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From Mineral Projects to Resilient Supply: Value-Chain Bottlenecks in EU Strategic Projects and Ukraine's Mineral Assets

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Abstract

European raw-material security depends not only on deposits and mine output but also on whether materials can be processed and used by European industry. We assess when a mineral project can strengthen supply resilience by combining investment maturity with six conditions that link a project to a recipient plant: material identity, grade match, validated processing, available capacity, a commercial connection and product qualification. The analysis covers all 13 Strategic Projects selected outside the European Union (EU) in the first round under the Critical Raw Materials Act (CRMA) and a purposive set of Ukrainian mineral assets, using dated public evidence to 30 September 2026. Ten of the 13 projects were in preparation; the three in implementation accounted for 5.8–12.0% of the cohort's disclosed investment budgets, and no complete supply route to a qualified EU recipient could be verified. On a selected Ukrainian graphite route to an Italian purification pilot, processing is the binding constraint under stated assumptions: if the pilot accepts Ukrainian feed and an operating mine's nominal capacity is available to the route, a planned 50 kt/y mine raises route throughput only once purification capacity exceeds about 6.1 kt/y, some thirty times the 200 t/y pilot under construction. Issuer-reported unit values for purified graphite and Ukrainian concentrate differ about 4.6-fold. EU accession and recovery of occupied deposits would change institutions and investment options, while supply would still depend on the same project gates. Strategic Project registers should publish stage-compatible evidence, and policy should target the bottlenecks that limit usable supply.

1. Introduction

A mineral project can be designated as strategic, rest on a large resource and announce substantial output, and still supply nothing that European manufacturers can use. Between the mine and the factory lie concentration, refining, product qualification and contracts, and any of these stages can bind. The question matters for the EU's Critical Raw Materials Act (CRMA), which selected its first 13 external Strategic Projects on 4 June 2025 and, after a second internal list on 9 October 2026, counts 106 projects (European Commission 2026). It matters equally for Ukraine, whose deposits featured in the April 2025 United States–Ukraine reconstruction-investment framework and whose possible accession would change the institutional geography of European supply.

Designation and readiness are different things. Recognition under the CRMA signals an expected contribution to security of supply and technical feasibility within a reasonable time; it precedes financing, construction and commercial output and certifies none of them. The Commission has confirmed that Strategic Project status gives no automatic access to financing (European Commission 2025c), and its RESourceEU Action Plan singles out a narrower set of mature projects that could operate in the near term (European Commission 2025a). Ukraine raises the same issue in a sharper form: operating plants, development projects, idle industrial capacity and deposits in occupied territory differ greatly in how soon they could supply European industry.

Existing research measures network criticality, import provenance, technological substitution, midstream power and upgrading options (Fetzer and Lambert 2026; see Section 2). It says less about whether a named project can connect to a named downstream plant at a given date, and about what blocks the connection when it cannot. Aggregate Ukrainian production and trade series are analysed elsewhere (Piech et al. 2026; Piech 2026); this paper works at the level of named assets, project gates and recipient plants.

We ask when an additional mineral project relaxes a binding constraint in a European value chain, as opposed to adding geological options or nominal tonnes. To answer it, we audit the complete first cohort of 13 CRMA Strategic Projects in third countries and overseas territories and, separately, a purposive set of Ukrainian assets. Using dated public evidence frozen at 30 September 2026, we code each project's maturity, the product of its designated stage and six conditions that link a supplier to a recipient: material identity, grade match, validated processing, available capacity, commercial

connection and product qualification. We then weight maturity classes by disclosed project budgets and evaluate a fixed-coefficient bottleneck benchmark on a Ukrainian graphite route.

The external portfolio is overwhelmingly one of options. Ten of the 13 projects were still in development at the cut-off and three had entered construction or recommissioning; these three are small, mostly brownfield projects holding 5.8–12.0% of the cohort's disclosed budgets. Eight projects have credible precursor routes and four disclose a counterparty, yet none has a publicly verifiable complete route to a qualified EU recipient. In graphite, Ukrainian concentrate already sells to European customers under prepaid contracts, but the route to EU purification is limited by processing. Under stated assumptions, a planned 50 kt/y Ukrainian mine adds throughput to that route only once purification capacity exceeds about 6.1 kt/y, some thirty times the Italian pilot under construction. Issuer-reported prices for purified graphite are about 4.6 times those for Ukrainian concentrate.

The paper makes three contributions. It turns fixed-coefficient bottleneck logic into an evidence protocol for named project–recipient routes, documented in an auditable evidence register. It applies that protocol to a complete policy cohort and reports the result in budget as well as project terms. And it separates the institutional effect of possible Ukrainian accession from the physical effects of investment, processing and territorial access. Bottleneck reasoning itself is standard; the contribution lies in applying it to dated, project-specific evidence. The analysis estimates neither causal effects of CRMA recognition nor welfare gains.

Section 2 reviews the literature and sets out the framework, Section 3 describes the data and methods, Section 4 reports the results, Section 5 discusses implications and limitations, and Section 6 concludes.

2. Project–chain complementarity and related literature

2.1 Strategic designation, project maturity and deployable capacity

Strategic autonomy is often used loosely; raw-material policy needs an operational definition. Here, European raw-material autonomy means resilience: the capacity to keep access to strategically important materials through a diversified, reliable and industrially usable set of supply channels. This reading matches the structure of the CRMA, which combines internal-capacity benchmarks with an explicit diversification objective (Regulation (EU) 2024/1252, Art. 5).

RESourceEU directs near-term support to projects expected to become operational and ties implementation to dependency reduction in selected value chains (European Commission 2025a). EU policy itself thus separates the designated portfolio from near-term capacity, which makes observable project transitions the relevant measurement target.

The 2026 audit by the European Court of Auditors gives the strongest institutional evidence for this distinction. The applications it examined were concentrated in scoping, pre-feasibility and feasibility stages; few projects were in construction and none was in full production. The audit also identified permitting, finance and offtake as recurring risks (European Court of Auditors 2026). The Strategic Project portfolio is therefore heterogeneous in maturity, and designation alone is a weak proxy for commercial readiness.

Legal scholarship reaches a compatible conclusion. Andreotti (2026) analyses designation and accelerated permitting as a prioritising mechanism that changes administrative sequencing while leaving environmental-law requirements in place. Pettersson, Johansson and Engman (2026) show that overlapping environmental, water and waste-law frameworks can limit the practical effect of acceleration. For project-level measurement, permits and legal progress are best treated as observable maturity gates, with neither success nor failure presumed.

2.2 Product-stage readiness and value-chain integration

Project maturity is necessary but insufficient for strategic-material readiness, because mineral supply chains consist of technically and economically distinct stages. Atakhanova et al. (2026) show for copper that productive capacities and export performance differ across ores and concentrates, refined products, semi-finished products and secondary materials. Jakimów, Samokhalov and Baldassarre (2024) reach a similar conclusion for European titanium: upstream resource access leaves vulnerability in place when transformation capacity is missing. Their analysis already links European titanium midstream gaps, Ukrainian upstream investment and prospective accession; the present study addresses a narrower measurement question about dated, project-specific evidence. Work on 'midstream geopolitics' locates strategic power in smelters, refineries and other transformation facilities (Deberdt, Le Billon and DiCarlo 2026). The relevant unit of strategic supply is therefore a material at a specified stage of transformation.

Import-dependence measures face a related problem. Brainard, Gulley and Nassar (2026) show that the apparent origin of mineral imports can differ from the upstream provenance of the feedstock once indirect trade and multi-stage processing are reconstructed. Their subject is trade provenance, but the measurement lesson carries over: observations at different stages of a mineral chain are not interchangeable. A project can be commercially mature at one stage and still depend on external processing before it supplies the material form that downstream industry requires.

The framework separates three questions. Designated-stage concordance asks which physical output belongs to the extraction or processing stage named in the Commission's decision. Terminal-product readiness asks whether the intended battery-, magnet- or metal-grade material has been demonstrated. Project–chain complementarity asks whether a downstream recipient can technically and commercially accept the input. For extraction-only designations that refer to grade-qualified materials, the extracted or concentrated material is a credible precursor even when the promoter plans its own later-stage refining. On this basis the designated extraction stages of Jadar and Balakhivka are precursor routes, and their planned lithium-carbonate and SPG plants are recorded separately.

2.3 Ukraine: accession, territorial access and strategic option sets

Haneklaus, Hrabušajová and Mišík (2026) treat Ukraine and Greenland as medium- to long-term diversification options in view of geology, project readiness, governance and infrastructure. Baranowski, Jabkowski and Kammen (2026) identify geological uncertainty, wartime investment barriers and limited allied downstream capacity in the U.S.–Ukraine minerals framework. Their findings motivate a more granular assessment of named investment and processing interfaces.

Aggregate Ukrainian production and trade series, including data-vintage and territorial-break problems, are analysed elsewhere (Piech et al. 2026; Piech 2026); no numerical estimate from those studies is used here.

Network criticality (Fetzer and Lambert 2026), lithium-supply resilience (He et al. 2026), technological substitution (Janjua, Vivoda and Xu 2026) and project-level upgrading options (Kiselicki et al. 2026) provide complementary points of comparison. This study adds an auditable diagnosis at the supplier–recipient interface that keeps source uncertainty visible for product specification, process validation, capacity, commercial access and qualification.

The framework also separates EU accession from territorial access. Ukraine had been an EU candidate since 2022, accession negotiations formally opened in 2024, and by the empirical cut-off negotiations had opened on the fundamentals cluster on 15 June 2026 and on external relations on 14 July 2026 (Council of the European Union 2026a, 2026b). Candidate-country mineral policy can be analysed through upgrading and value-chain integration, as illustrated by North Macedonia (Kiselicki et al. 2026). Ukraine adds two complications absent from that setting: active territorial disruption and the possibility that future accession would change the legal and institutional geography of European raw-material capacity.

2.4 Complementarity, binding constraints and route resilience

The analytical mechanism can be represented as a sequence of conditional conversions (Fig. 1).

Note

Strategic Project designation is an institutional intervention, outside the maturity sequence. Brownfield restarts require reassessment before rejoining the chain at commissioning/ramp-up; arrows depict conditional transitions, not a production timetable. Territorial access affects the feasible investment set; EU accession affects the institutional and accounting perimeter.

The conversion sequence maps project maturity; it does not measure strategic contribution. Let K_s denote feasible capacity at processing stage s and a_s the evidenced units of that stage required per unit of a consistently specified qualified material. Under a serial, fixed-coefficients benchmark (Miller and Blair 2009), qualified throughput is

$$Q^*(K) = \min_s \left(\frac{K_s}{a_s} \right)$$

1

and a project's conditional marginal throughput contribution is

$$\Delta Q_i = Q^*(K + \Delta K_i) - Q^*(K)$$

2

Enlarging a non-binding stage leaves qualified throughput unchanged, however large the announced mine output. The benchmark also implies a switching threshold: an upstream expansion raises Q^* only once downstream capacity exceeds the throughput that existing upstream capacity can already supply. Both the minimum and the capacity vector must refer to an actual, compatible sequence of material forms, and projected investments and unverified yields are kept out of current-state calculations. Real mineral systems allow substitution, alternative routes and switching, so the expression serves as a diagnostic limiting case for Europe's chains.

