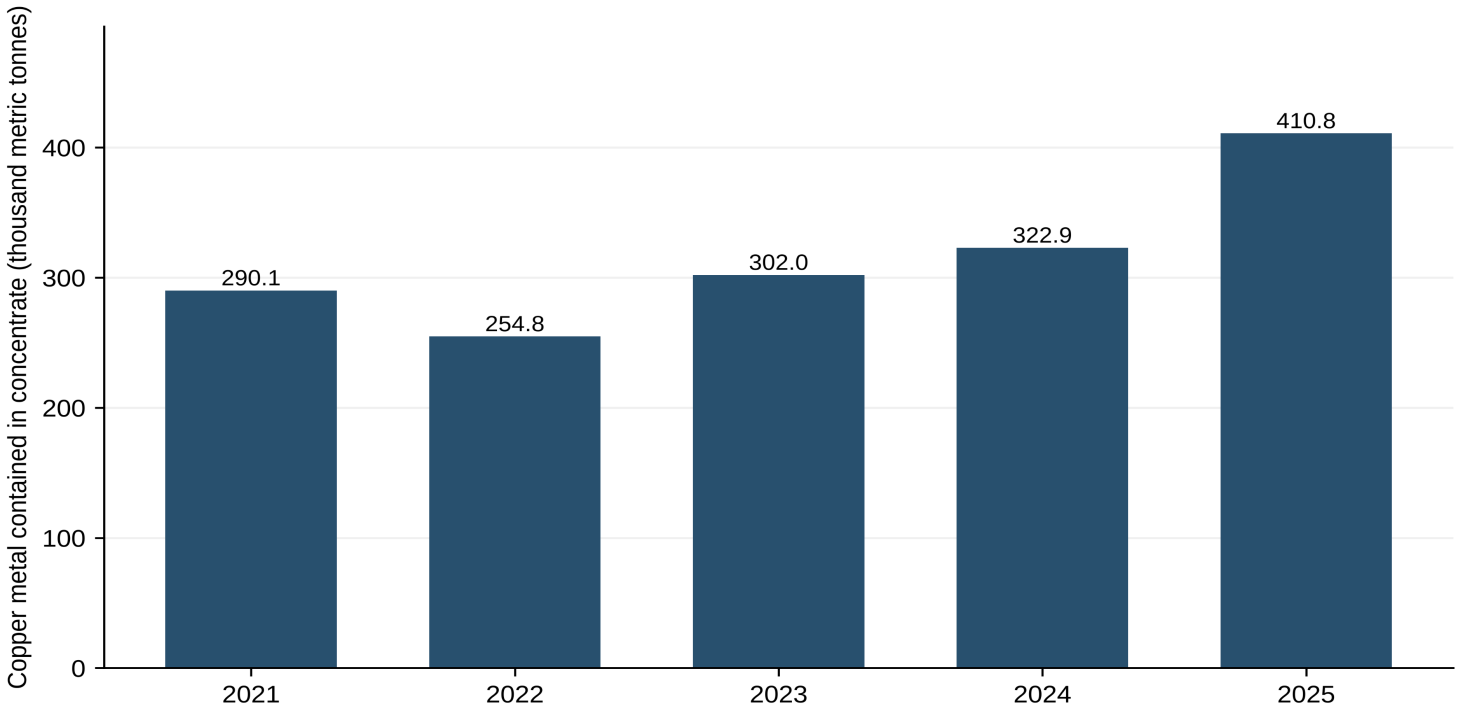


Figure 5

Las Bambas copper **metal contained in concentrate**, 100%-asset basis. Sources: MMG (2022a, 2023a, 2025a, 2026b); authors' compilation. Metal contained differs from physical concentrate and payable

sales

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- OnlineResource1EvidenceCodebook.pdf
- OnlineResource2DataandCode.zip