A spare supplier might add no present throughput yet reduce shortages during a disruption; such resilience gains from standby routes are not quantified here. The interface conditions also have a contractual side familiar from transaction-cost economics. Qualifying a new feed, tuning a purification circuit to it or dedicating capacity to one buyer are relationship-specific investments, and the party that sinks them is exposed to ex-post hold-up (Klein, Crawford and Alchian 1978; Williamson 1985). Long-term and prepaid contracts are the standard safeguard; Joskow (1987) shows for coal supply that contract duration rises with the importance of relationship-specific investment. Conditions (5) and (6) can therefore be expected to be completed through binding offtake, prepayment or qualification agreements negotiated around the investment decision, which makes their public disclosure an informative, if incomplete, signal of interface progress.

Two analytical expectations motivate a retrospective comparison of all thirteen external projects across three evidence layers: maturity (A), designated-stage product (B) and counterparty links (C). First, a maturity rung alone cannot establish whether a project's output reaches the specified grade; the product-stage field may reclassify a mature project as a precursor or leave the route publicly unresolved. Second, a named or contracted off-taker need not represent an operating EU end-user route, so partner destination, legal condition, operating output and shipment are documented separately. Both are information distinctions testable in the disclosed record; they are neither preregistered directional hypotheses nor claims about undisclosed private arrangements. The graphite application traces observed and

prospective interfaces, and a single observed transaction cannot establish a population-level relationship. EU accession changes institutional eligibility and possibly investment and permitting transitions; output changes only through those channels.

3. Data and methods

3.1 Research design and units of analysis

The empirical design combines two datasets constructed for different analytical purposes. Dataset A is policy-defined and exhaustive: it covers the complete first cohort of Strategic Projects located in third countries and in overseas countries or territories (OCTs) recognised by Commission Decision (EU) 2025/1174 of 4 June 2025. Dataset B is analytically constructed: it covers a bounded set of Ukrainian assets that are relevant to the study's questions about operating capacity, development projects, dormant industrial capability, territorial access and possible future integration into the Union's raw-material system. The two datasets are therefore not pooled statistically. Dataset A is used to characterise the observable maturity of a complete policy cohort; Dataset B is used to examine how different forms of mineral and industrial capacity in Ukraine map onto deployability and strategic autonomy.

The primary coding unit in Dataset A is a project component, defined by its designated value-chain stage, strategic material and jurisdiction, and coded as at the cut-off date. This component-level unit is necessary because several Strategic Projects combine extraction, beneficiation, processing or downstream conversion activities that do not share the same maturity. A project-level summary code is reported for portfolio analysis, but it is derived from the least mature necessary component covered by the designation rather than from an average or the most advanced component. This prevents a pilot plant, downstream test line or advanced processing component from mechanically elevating an integrated project whose necessary mine or commercial-scale processing stage remains less mature.

All empirical statuses are frozen at 30 September 2026, so the study measures publicly verifiable maturity and capacity at that date. Information published after the cut-off is used only when it unambiguously documents an earlier event, and it is flagged as retrospective evidence. Absence of public evidence is treated as absence of verification, and non-public or inferred progress is not credited to a project; this rule applies throughout the paper.

3.2 Dataset A: the first external CRMA Strategic Project cohort

Dataset A comprises all 13 projects recognised by Commission Decision (EU) 2025/1174 as Strategic Projects located in third countries and in overseas countries or territories. The Decision was adopted on 4 June 2025 under Regulation (EU) 2024/1252. Using the full cohort avoids case-selection based on subsequent project performance and provides a fixed population against which publicly verifiable maturity can be assessed.

Each of the 13 projects was decomposed into its necessary physical components where the public project structure required it. Evidence was then collected for permitting, feasibility and engineering, final investment decision, financing, offtake, physical construction or refurbishment, commissioning and commercial output. The coding process also records the stage and product to which each item of evidence applies. For example, commercial activity at an existing host facility is not inherited by a proposed new processing line, and pilot-scale downstream material does not count as commercial output from an integrated mine-to-material project.

3.3 Dataset B: the Ukraine strategic mineral option set

Dataset B is a purposive, illustrative set of Ukrainian assets. It was constructed to test how different forms of mineral endowment and industrial capability translate into potential relevance for European supply. An asset enters the core set if it informs at least one of four questions: current or recent operating capacity; a development project with identifiable

technical or institutional progress; dormant but historically demonstrated industrial capability; or a territorially inaccessible option whose status would change under a territorial counterfactual. The screening universe was assembled mainly from assets in the study's materials (graphite, lithium, titanium, manganese, rare earths and gallium) named in the State Geology Service's investment and critical-raw-materials listings, the 2025 government critical-raw-materials white paper, State Property Fund privatisation notices and USGS country reporting; Online Resource 1 (cited hereafter as 'Supplement' with its sheet codes), sheet S1d, gives the source for each of the 14 screened entries, including a sectoral titanium comparator, and S1e lists the exclusions.

The inclusion rule produces three strata. The first contains accessible operating and development assets, the cases most directly relevant to present or prospective supply under current territorial control. The second contains dormant industrial capabilities, such as historically demonstrated processing assets whose restartability cannot be inferred from nameplate capacity. The third contains territorially locked geological or development options; they inform the territorial-access question and are kept out of current and planned supply totals.

A stop rule limits scope: additional minerals or assets enter the core analysis only if they could alter a quantitative European-supply comparison, a maturity or deployability conclusion, the territorial-access scenario or a product-chain conclusion. Other materials are kept as context cases in Supplement S1d–S1e, including Yastrebetske as an early-stage REE–zirconium case. National titanium upstream data serve as a marked sectoral benchmark.

3.4 Evidence hierarchy and public verifiability

The register follows a source hierarchy that favours evidence both attributable and specific to the project component being coded. The hierarchy resolves conflicts between sources; it does not produce a score. Official legal and administrative records, regulator or government decisions, audited financial statements and comparable records of legally or financially consequential events carry the most weight. Regulated issuer filings, geological-survey records, investment-agency material and documentation from international financial institutions form the next layer. Promoter websites and presentations are used where stronger sources are unavailable or for project-specific technical detail. Press, trade publications and commentary serve mainly for triangulation and source discovery.

Three additional rules govern conflicts between sources. First, evidence must relate to the exact physical component and project stage being coded: a permit, pilot or operating record for an existing host facility is not transferred to a proposed new line or downstream plant. Second, direct evidence of an observed gate event takes precedence over a target or schedule. A dated final investment decision, executed financing agreement, construction record or commercial sale therefore outweighs an earlier statement that such an event was merely planned. Third, when two sources describe project status at different dates, the later source is preferred for the cut-off classification if it is at least as direct and authoritative as the earlier one. This rule is particularly important where announced schedules were subsequently deferred, paused or superseded.

Negative statements are treated conservatively. Where no public document records a permit, FID, financing or offtake, the field reads 'not publicly verified'; absence, expiry, cancellation or suspension are coded only on affirmative evidence. Searches for potentially decisive missing events are logged when the outcome affects a maturity rung, because CRMA applications may contain commercially sensitive information that open sources cannot reconstruct.

3.5 Maturity, operational state and aggregation rules

Applications for Strategic Project status must classify the project under the United Nations Framework Classification for Resources (UNFC), which grades environmental–socio-economic viability, technical feasibility and confidence in estimates (Regulation (EU) 2024/1252, Art. 7(1)(b); Commission Implementing Regulation (EU) 2025/2194). The M0–M7 ladder used here is narrower: a supporting taxonomy of publicly documented milestone events at a fixed date, which

neither reproduces nor infers the confidential UNFC classifications and does not measure industrial complementarity. M0 marks an identified occurrence; M1 requires a valid project right and a classified resource or, for a processing-only component without a deposit of its own, a valid right to the host site or facility; M2 records a PEA/PFS or equivalent documented concept for a necessary component. M3 requires advanced feasibility (a DFS or comparable study) together with either a granted project-specific mining or development right or a final, approved project-specific environmental authorisation (EIA/ESHIA). EIA scoping, provisional spatial planning and pending applications fall below this threshold. The two legal routes to M3 are recorded separately, so an environmental approval is never represented as a mining licence. The environmental route reflects jurisdictions in which the final environmental decision is the binding substantive permission preceding a mining lease; the mining-right-only alternative is reported as a sensitivity.

M4 requires a binding investment decision and secured finance; M5 indicates actual construction, refurbishment, ore processing or commissioning in a necessary designated component. M6 requires a commercial sale, or saleable specified output, produced by the designated component's current operations. Hemerdon's December 2025 sale preceded the restart of ore processing on 15 September 2026 and therefore fails the strict rule; an announcement that processing has begun during ramp-up is likewise insufficient. M7 requires sustained commercial operations. Under the baseline definition, Jadar and Balakhivka remain M2, while Dumont, Maniry and Songwe Hill reach M3. The mining-right-only sensitivity yields M2 = 9 and M3 = 1 (Maniry alone), with the grouped classification unchanged at 10/3/0 (Supplement S2). Hemerdon is M5 under the strict rule and M6 under a broader site-sale/start-of-processing alternative.

For early Ukrainian institutional options without evidence of a valid project right and a classified resource, no M1 rung is assigned, because territorial or institutional interest alone is not an M1 event; Dobra is therefore unassigned. Occupied geological options with partial licence or resource evidence are marked M0/M1 provisional, which implies no observed production stage and keeps them out of the external-cohort counts. A separate operational-state variable (DEVELOPMENT, UNDER_CONSTRUCTION, COMMISSIONING/RAMP_UP, OPERATING, PAUSED, DORMANT) and a distinct territorial-accessibility axis complement the ladder. This separation keeps temporary operating conditions from rewriting accumulated technical maturity: a project on care and maintenance may remain technically mature, and a historically operating asset may be DORMANT. For the Ukrainian brownfield cases, historically demonstrated commercial capability is recorded separately from current operational state.

For portfolio interpretation, rungs are grouped into three classes: Development option (M0–M3), Committed pipeline (M4–M5) and DEPLOYED (M6–M7). ‘Committed’ identifies projects that have moved from development evidence into binding investment or physical implementation; financing, permitting, feedstock and market risks may remain. ‘Deployed’ means that a commercial sale, dispatch or production event at the assessed stage has been demonstrated; nameplate utilisation and sustained production are reserved for M7.

Integrated projects require an aggregation rule. Component-level coding is primary, and the project-level rung is the minimum maturity among the necessary components covered by the designation. This ‘binding component’ rule reflects the fact that an integrated mine-to-material project cannot deliver its designated output while one necessary part of the chain lags substantially. Optional pilots, demonstration lines and ancillary facilities enter the minimum set only if they are necessary to the designated commercial route.

3.6 Product-stage concordance and project–chain interface gates

When the designation names an extraction stage without a downstream-grade qualification (for example copper extraction), concentrate can be Direct for that stage. Where the designated material itself specifies battery grade or magnet use, the grade and the necessary downstream transformation must be shown, and upstream concentrate is a Credible precursor. A mature extraction-stage project may thus still produce an intermediate that requires further conversion: natural-flake graphite concentrate before battery-grade spherical purified graphite, nickel sulphide

concentrate before a battery-grade nickel product, and titanium or manganese concentrates before titanium metal or battery-grade manganese.

The register codes designated-stage output separately from prospective final-product output. A credible precursor needs a distinct transformation or qualification before it meets a grade-specific claim, and a planned final-grade process is recorded as a conditional route. Direct denotes a route whose identified output matches the designated-stage specification, whether operating or planned. Publicly unresolved preserves missing positive evidence; Not concordant requires affirmative evidence of a mismatch. A separate, non-ordinal interface ledger examines six necessary conditions at each supplier–recipient interface: (1) material and chemical identity; (2) product-grade match; (3) process validated on the relevant feed; (4) physical capacity available at the relevant date; (5) commercial connection; and (6) downstream product qualification (Fig. 2; Supplement S4b). The six are assessed jointly; none compensates for another, and they are not summed into a score. They follow from the benchmark in Section 2.4: conditions (1)–(3) define the stage sequence and the conversion coefficient a_s, condition (4) supplies K_s at the relevant date, and conditions (5)–(6) determine whether that capacity is allocated to, and usable by, the recipient chain. Where a necessary condition demonstrably fails, route-specific Q^* is zero; where evidence is insufficient, Q^* is not identified. Commercial connection records the existence of a contractual or market link; its economic content is examined separately through the price and capital evidence described in Section 3.7.

The register also records value-chain conditions that affect the conversion of project maturity into usable European supply: financing and permitting status, feedstock security, processing dependence, offtake security, downstream linkage to the Union, logistics and security. They remain separate variables without a composite index; with 13 projects in Dataset A and highly heterogeneous assets in Dataset B, numerical weights would create precision without an empirical basis. Their role is diagnostic: they show which links must be completed before a strategically relevant asset becomes a reliable source of qualified material.

Note

The conditions are non-ordinal and are assessed jointly without an additive score. Figure 3 applies them to four graphite routes.

3.7 Quantitative measures and denominator matching

The study combines dated project-level classifications with a constrained-flow diagnostic and two descriptive economic measures; it does not estimate an econometric or engineering supply model. The bottleneck benchmark in Eq. (1) is evaluated only where stage capacities and conversion coefficients refer to a common product, a matched period and technically compatible inputs; where any of these is assumed, the result is a scenario. For graphite, the only documented coefficient is the issuer-reported mass yield of 87% in the March 2026 campaign on African feed (Volt Resources 2026a). We use it as an illustrative coefficient (a ≈ 1.15 t of concentrate per tonne of purified graphite; assumed range 80–95%); its transfer to Ukrainian feed and to the PureGraph process is untested. The calculation stops at purification, because public sources document no coefficients for spheronisation and coating.

Project counts are complemented by disclosed project budgets. For each project, the most recent published capital estimate available before the cut-off was recorded with its basis, date and scope (Supplement S6). The estimates mix cost concepts and vintages: initial capital expenditure from feasibility studies, remaining development capital (Nussir), a restart budget (São Miguel Paulista) and a restart financing requirement that includes pre-production operating costs (Hemerdon). They are nominal and were converted to US dollars at ECB reference rates of 30 September 2026. The share of maturity class c in the budgets retained, $s_c = \frac{\sum_{i \in c} B_i}{\sum_i B_i}$, where B_i is the disclosed budget of project i, is

therefore reported as a range across five scope rules: all published estimates; the same with Dumont's current Phase 1 estimate; excluding Jadar, whose US$2.4 billion commitment includes a chemical plant beyond the designated extraction stage; additionally excluding Balakhivka's press-reported figure, which includes its SPG plant; and the last rule with Dumont's current estimate. A separate component-boundary sensitivity restricts Norgraph, designated as an integrated project, to its mine-side estimate. CaledoNi has no official estimate and is omitted. The shares describe the distribution of announced budgets, not realised investment or productive capital.

A cross-transaction unit-value comparison sets two issuer-reported prices against each other: Ukrainian concentrate sold under two prepaid European contracts announced in July 2026, and high-purity graphite from African feed sold in March 2026. Because feed, date, contract and product specification differ, the comparison is descriptive; it does not identify a purification margin, processing costs or profitability.

Polokhivske's planned 22,000 t/y of Li_2CO_3 contains 4,132.74 t/y of elemental lithium by stoichiometric conversion. This conditional scale says nothing about a compatible EU downstream route and is not interchangeable with lithium hydroxide capacity. Balakhivka's planned 50,000 t/y of concentrate and the 200 t/y PureGraph pilot belong to different material stages; they are compared only through the conversion coefficient above, in a bottleneck calculation.

Arithmetic validity therefore differs from economic comparability. A ratio may be correct yet analytically unsuitable if, for example, a natural-graphite product is divided by a demand denominator that combines natural and synthetic graphite, or if historical titanium-sponge output is compared with a customs category covering a broader set of unwrought titanium products. Such calculations are retained only as diagnostic or historical scale comparisons, never as market shares, CRMA benchmark contributions or deployable supply.

Project capacity is not translated into the CRMA's Union-level benchmarks, which depend on the material, processing stage and consumption denominator; enlargement could change both the numerator and the denominator. The quantitative exercise asks a narrower question: whether selected capacities are material in scale relative to transparent European reference denominators, keeping scenario magnitude separate from legal benchmark compliance.

3.8 Accession and territorial-access counterfactuals

The Ukraine counterfactual combines two independent binary conditions: present versus hypothetical future EU membership, and observed versus restored physical access to occupied assets. These four states describe institutional and territorial constraints, not forecasts of membership or military events.

Accession can change the legal accounting perimeter and investment conditions of realised Ukrainian output, but leaves physical production, maturity and product specifications unchanged by assumption.

Territorial restoration may enable renewed title, geological, security and technical assessment of occupied assets; operating capacity is credited only after new project-development gates are passed.

Territorial status is coded independently from legal sovereignty and from operational accessibility. Geological location is established from Ukrainian official or project documentation, while de facto control is corroborated through dated conflict-monitoring sources where required. The study uses a territorial vintage fixed at the cut-off date and does not infer operational security solely from formal control. An asset may be under Ukrainian control yet remain constrained by attack risk, damaged infrastructure, energy shortages, insurance availability or logistics.

Probabilities, unobserved operating output and notional ‘post-war tonnes’ are not added across states. Each counterfactual corresponds to a different economic transmission mechanism.

3.9 Validation and robustness

Model-assisted coding runs served only to diagnose rule consistency on an earlier, incomplete source packet and an earlier codebook. Their output is neither human intercoder reliability nor a test of the final thresholds, the full historical response matrix is not included, and no replicability claim is made for them. The baseline rests on the dated issuer evidence, the current codebook, the thirteen project rows and the auditable descriptive formulas.

Adversarial source checks identified a 2023 NI 43–101 PEA for Norgraph (GreenRoc Mining plc 2023), an audited December 2025 concentrate sale from Hemerdon's existing processing facility and a 15 September 2026 statement that Hemerdon had resumed ore processing during ramp-up. The last is positive evidence that the restart had entered production. Under the strict M6 rule, a start-up statement without dated evidence of saleable, specified output or a sale from the restarted designated route remains M5; the earlier legacy-facility sale and a broader ‘entered production’ rule yield M6 as a sensitivity. The boundary affects one case and leaves the development group unchanged.

Under the strict rule, ten projects are development options, three are physically implementing or commissioning, and none has verified commercial output from the complete designated route; the broader Hemerdon rule yields 10/2/1. Jadar and Balakhivka remain M2 because their component evidence does not jointly pass the M3 technical and permitting tests, whereas Maniry, Dumont and Songwe Hill meet M3 under the baseline permission rule. Requiring granted mining or development rights alone gives M2 = 9 and M3 = 1 without changing 10/3/0 (Supplement S2). Eight projects have credible designated-stage precursor routes. All figures are codebook-dependent classifications of public evidence.

Generative AI tools served as instruments for structured recoding, adversarial source discovery and manuscript support. Decisive claims are anchored to the cited public sources, against which classifications, calculations and interpretations were adjudicated. Coding was performed by the author; auditability rests on the dated evidence register in the Supplement.

4. Results

4.1 Maturity of the first external CRMA cohort

At the 30 September 2026 cut-off, ten of the thirteen external Strategic Projects (76.9%) remained development options. Under the strict necessary-component and commercial-route rule, three (23.1%) had reached physical implementation or recommissioning, and none had verified commercial deployment of its complete designated route. The rung distribution is M1 = 0, M2 = 7, M3 = 3, M4 = 0, M5 = 3, M6 = 0 and M7 = 0 (Table 1). The broader interpretation of Hemerdon's existing-facility sale or start of ore processing produces 10/2/1, and the mining-right-only M3 variant gives M2 = 9 and M3 = 1 with the grouped count unchanged at 10/3/0. If operator photographs of site works are not accepted as construction evidence for São Miguel Paulista, the grouped count becomes 10/3/0 with its investment decision and financing treated as M4, or 11/2/0 otherwise (Supplement S2). These are retrospective evidence classifications.

In the development group, Norgraph, Balakhivka, CaledoNi, Kobaloni, Sarytogan, Zandkopsdrift and Jadar meet M2 under the component-specific technical gate, and Dumont, Maniry and Songwe Hill meet M3 through advanced feasibility and a qualifying project-specific approval. Songwe Hill holds an approved ESHIA, an environmental approval; its exploitation licence had not been granted at the cut-off, and Malawi suspended the issuance of new mining licences on 13 February 2026 (Supplement S1b). CaledoNi's rung is unresolved within early development: its regulated host plant meets the processing-specific M1 condition, but no public technical study was located, so M2 is provisional; coding it M1 would change M2 from 7 to 6 and leave the grouped classes unchanged (Supplement S2). Dumont's environmental authorisation (decree 526–2015, last amended by decree 1225–2026) is likewise distinct from a mining lease. Jadar remains M2 (Rio Tinto 2025): its reinstated spatial plan and EIA-scoping record fall short of final exploitation permission, and its PAUSED/care-and-maintenance state is recorded separately. Balakhivka holds special permit 6345

(13 June 2019) for the southern part of the deposit, but its processing-plant feasibility documentation was still being finalised in July 2026, so the permit alone establishes neither a complete DFS nor a construction milestone. Sarytogan published its upstream DFS on 20–21 October 2026, after the cut-off; its M2 code reflects the evidence at 30 September (Supplement S1b).

Hemerdon is the material coding sensitivity case. Audited Tungsten West accounts record £601,550 of tungsten-concentrate sales in December 2025 from the pre-existing mineral-processing facility (Tungsten West 2026a, note 5). A separate RNS of 15 September 2026 states that ore processing had started at the restarted mine during ramp-up but documents no dated sale from the restarted route (Tungsten West 2026b). The strict commercial-output rule therefore retains M5, and the broader operational-start/site-sales interpretation gives M6. On 22 September 2026 Elmet Technologies LLC, a US company, signed a concentrate offtake running to 31 December 2034, with purchases envisaged from 2027 (The Elmet Group Co. 2026); the contract documents a future commercial link. Elmet's announcement also mentions possible conversion at its Schwabmünchen plant in Germany, conditional on completing an asset purchase from OSRAM, so the counterparty is coded as non-EU with a conditional EU processing route. The case separates offtake geography from realised European supply.

Table 1
First external CRMA Strategic Projects: maturity and operational state at 30 September 2026

Project / jurisdiction	Designated stage; strategic material	Binding component	Rung (strict) and operational state	Basis for rung
Balakhivka (Ukraine)	Extraction; battery-grade graphite	Mine + concentrator	M2 – DEVELOPMENT	PFS and basic engineering; subsoil permit (2019); no full DFS
CaledoNi (New Caledonia)	Processing; battery-grade nickel	Third AEP line (dust extrusion/recycling)	M2[b] – DEVELOPMENT	No public technical study; awaiting financial commitment
Dumont (Canada)[a]	Extraction; nickel + cobalt	Mine + concentrator	M3 – DEVELOPMENT	Feasibility study; environmental authorisation (decree 1225–2026); no FID
Hemerdon / Tungsten West (United Kingdom)	Extraction; tungsten	Brownfield mine/processing restart	M5 – COMMISSIONING/RAMP_UP	Ore processing from 15 Sep 2026; broad-rule M6 (Dec 2025 sale)
Jadar (Serbia)	Extraction; lithium + boron	Designated extraction component	M2 – PAUSED	PFS; no exploitation licence; care and maintenance
Kobaloni (Zambia)	Processing; cobalt	Cobalt sulphate refinery	M2 – DEVELOPMENT	Feasibility study; no FID or financial close
Maniry (Madagascar)	Extraction; battery-grade graphite	Mine + concentrator	M3 – DEVELOPMENT	DFS (2022); mining permits (Jul 2026); no FID
Norgraph / Greenland Graphite (Greenland + Norway)	Integrated extraction + processing; battery-grade graphite	Amitsoq mine development	M2 – DEVELOPMENT	Mine PEA (2023); mine PFS incomplete
Nussir (Norway)	Extraction; copper	Mine + concentrator construction	M5 – UNDER_CONSTRUCTION	FID (Apr 2026); construction under way
Sarytogan (Kazakhstan)	Extraction; battery-grade graphite	Mine + concentrator	M2 – DEVELOPMENT	PFS (2024); DFS after cut-off (Oct 2026)

Note: Strict rule; the project-level rung is that of the least mature necessary component (Section 3.5). M6 denotes initial commercial deployment and M7 sustained operations; Hemerdon is M6 under the broader rule. [a] M2 under the mining-right-only variant (Supplement S2). [b] CaledoNi: rung unresolved within M1–M2; the processing-specific M1 condition is met, while M2 is provisional because no public technical study was located (Supplement S1b, SP02-9 and SP02-10; S2). Full evidence and sources: Supplement S1a–S1c. Abbreviations: PEA, preliminary economic assessment; PFS, pre-feasibility study; DFS, definitive feasibility study; FID, final investment decision; ESHIA, environmental, social and health impact assessment; SPG, spherical purified graphite; REE, rare-earth elements.

Project / jurisdiction	Designated stage; strategic material	Binding component	Rung (strict) and operational state	Basis for rung
Songwe Hill (Malawi)[a]	Extraction; magnet rare earths	Mine + integrated processing complex	M3 – DEVELOPMENT	Updated DFS (2026); approved ESHIA; no mining licence
São Miguel Paulista (Brazil)	Processing; nickel + cobalt	Brownfield refinery restart	M5 – UNDER_CONSTRUCTION	Investment approved (Nov 2025); refurbishment under way
Zandkopsdrift (South Africa)	Extraction; REE + battery-grade manganese	Mine + on-site processing complex	M2 – DEVELOPMENT	PFS (2025); DFS under way; no FID

Note: Strict rule; the project-level rung is that of the least mature necessary component (Section 3.5). M6 denotes initial commercial deployment and M7 sustained operations; Hemerdon is M6 under the broader rule. [a] M2 under the mining-right-only variant (Supplement S2). [b] CaledoNi: rung unresolved within M1–M2; the processing-specific M1 condition is met, while M2 is provisional because no public technical study was located (Supplement S1b, SP02-9 and SP02-10; S2). Full evidence and sources: Supplement S1a–S1c. Abbreviations: PEA, preliminary economic assessment; PFS, pre-feasibility study; DFS, definitive feasibility study; FID, final investment decision; ESHIA, environmental, social and health impact assessment; SPG, spherical purified graphite; REE, rare-earth elements.

Weighting projects by disclosed budgets sharpens this picture (Table 2). The twelve projects with published estimates account for about US$5.9 billion, close to the Commission's estimate of €5.5 billion for the cohort (European Commission 2025d). The three committed projects – Nussir, São Miguel Paulista and Hemerdon – make up 23.1% of the 13 projects but 5.8% of the disclosed budgets under the broadest rule and 5.8–12.0% across the five scope rules (13.7% when Norgraph is restricted to its mine-side estimate). Their budgets are modest (US$65–184 million), and two of them are brownfield restarts, whereas six of the nine development-stage projects with estimates exceed the largest committed budget. Under every scope rule at least 88% of the disclosed budgets (86% under the mine-only sensitivity) belonged to projects that had crossed neither the investment decision nor into physical implementation, and the projects that had done so were among the smallest. Because the estimates mix study vintages, phases and cost concepts, these shares describe the distribution of announced budgets rather than realised investment.

Table 2
Disclosed capital budgets of the first external CRMA Strategic Projects by maturity class

Project	Class (strict)	Disclosed budget, US$ m	Basis and date	Scope
Nussir	Committed (M5)	184	Feasibility study, Apr 2026 (remaining capex)	Mine + concentrator
São Miguel Paulista	Committed (M5)	65	Restart budget at 2022 FID (BFS 2022: 54.8)	Refinery restart
Hemerdon	Committed (M5)	93	Restart plan, May 2025 (pre-production capital and operating costs)	Mine + processing restart
Balakhivka	Development (M2)	450	Promoter preliminary estimate reported in the press, Mar 2025 (exception to the source hierarchy; excluded in rules iv–v)	Includes SPG plant beyond designated stage
Dumont	Development (M3)	1,018 [846]	Feasibility study update, 2019 [company Phase 1 estimate C$1.2 bn, 2026; Dumont Nickel 2026]	Mine + concentrator
Jadar	Development (M2)	2,400	Board funding commitment, Jul 2021	Includes chemical plant beyond designated stage
Kobaloni	Development (M2)	85	Company project profile, Nov 2025 (€75 m)	Refinery
Maniry	Development (M3)	79	DFS, Nov 2022 (Stage 1)	Mine + concentrator
Norgraph	Development (M2)	471 (131 mine)	PEA, Oct 2023 + plant PFS, Jul 2024	Mine + anode-material plant
Sarytogan	Development (M2)	62	PFS, Aug 2024 (Stage 1a)	Mine + concentrator
Songwe Hill	Development (M3)	326	Updated DFS, Mar 2026	Mine + processing to MREC
Zandkopsdrift	Development (M2)	628	Updated PFS, 2025 (Phase 1, excl. contingency)	Mine + processing
CaledoNi	Development (M2)	–	No official estimate	–
Total (12 projects)		5,861	Committed: 342 (5.8%); 5.8–12.0% across scope rules; 13.7% with Norgraph mine-only	Committed share of the 13 projects (3/13): 23.1%

Note: Most recent published estimate available before 30 September 2026; nominal values converted at ECB reference rates of 30 September 2026 (US$1.1355 per euro; C$1.6105 per euro). Budgets mix initial capital expenditure, remaining capital and restart financing including pre-production operating costs. Shares are reported across five scope rules and one component-boundary sensitivity (Section 3.7). Committed = M4–M5 under the strict rule; no project is M6–M7. Bracketed values: alternative estimates used in the scope rules and sensitivity. Sources: Supplement S6; Dumont Phase 1 estimate: Dumont Nickel (2026).

4.2 Designated-stage precursors and planned terminal-product routes

Maturity does not map one-to-one onto stage-complete qualified supply. Eight of thirteen projects (61.5%) have at least one extraction- or processing-stage route classified as a credible precursor, which by itself implies no commercial production. Balakhivka, Jadar, Dumont, Maniry, Sarytogan, Songwe Hill and Zandkopsdrift require further transformation before reaching the final product, and Norgraph adds an integrated-project bottleneck. The Commission designates Balakhivka and Jadar at the extraction stage, while their promoters also plan an SPG plant and a lithium-carbonate plant respectively; those future terminal-grade outputs are kept separate from the extraction-stage component. Product-stage coding thus feeds the interface analysis.

Conversely, an identified terminal product can remain entirely prospective. Kobaloni has a defined cobalt-sulphate refinery route without commercial operation, and Jadar's lithium carbonate and Balakhivka's SPG depend on investment and plant completion. Hemerdon's existing-facility sales are a commercial event, yet no qualified European downstream delivery follows from them. The next question is whether each potential material transfer has the physical grade, process, contractual and market connections it needs, and whether it relieves an actual chain constraint.

The three-layer comparison (Supplement S5) adds evidence to the maturity census. Layer A records the thirteen rungs: ten development options and three physical-implementation or commissioning cases. Layer B distinguishes eight credible precursors, four direct designated-stage routes and one publicly unresolved match; neither a Direct classification nor an M5 rung implies a qualified sale. Layer C identifies four publicly disclosed counterparty or offtake/finance relationships, which differ in bindingness and source tier: a signed offtake disclosed in a regulatory filing (Elmet), a conditional binding terms sheet (Maniry), a supply and technology agreement disclosed in a corporate announcement (Carester) and a relationship without a disclosed destination (Hartree). Three name a destination or counterparty country: Germany for Maniry's purchaser (Evion Group NL 2026), Lacq in France for Zandkopsdrift's mixed heavy rare-earth carbonate (Frontier Rare Earths 2026), and the United States for Elmet, with deliveries expected from 2027. Two of the four relationships therefore point to an EU country and one to a non-EU counterparty with a conditional German processing route. Public counterparty relationships were recorded for two of the three committed projects and two of the ten development options; this descriptive difference is compatible with the contracting logic of Section 2.4 but does not identify the timing or causal role of contracting. No completed route to a qualified EU terminal user could be verified from public evidence at the cut-off. Table 3 summarises product stages and counterparty links; agreements are not equated with physical supply.

Table 3
Designated-stage product and public counterparty links of the first external CRMA Strategic Projects

Project / jurisdiction	Designated-stage product	Public counterparty link	Destination
Balakhivka (Ukraine)	Credible precursor (concentrate); SPG plant planned	None verified	–
CaledoNi (New Caledonia)	Publicly unresolved (battery-grade nickel route)	None verified	–
Dumont (Canada)	Credible precursor (nickel sulphide concentrate)	None verified; offtake sought	–
Hemerdon / Tungsten West (United Kingdom)	Direct (tungsten concentrate)	Elmet offtake to 2034; purchases from 2027	United States; conditional route to Germany
Jadar (Serbia)	Credible precursor; Li2CO3 and boric acid only in planned plant	None verified	–
Kobaloni (Zambia)	Direct (planned cobalt sulphate)	None verified	–
Maniry (Madagascar)	Credible precursor (flake concentrate)	Conditional binding terms sheet with German purchaser	Germany (EU)
Norgraph / Greenland Graphite (Greenland + Norway)	Credible precursor; anode-material pilot only	Partnership discussed; no binding link	–
Nussir (Norway)	Direct (copper concentrate)	Hartree offtake/finance relationship	Not disclosed
Sarytogan (Kazakhstan)	Credible precursor (graphite concentrate)	None verified	–
Songwe Hill (Malawi)	Credible precursor (mixed rare-earth carbonate)	Internal processing plan only	Not established (internal plan: Poland)
São Miguel Paulista (Brazil)	Direct (Class 1 nickel and cobalt)	None verified	–
Zandkopsdrift (South Africa)	Credible precursor (REE); unresolved (battery-grade manganese)	Carester: 7-year supply, offtake and technology agreement	France (EU)

Note: Product-stage codes as defined in Section 3.6. 'None verified' means that no link was located in the public sources reviewed (Supplement S1a–S1c, S5); private agreements may exist. Countries identify disclosed counterparties or planned processing destinations, not completed deliveries.

4.3 Ukraine's strategic mineral option set

4.3.1 Accessible operating and development assets

Graphite contrasts dated upstream output with incomplete downstream connections. Zavalivske produced 830 t of concentrate between 14 July and 13 August 2025 (Volt Resources 2025). On 16 July 2026 the issuer announced a new campaign targeting about 1,200 t of concentrate grading 80–94% total graphitic content, supported by two firm prepaid contracts with European customers for about 660 t (± 10%) worth approximately €377,140, with deliveries scheduled for July–November 2026 (Volt Resources 2026d). The campaign produced about 850 t between 3 August and 3 September

2026; the result was disclosed on 1 October and corroborated on 8 October, and it is admissible retrospective evidence of a pre-cut-off event under Section 3.1 (Volt Resources 2026c). Shipment and receipt of the contracted tonnes are not independently verified. The geological-survey figure of about 7 kt/y is a nominal capacity reference. Separately, on 6–10 March 2026 the Ukrainian refinery produced 19.14 t of high-purity graphite from imported African flake (the figure refers to output), which the issuer reported as sold to an unidentified European battery-sector purchaser (Volt Resources 2026a,b).

Lithium is less mature operationally but allows a cleaner conditional scaling exercise. Polokhivske was an M2 development project at the cut-off, with a DFS/BFS in preparation and no FID or construction. Project and geological-survey material indicate planned output of about 300 kt/y of petalite concentrate and, in the downstream scenario, up to 22 kt/y of lithium carbonate. With a stoichiometric lithium share of 18.785%, the carbonate output corresponds to about 4.13 kt Li per year. Carrara et al. (2023, figure ‘Material demand forecast – All sectors – EU’, lithium row) report 2030 EU all-sector demand of 42,313 t Li in the Low Demand Scenario and 58,208 t Li in the High Demand Scenario; the Commission's lithium factsheet rounds the latter to 58,000 t/y (European Commission 2025b). If completed, Polokhivske's output would equal about 9.8% and 7.1% of these scenarios. The comparison indicates scale; it is neither a market-share forecast nor a contribution to the CRMA Union-capacity benchmark.

Dobra is a different kind of option. In January 2026 the Ukrainian government selected Dobra Lithium Holdings as preferred developer under the production-sharing-agreement procedure. The associated investment commitments establish institutional and financial interest without defining annual output, and a signed PSA had not been publicly confirmed by the cut-off. Dobra is therefore retained as an institutional option without a maturity rung or an annual supply quantity; selection as preferred developer is distinct from an effective PSA or mining licence. Table 4 summarises the accessible assets and the national titanium comparator.

Table 4
Ukraine strategic mineral option set: accessible operating and development assets

Asset / material	Stratum / control	Maturity / state	Value-chain & product readiness	Quantitative evidence	Interpretation / qualification
Zavalivske / graphite	Accessible operating / Ukrainian-controlled	M6 upstream observed commercially; operating campaign-based; planned expansion unranked	Mining + beneficiation; natural-flake Credible precursor; CSPG planned	7 kt/y indicated capacity; completed campaigns 0.83 kt (Jul–Aug 2025) and 0.85 kt (Aug–Sep 2026; reported 1 Oct); planned 50 kt/y CSPG	Capacity ≠ annual output; downstream CSPG not built
Balakhivka / graphite	Accessible development / Ukrainian-controlled	M2 – DEVELOPMENT	Extraction/concentrate; planned SPG downstream	50 kt/y concentrate + 19 kt/y SPG planned	No commercial output; planned tonnes only; no headline percentage
Polokhivske / lithium	Accessible development / Ukrainian-controlled	M2 – DEVELOPMENT	Mine/petalite + planned Li2CO3; Direct only if conversion is built	22 kt/y Li2CO3 ≈ 4.13 kt Li ≈ 7.1–9.8% of selected projected EU 2030 Li demand if completed	Conditional scale only; not market share or Article 5 contribution
Dobra / lithium	Accessible institutional option / Ukrainian-controlled	Institutional option – rung unassigned	Exploration + future PSA development; product route unresolved	No defensible annual production capacity	Preferred developer selected; signed PSA not publicly confirmed by cut-off
Ukraine titanium upstream (sectoral contextual aggregate)	Accessible operating / Ukrainian-controlled	Not project-rung coded (national aggregate); production observed historically	Ilmenite/rutile concentrate = Credible precursor, not titanium metal	286 kt TiO2 content in ilmenite (USGS estimate, 2024); 2025e 200 kt	Demonstrates upstream/final-product gap; no EU market-share percentage
Pokrov + Marhanets / manganese	Accessible upstream / Ukrainian-controlled	Historical production evidenced; 2026 operating status not publicly verified	Manganese concentrate = Credible precursor, not battery-grade manganese	Reported 171 kt 2025 manganese concentrate (industry sources; attribution not independently verified)	2026 status incomplete; no verified HPMSM chain

Note: Sources: Supplement S1b and S1d–S1e. The titanium entry is a national sectoral aggregate, not a named project; USGS reports Ukrainian ilmenite output on a TiO2-content basis and notes significant revisions to 2024 data (U.S. Geological Survey 2026a, 2026b). The Polokhivske scale comparison uses Carrara et al. (2023) EU 2030 all-sector lithium-demand scenarios of 42,313 t Li (LDS) and 58,208 t Li (HDS); it is not a projected market share. Abbreviations: CSPG, coated spherical purified graphite; SPG, spherical purified graphite; PSA, production-sharing agreement; HPMSM, high-purity manganese sulphate monohydrate; USGS, U.S. Geological Survey; LDS/HDS, low/high demand scenario.

4.3.2 A project–chain interface test: Ukrainian graphite and European processing

A raw-material label and adjacent project designations are insufficient to verify a functioning industrial interface. Before the cut-off, Commission Decision (EU) 2025/840 had selected several EU projects with graphite processing stages: BAM4EVER (France), Northern Graphite's European Initiative for Strategic and Sustainable Graphite Production (France/Namibia/Germany) and CO2Graphite (Estonia); Talga Natural Graphite ONE (Sweden) is an extraction comparator. Northern Graphite planned to feed a prospective French battery-anode-material plant with Okanjande graphite from Namibia, initially targeting 2028 (Northern Graphite 2025a), an affirmative, named non-Ukrainian supply plan. PureGraph was recognised on 9 October 2026 and is included only as a later, dated policy comparator.

The March 2026 purification campaign at Zavalivske produced 19.14 t of high-purity graphite (99.60–99.75% carbon, reported yield 87%) from feedstock supplied by an unnamed African mine. Volt's filing describes the batch as sold to a ‘European battery customer’ at US$3,000/t with 50% prepayment and delivery scheduled for March; the customer's jurisdiction, dispatch, receipt and anode-product qualification are not independently established. The parent company's consolidated Appendix 5B for the quarter reports no receipts from customers; Volt later explained that, on its auditors' advice and under IFRS, Zavalivske revenues are not consolidated into its balance sheet, profit and loss or cash-flow reporting (Volt Resources 2026b, pp. 1, 9; 2026d).

The same issuer's disclosures report unit values on both sides of the purification stage. The July 2026 contracts imply about €571/t for Ukrainian concentrate (€377,140 for about 660 t), or about US$650/t at the ECB reference rates of 1 and 23 July 2026 (US$1.1383 and US$1.1392 per euro), whereas the March 2026 high-purity graphite from African feed sold at US$3,000/t, about 4.6 times as much. Applying the illustrative coefficient of 1.15 gives a feed value of roughly US$750 per tonne of purified product and an arithmetic difference of about US$2,250/t. This difference is an indicative issuer-reported price spread; it is not an estimated processing margin or value added, because the two observations differ in feed, date, contract and product specification. For reference, the average unit value of US flake-graphite imports was about US$1,000/t in 2025 (U.S. Geological Survey 2026c). Two Ukrainian-processed routes thus carry issuer-reported commercial links to European buyers, one from African flake and one from Zavalivske's own concentrate; neither discloses a named EU recipient, end use or product qualification, and no Ukrainian-feed relationship with the Italian processing projects is disclosed (Fig. 3).

Note

For African-origin feed purified at Zavalivske, sale and prepayment are issuer-reported, while delivery, receipt and downstream qualification remain unverified; capacity is documented for the March 2026 campaign only. Zavalivske concentrate is covered by two issuer-reported prepaid contracts with European customers for about 660 t (deliveries July–November 2026); buyer identity, destination country, end use and qualification are undisclosed. The proposed Zavalivske and Balakhivka routes to the Italian PureGraph pilot have no documented feed-specific validation or shipments. Sources: Supplement S4a–S4b; Volt Resources (2026a,b,d); International Graphite (2026b,c). PureGraph's designation on 9 October 2026 postdates the cut-off.

The Italian projects do not form a single available capacity figure. Alkeemia's PureGraph purification pilot of about 200 t/y was still under construction according to International Graphite's 30 July quarterly filing and 30 September annual report (International Graphite 2026b, 2026c), with an aspirational purification scale of 20,000 t/y by 2030. Northern Graphite announced a letter of intent for up to 100 t/y of pilot capacity, referring to feedstock from Namibia and Canada (Northern Graphite 2025b). The separate Alkeemia–International Graphite venture contemplates about 10,500 t/y of micronised graphite from about 10,800 t/y of concentrate, with a different process and product specification and

conditional investment status (International Graphite 2026a). Balakhivka's own prospective 19 kt/y SPG line would partly duplicate this processing function.

The benchmark of Section 2.4 can be evaluated for the selected PureGraph route as a conditional scenario at the purification stage (Table 5). No commissioned purification capacity was documented for this route at the cut-off, so a current-state scenario yields no throughput through that installation; this is a statement about the selected route, not an estimate of all EU capacity accessible to Ukrainian feed. If the pilot operates and is shown to accept and qualify the relevant Ukrainian concentrate, its 200 t/y nameplate is an upper bound on route throughput. At the illustrative yield this requires about 230 t/y of concentrate, about 3.3% of Zavalivske's nominal 7 kt/y and less than the 850 t produced in a single 2026 campaign. If, in addition, Zavalivske's nominal capacity is achievable, compatible and freely allocable to the route, Balakhivka's planned 50 kt/y would raise route throughput only once purification capacity available to Ukrainian feed exceeds about 6.1 kt/y (5.6–6.7 kt/y across the assumed yield range). This conditional switching threshold equals about 30 PureGraph pilots, or 30% of PureGraph's 2030 aspiration; absorbing Balakhivka's full planned output would require about 43.5 kt/y, 2.2 times that aspiration. Within these assumptions the purification stage binds by roughly two orders of magnitude, and additional mine capacity adds nothing to route throughput until it is relieved. The calculation stops at purification, because spheronisation and coating coefficients are not publicly documented; the six conditions are assessed for the selected graphite routes, and their empirical validation across other material chains remains for future research.

Table 5
Purification bottleneck on the selected Ukrainian graphite route to PureGraph: conditional scenario

Quantity	Value	Basis
Conversion coefficient a	1.15 t concentrate per t purified graphite (illustrative: observed 87% yield on African feed; 80–95% assumed range)	Volt Resources (2026a)
Commissioned purification capacity documented for the selected PureGraph route, 30 Sep 2026	0 t/y	PureGraph pilot under construction
Route Q^* at the cut-off (current-state scenario)	0 t/y	$\min\left(\frac{K0}{a}, Q_{mine}\right)$
Upper bound once the pilot operates, if Ukrainian feed is accepted and qualified	≤ 200 t/y	Pilot nameplate; feed-specific validation not documented
Concentrate needed to fill the pilot	≈ 230 t/y (3.3% of Zavalivske nominal capacity)	200 × 1.15
Conditional switching threshold for Balakhivka's $\Delta Q > 0$ (assumes Zavalivske nominal capacity achievable and allocable)	≈ 6,090 t/y (5,600–6,650)	Zavalivske 7,000 t/y × yield
in PureGraph pilots / share of PureGraph 2030 aspiration	≈ 30 pilots / ≈ 30%	6,090 / 200; 6,090 / 20,000
Purification capacity to absorb Balakhivka's 50 kt/y	≈ 43,500 t/y (40,000–47,500)	50,000 × yield; 2.2 × 20,000

Note: Conditional scenario for one selected route; purified graphite in t/y unless stated. The yield refers to the March 2026 campaign on African feed and is used illustratively; Ukrainian-feed yields and acceptance by the recipient are undocumented. Spheronisation and coating are excluded. Sources: Supplement S4c and S6; Volt Resources (2026a); International Graphite (2026b, 2026c).

The reviewed disclosures identify no feed-specific testing of Zavalivske or Balakhivka graphite at the French or Italian plants and no Ukrainian-origin shipment into those projects. The origin of an International Graphite sample described only as ‘European’ remains indeterminate. The six conditions therefore remain incomplete for a Ukrainian-origin EU anode-material route (Supplement S4b). The public record is insufficient to verify the route; it says nothing about whether the route is physically feasible.

4.3.3 Dormant industrial capability

The Zaporizhzhia Titanium and Magnesium Combine (ZTMC) is the clearest example. Ukraine historically produced titanium sponge at the plant, with about 6 kt reported in both 2020 and 2021 and around 1 kt in 2022; reported output fell to zero in 2023 and 2024. The asset is therefore classified as DORMANT at the cut-off, with its historical commercial capability retained as a separate attribute. The distinction matters because titanium sponge belongs to the titanium-metal stage, unlike the upstream ilmenite concentrates reported in Table 4. Prior commercial production shows that Ukraine possessed downstream capability beyond extraction; whether the plant could be restarted at its historical output is a separate question.

The Mykolaiv Alumina Plant provides a comparable but more conditional brownfield case for gallium. The plant historically operated an alumina-refining chain from which gallium could be recovered as a by-product. Available

historical data indicate approximately 1 t of gallium output in 2021, while a higher figure of about 5 tpa refers to historical nominal recovery capability rather than recent realised production. The plant has been non-operational since 2022. By 2026, state actions had focused on legal consolidation and preparation of the asset for privatisation rather than on a funded operating restart.

4.3.4 Territorially locked options

The third stratum consists of deposits and early-stage projects whose strategic relevance is constrained mainly by lack of physical access at the 30 September 2026 cut-off. They contribute no current output, and their geological or historical significance is not converted into annual supply estimates. Their role is to show how the accessible option set would change under a territorial-access counterfactual.

Shevchenkivske and Kruta Balka illustrate this category most clearly for lithium and associated materials. Ukrainian Geological Survey investment materials (undated, with data as of 2024) locate both deposits and describe them as lying in temporarily occupied territory. Control at the cut-off is established separately from dated conflict-monitoring sources: DeepState reported the occupation of Shevchenko, the locality of the Shevchenkivske deposit, in July 2025, and ISW assessments for September 2026 place the Zaporizhzhia front far north of the Berdiansk district, where Kruta Balka lies (Supplement S1b). Shevchenkivske is treated as a resource-defined lithium option, and Kruta Balka is relevant to lithium, tantalum and niobium. Neither is assigned current production capacity or qualified annual output. Territorial restoration would remove the immediate access constraint without moving either project into committed development: geological verification, licence and title review, updated technical studies, permitting, security assessment, financing and product-route definition would still be required.

For the Velyko-Tokmatske manganese deposit, Ukrainian media in April 2026, citing Kommersant via The Moscow Times, reported that Reale Engineering Invest, a Russian company 25.1% owned by an affiliate of the state conglomerate Rostec, had obtained a Russian-issued extraction licence for the deposit in February 2026 and begun exploration in April. This report documents an occupation-authority licence claim, not recognised legal title under Ukrainian law. Restoration of physical control could require renewed title adjudication and site-access verification before project development (Ukrainska Pravda 2026).

The rare-earth and multi-metal cases are still more upstream. Novopoltavske is retained as a territorially locked option for rare earths, niobium and tantalum: its placement within the occupied part of Zaporizhzhia oblast is inferred from the documented locality near Chernihivka rather than from a deposit-boundary/control overlay. No current commercial separated-REE chain is demonstrated. Historical technological and economic limitations further restrict inference from the geological resource alone. Azovske is kept outside the core quantitative set unless a precise deposit-location-to-control linkage is independently established (Table 6).

Table 6
Ukraine strategic mineral option set: dormant industrial capability and territorially locked options

Asset / material	Stratum / control	Maturity / state	Value-chain & product readiness	Quantitative evidence	Interpretation / qualification
ZTMC / titanium sponge	Dormant brownfield / Ukrainian-controlled	DORMANT; historical M6 capability demonstrated	Direct historically for titanium-metal stage	~ 6 kt in 2020 and 2021; ~1 kt in 2022; 0 reported in 2023–24	Historical capability only; no verified current or restartable capacity
Mykolaiv Alumina Plant / gallium	Dormant brownfield / Ukrainian-controlled	DORMANT since 2022	Direct historically only when host alumina circuit operates	~ 1 t gallium in 2021; historical nominal recovery ~ 5 tpa	Restart depends on whole alumina chain; historical nameplate is not current capacity
Shevchenkivske / lithium	Territorially locked / Russian-occupied	M0/M1 provisional; territorially locked (current licence unverified)	Geological/resource-defined Li option; Publicly unresolved	0 current output; no defensible annual qualified capacity	Restoration removes access constraint only; project development must restart
Kruta Balka / Li-Ta-Nb	Territorially locked / Russian-occupied	M0/M1 provisional; territorially locked (current licence unverified)	Exploration/development option; Publicly unresolved	0 current output; no defensible annual qualified capacity	Option-set case only; restoration does not create deployable capacity
Velyko-Tokmatske / manganese	Territorially locked / Russian-occupied	M0/M1 geological-development option	No demonstrated battery-grade manganese chain	0 current qualified output	Russian-issued extraction licence reported (Feb 2026); title not recognised under Ukrainian law; resource scale does not establish battery-grade supply
Novopoltavske / REE-Nb-Ta	Territorially locked / Russian-occupied	M0/M1 provisional; territorially locked (current licence unverified)	Geological/development option; separated-REE chain unresolved	0 current qualified output	No modern commercial separated-REE chain; option-set only

Note: The three Ukrainian strata (Tables 4 and 6) are non-additive. Historical capability is not current capacity; inaccessible assets are excluded from qualified annual supply. Strata reflect locality-level control inference against the 30 September 2026 snapshot; deposit-boundary control is not verified (Fig. 4). Abbreviations as in Table 4. Sources: Supplement S1b and S1d–S1e.

Figure 4 illustrates this distinction. Pokrov and Marhanets are located on Ukrainian-controlled territory, but geographic proximity to the active conflict area means territorial control cannot by itself establish safe or commercially accessible operating capacity.

Note

Equirectangular projection with standard parallel 49°N. Occupied areas use the dated 30 September 2026 DeepState GeoJSON snapshot (simplified). Points represent approximate localities, not deposit boundaries, and cannot support site-level territorial determinations. The distinction between de facto control and operational access is retained: some Ukrainian-controlled facilities lie near contested areas. Sources: Supplement S1d–S1e; DeepState (2026).

4.4 Accession and territorial-access counterfactuals

The four accession–territory cases (Table 7) summarise institutional and physical options without converting either transition into new tonnes or forecasting enlargement, recovery or production. Within the observation window no cell changes physical output: the accession axis alters eligibility and accounting, the territorial axis alters the investable set, and each acts on output only through later project gates.

Table 7
Institutional perimeter and territorial access: four non-additive Ukrainian option states

Territorial access	No EU accession	Hypothetical EU accession
Observed access, 30 September 2026	Accessible projects remain external supply options; physical capacity depends on project and chain gates.	Institutional accounting perimeter changes; mine, processing and qualification status do not.
Restored access (counterfactual)	New deposits become accessible for title and development assessment, not automatically deployable.	Access and institutional perimeter both change; investment, process validation and qualification remain necessary.
Note: No state implies instantaneous additional production or commercially qualified EU deliveries. Territorial restoration also requires renewed legal-title, infrastructure and security assessment.		

5. Discussion

5.1 From designation counts to the marginal value of compatible supply

A maturity census describes the implementation backlog; the strategic benefit of an investment depends on the complementarity between its output and the stages, specifications and market links of a destination chain. A commercially operating project may supply only an intermediate that relies on a concentrated third-country conversion facility, while a planned refinery can matter more than a larger mine if refining binds. The graphite case illustrates this under explicit assumptions. No commissioned purification capacity was documented for the selected PureGraph route at the cut-off; once its 200 t/y pilot operates, and provided it accepts Ukrainian feed, Balakhivka's planned 50 kt/y would add nothing to route throughput until available purification exceeds about 6.1 kt/y. Issuer-reported unit values differ by a factor of about 4.6 between Ukrainian concentrate and purified graphite from African feed, an indicative spread rather than a measured margin. Ukrainian processing already supports issuer-reported sales to European buyers from African and from Ukrainian feed, but no verified link to an EU purifier or anode producer.

Committed projects hold 5.8–12.0% of the disclosed budgets; the rest sits in options. The projects that had reached implementation are mostly brownfield restarts, while the large greenfield projects that would carry most of the designated tonnage remain options. If CRMA support aims at near-term capacity, its leverage lies less in recognition itself than in the financing and offtake conditions that move capital-intensive projects across the investment decision.

5.2 Policy portfolio, enlargement and wartime risk

The first external CRMA cohort is a policy-defined population, not an exhaustive inventory of all mineral or industrial assets relevant to European raw-material security. Ukraine makes the distinction visible. Zavalivske, Polokhivske, ZTMC, Mykolaiv and the territorially locked deposits examined here sit in different operating, development, brownfield or accessibility states, yet all may matter to future supply without belonging to the first external Strategic Project cohort.

Accession and territorial access affect two distinct mechanisms in Ukraine's mineral option set. Under fixed physical capacity, accession would change the eligibility and jurisdictional accounting of qualified Ukrainian material, not automatically create tonnes. Over time, however, EU law, faster permitting procedures for Strategic Projects in the Union, financing and offtake incentives could alter the transition probability and timing between project stages. Serbia's paused Jadar project illustrates why this institutional channel must be treated separately: its current project permissions are governed by Serbian law, and CRMA procedures applicable to Union projects cannot be assumed to apply there before possible accession. Warfare, damaged infrastructure, logistics, energy security and insurance impose independent physical constraints; restoring territorial access alone also does not create productive capacity.

5.3 Implications for European raw-material autonomy

The policy implication is to evaluate candidate Strategic Projects by their interface with other stages before treating nominal output as a contribution to resilience. A project dossier can explicitly distinguish six conditions: material and chemical identity; product-grade match; process validated on the relevant feed; physical capacity available at the relevant date; commercial connection; and downstream product qualification. Separate maturity and territorial-access information remains necessary, but does not substitute for those interface conditions. A project that duplicates an already planned purification stage does not raise baseline qualified throughput, although it may have resilience value as a standby route.

The constrained-flow benchmark shows why the relevant policy target need not be the project with the largest announced mine output. Where downstream processing binds, relief can come from conversion capacity, qualification of an alternative feed, or logistics and contractual access. Costs, competing sources, technological substitution, environmental effects and the insurance value of a standby route must still be weighed, so the argument does not by itself justify subsidising refining. The 2026 EU processing and recycling designations offer an occasion to assess cross-project complementarity across both lists.

For Ukraine, the institutional issue is distinct from the technological bottleneck. Accession can relocate already qualified Ukrainian extraction or processing inside the Union's accounting and regulatory perimeter, potentially changing investment incentives or market access, but without increasing physical output automatically. Territorial recovery would expand possible investment options but not their present commercial maturity. Before crediting a project with diversification, policy assessment needs to establish where the ore is mined, where it is processed, how the product is certified and where it is sold.

5.4 Limitations

The results measure publicly verifiable status. Sponsors, financiers and public authorities hold more complete private information, and CRMA applications, financing documents and permitting progress may be confidential. The external cohort is finite, small and policy-selected, so its proportions cannot be generalised statistically to other vintages, and the Ukraine asset set is deliberately selective. Sixteen months separated designation from the cut-off, a short interval relative to typical project-development and first-delivery timelines; the finding is an evidence-verification result about the 13 designated external projects. No positive control is available within the cohort, because no external project had a publicly documented qualified delivery route at the cut-off; a route would pass all six conditions if public records named the recipient plant, documented feed-specific testing or qualification, showed operating recipient capacity at the relevant

date, and recorded a binding supply contract and a delivery of qualified product. Disclosed budgets come from studies of different dates, cost concepts and scopes, which is why budget shares are reported as ranges.

The M0–M7 ladder is an analytical classification, not a probabilistic model of project success, completion time or economic value, and it does not identify a single causal bottleneck. Product-stage coding is likewise constrained by public disclosure: Publicly unresolved preserves uncertainty where the exact commercial route cannot be established, while planned downstream routes remain plans until built and qualified. The approach identifies constraints and the conditions for using a project; estimating the effect of individual projects on EU security of supply, or the welfare effects of the CRMA, would require data on full flows, costs and alternative routes.

Territorial control, security and operating conditions are time-sensitive and fixed to the 30 September 2026 observation date. The map provides approximate localities and a dated, simplified occupation geometry; it does not establish deposit boundaries or site-specific security conditions. Enlargement and restoration are counterfactuals, not predictions. Lithium demand ratios are conditional, matched on elemental-Li content, and not presented as evidence of carbonate/hydroxide process compatibility. No mixed-stage graphite, titanium, manganese or gallium ratio is reported as deployable supply.

6. Conclusions

This article asked when investment in critical-mineral extraction and processing actually strengthens supply for European industry. Resource size, planned output and Strategic Project status do not, by themselves, establish deployable supply. What counts is whether a project's output can be used at the next stage of an industrial chain, because adding supply at one stage raises final output only if the constraint lies at that stage.

The framework separates a project's nominal potential from its capacity to strengthen a supply chain. It combines investment maturity with six conditions that link a project to its industrial buyers: material and grade compatibility, a validated process, available capacity, a commercial connection and product qualification. The conditions are complements, so meeting one does not make up for missing another, and the throughput of a chain is set by its weakest stage, whatever the sum of planned capacities.

Applied to the 13 Strategic Projects selected outside the EU in the first CRMA round, the framework shows a wide gap between political recognition and industrial readiness. Ten projects were still in preparation at 30 September 2026, and the three in implementation held only 5.8–12.0% of the cohort's disclosed budgets, so at least 88% of the disclosed project budgets related to projects still at the development stage. Public sources documented no complete supply route from a newly designated project to a qualified EU industrial buyer. The selection itself is not in question; recognition and contribution to supply security simply have to be assessed separately. Strategic status can ease investment, but capacity has to be built.

The Ukrainian graphite case puts figures on the complementarity of stages. Ukrainian concentrate is already sold to European customers under prepaid contracts, and a Ukrainian refinery has an issuer-reported sale to a European battery-sector buyer of 19.14 t of purified graphite made from African feed. The link to EU processing, however, is limited by purification. Under the assumptions of Section 4.3.2, the planned Balakhivka mine would add throughput to the route studied only once purification capacity available to Ukrainian feed exceeds about 6.1 kt/y, whereas the Italian pilot under construction is designed for 200 t/y. The investment that matters most for supply security may therefore be the one that removes the binding constraint, and alternative routes can add resilience even when they leave current throughput unchanged.

Ukraine's assets fall into distinct categories: active operations, development projects, idle industrial plants and deposits under occupation. They represent different economic opportunities and cannot be added up as potential annual supply. The graphite case also shows that the places of mining, processing and sale need not coincide. EU accession would change the institutional conditions of the sector and the statistical treatment of its output, and recovering occupied deposits would widen the set of possible investments; output and qualified deliveries would still depend on the project gates analysed here.

For EU policy, success is better measured by the reduction of real dependencies and bottlenecks in value chains than by the number of Strategic Projects, the size of identified resources or the sum of announced capacity. Investment support should be tied more closely to evidence on processing technology, product compatibility, the capacity of industrial buyers and binding offtake, weighed against costs, risks, substitution and the value of diversification. A practical first step is to publish, alongside the Strategic Project registers, the evidence this study had to reconstruct: the binding stage, target feed and product specification, process tests, operating capacity, links to qualified buyers and the origin of incoming material. With such data, the unit of analysis becomes what it should be: not the deposit or the single mine, but its place in a working, or workable, industrial chain.

Declarations

Author Contribution

K.P. conceived and designed the study, compiled and coded the evidence, performed the analysis, prepared all figures and tables, and wrote and revised the manuscript.

Data Availability

All data analysed in this study are compiled from publicly available sources (legal acts, regulatory and issuer disclosures, official statistics and the DeepState territorial-control archive), which are cited in the article and listed with URLs and dates in the supplementary workbook (Online Resource 1). The workbook contains the project and asset codes, the evidence register with source pinpoints, the codebook, alternative coding rules, search logs and all formula-based calculations reported in the article, with project status fixed at 30 September 2026.

Use of generative AI

Generative AI tools assisted structured application of the codebook, source discovery, review comparison and editorial checks, as described in Section 3.9. All substantive claims were assessed against the cited public sources.

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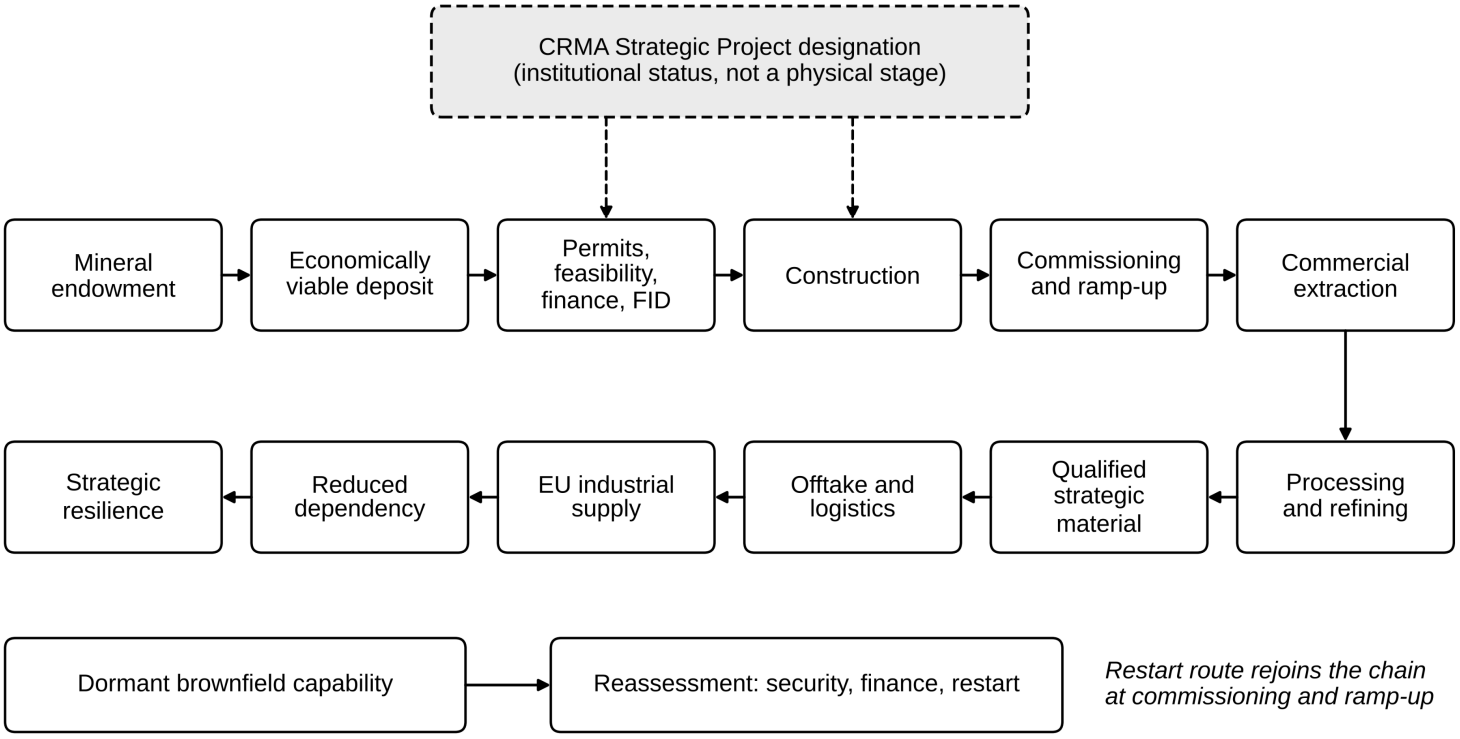
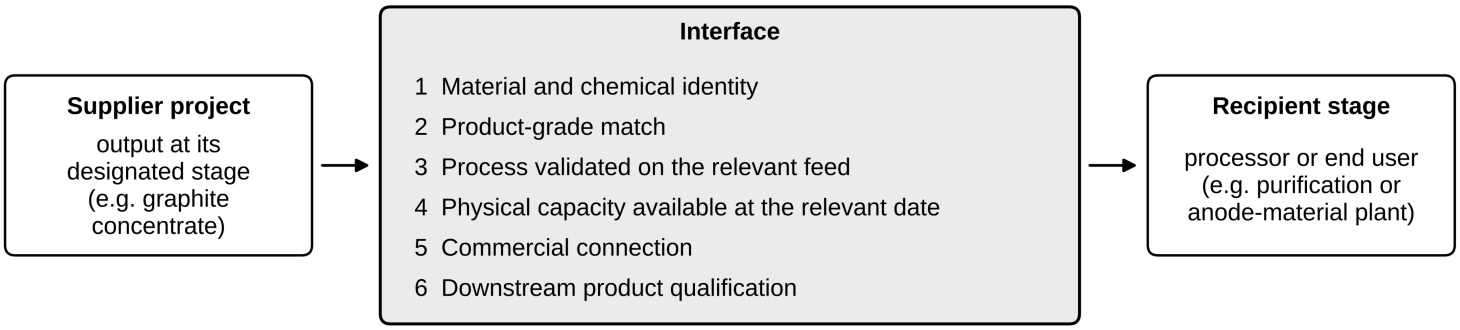


Figure 1

From mineral endowment to qualified strategic supply: the deployability conversion chain

Note: Strategic Project designation is an institutional intervention, outside the maturity sequence. Brownfield restarts require reassessment before rejoining the chain at commissioning/ramp-up; arrows depict conditional transitions, not a production timetable. Territorial access affects the feasible investment set; EU accession affects the institutional and accounting perimeter.



All six must hold; none substitutes for another; conditions are not summed into a score

Figure 2

Six jointly necessary project–chain interface conditions

Note: The conditions are non-ordinal and are assessed jointly without an additive score. Figure 3 applies them to four graphite routes.

	1 Identity	2 Grade	3 Feed validation	4 Capacity	5 Commercial	6 Qualification
African flake → purification at Zavalivske, Ukraine → European battery buyer	●	◐	●	●	●	○
Zavalivske concentrate → European customers (prepaid contracts, 2026)	●	◐	○	●	●	○
Zavalivske concentrate → PureGraph pilot, Italy	●	◐	○	○	○	○
Balakhivka stage-1 concentrate (planned) → PureGraph pilot, Italy	●	◐	○	○	○	○

● documented ◐ partial (intermediate grade; further processing needed) ○ not publicly documented

Figure 3

Public evidence for four graphite routes against the six interface conditions, 30 September 2026

Note: For African-origin feed purified at Zavalivske, sale and prepayment are issuer-reported, while delivery, receipt and downstream qualification remain unverified; capacity is documented for the March 2026 campaign only. Zavalivske concentrate is covered by two issuer-reported prepaid contracts with European customers for about 660 t (deliveries July–November 2026); buyer identity, destination country, end use and qualification are undisclosed. The proposed Zavalivske and Balakhivka routes to the Italian PureGraph pilot have no documented feed-specific validation or shipments. Sources: Supplement S4a–S4b; Volt Resources (2026a,b,d); International Graphite (2026b,c). PureGraph's designation on 9 October 2026 postdates the cut-off.

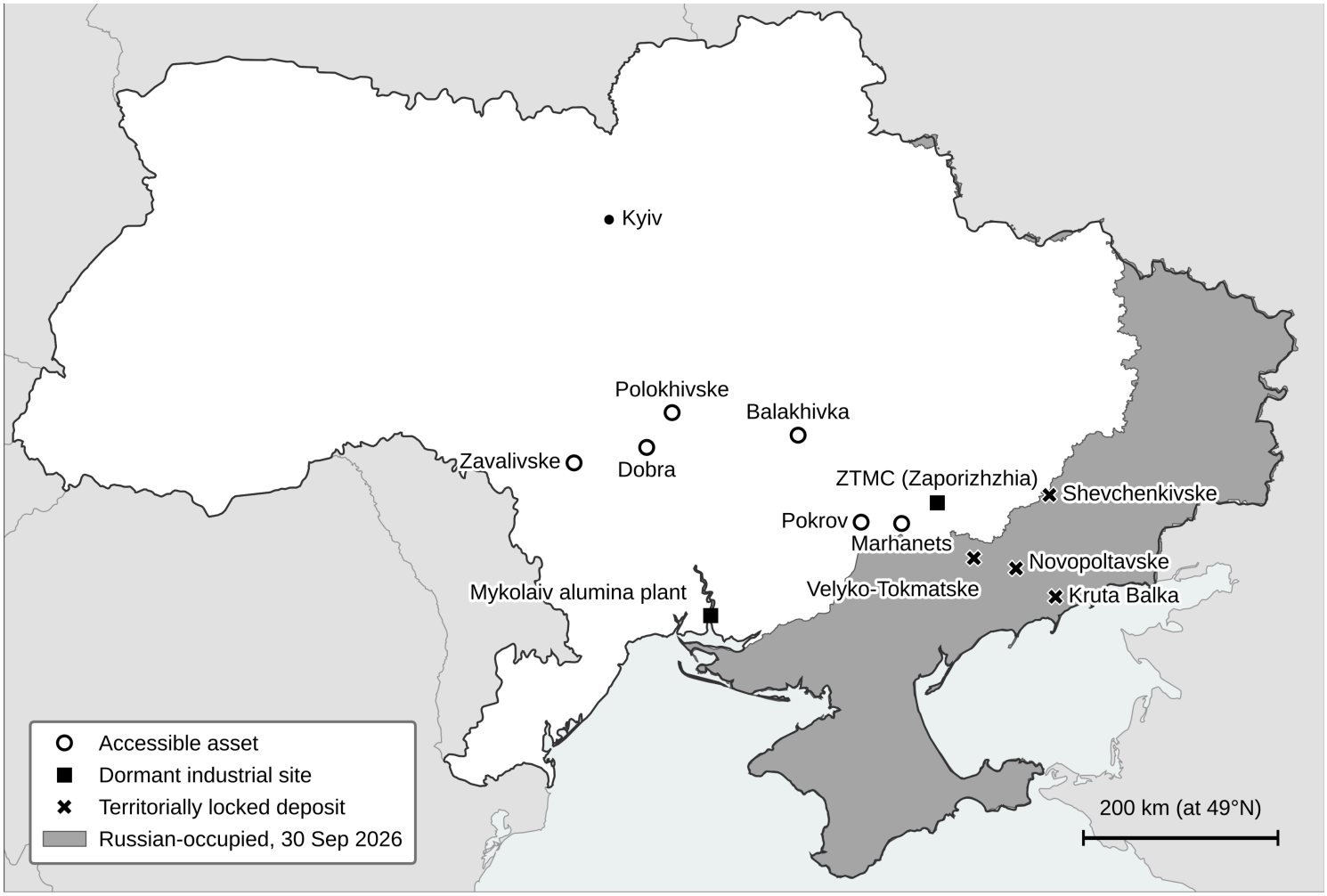


Figure 4

Ukrainian strategic-mineral assets by territorial access stratum, 30 September 2026

Note: Equirectangular projection with standard parallel 49°N. Occupied areas use the dated 30 September 2026 DeepState GeoJSON snapshot (simplified). Points represent approximate localities, not deposit boundaries, and cannot support site-level territorial determinations. The distinction between de facto control and operational access is retained: some Ukrainian-controlled facilities lie near contested areas. Sources: Supplement S1d–S1e; DeepState (2026).

Supplementary Files

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

- ESMv23.xlsx