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Firm-level Competitiveness and Investment Attractiveness in Peru's Formal Coal Industry: a Multicriteria Strategic Positioning Approach

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Abstract

This study evaluates the strategic positioning of Peru's main formal coal mining companies by integrating firm-level competitiveness and investment attractiveness within a transparent multicriteria framework. Six representative titleholders were selected using objective criteria related to productive relevance, operational continuity, and the availability of verifiable information for 2020–2025. Competitiveness was assessed through productive capacity, mineral resource base, commercial positioning, and management and compliance, while investment attractiveness was evaluated through geological potential, logistical accessibility, market conditions, and the socio-institutional environment. Ordinal rubrics were converted to a 0–100 scale, weighted using the Analytic Hierarchy Process, and synthesized through composite indices and the General Electric-McKinsey (GE-McKinsey) matrix. The results reveal a fragmented formal coal industry dominated by small-scale producers with heterogeneous strategic profiles. Productive capacity is the main driver of firm competitiveness, whereas the socio-institutional environment and logistics are the primary determinants of investment attractiveness. Obras Civiles and Mineras record the strongest overall strategic positions, followed by Minera Santa Mercedes and Carbonífera San Benito. Sensitivity tests based on ±20% weight perturbations indicate stable rankings, supporting the robustness of the multicriteria assessment. The study contributes a traceable firm-level adaptation of the AHP–GE-McKinsey framework for fragmented small-scale extractive industries, combining coal-specific rubrics, nested weights, and robustness testing.

1. Introduction

Coal remains a strategic resource in resource-based industrial economies because of its role in electricity generation and as an input for energy-intensive industries. Despite the transition toward low-carbon energy systems, coal still represents a substantial share of the global energy mix, supported by its availability, cost competitiveness, and perceived contribution to energy security in many emerging economies [1]. From an industrial and business economics perspective, coal mining also provides a relevant setting for examining firm performance, market positioning, and investment attractiveness in resource-based industries exposed to regulatory, logistical, and institutional constraints. Recent market outlooks indicate that global coal demand remains historically high, reflecting the resilience of this resource amid policy, technological, and market shifts [2].

However, the coal mining industry faces increasing pressure from environmental regulation, financing restrictions linked to environmental, social, and governance criteria, and competition

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from alternative energy sources [3, 4]. These pressures are especially relevant in developing countries, where the sector often combines high corporate heterogeneity, small-scale operations, and persistent logistical and institutional constraints that affect costs, continuity, and investment allocation [5]. In these contexts, the viability of coal supply for domestic industries depends not only on geology and output but also on governance quality, permitting, transport infrastructure, and stable community relations [6, 7].

In Peru, coal mining represents a relatively small subsector within the national mining industry, but it retains regional relevance and strategic value for specific industrial chains. Formal production is characterized by a fragmented business structure dominated by small-scale mining producers, with substantial differences in production scale, resource availability, market access, and territorial operating conditions. During 2020–2025, six companies accounted for a significant share of the country's formal coal production: Obras Civiles and Mineras S.A.C., Carbonífera San Benito S.R.L., Minera Santa Mercedes E.I.R.L., San Roque F.M. S.A.C., S.M.R.L. Coal Mine, and La Estrella Trading & Logistics S.A.C. These firms differ in strategic performance and exposure to external constraints, making them suitable for comparative assessment.

This setting is relevant for industrial and business economics because it illustrates how small-scale firms in a resource-based industry compete under asymmetric internal capabilities and uneven external conditions. In such industries, firm performance is shaped not only by output and resource endowment but also by market access, organizational capabilities, logistics, regulatory compliance, and institutional stability. Therefore, the Peruvian formal coal subsector offers an appropriate empirical context to examine how firm-level competitiveness and investment attractiveness interact in fragmented extractive industries.

Existing research examines mining performance at different analytical scales. Country-level studies relate geological potential and the investment climate to exploration allocation [8], while recent corporate research jointly evaluates competitiveness and attractiveness in leading Peruvian copper companies [9]. Broader approaches address sustainability-oriented competitiveness [10], national mining contributions [11], firm-level competitive determinants [12], and the interaction between corporate capabilities and external operating conditions [13]. Although these contributions broaden the understanding of mining performance, they differ in their units of analysis, indicators, and strategic purpose.

More recent studies reinforce the value of multidimensional assessment. Söderholm et al. [14] critically examined mining investment-attractiveness rankings and emphasized limitations associated with indicator validity, expert perceptions, and ranking instability. Kouskoura et al. [15] applied AHP to sustainable regional competitiveness, whereas Singh et al. [16] combined AHP and TOPSIS to prioritize strategic alternatives for abandoned surface coal mines. Yu et al. [17] compared several MCDM methods for evaluating sustainability performance across mining areas. These studies demonstrate the usefulness of explicit criteria, structured weighting, and comparative positioning, but focus mainly on jurisdictions, regions, mining areas, large companies, or post-closure alternatives rather than active small-scale firms.

Despite these advances, a gap remains in traceable firm-level frameworks that jointly distinguish endogenous competitiveness from exogenous investment attractiveness in fragmented small-scale extractive industries. This study addresses that gap by using the consolidated title holder as the unit of analysis, applying coal-specific observable rubrics, deriving nested AHP weights, integrating both dimensions through the GE–McKinsey matrix, and evaluating ranking stability through consistency and sensitivity analysis [18–21]. The novelty therefore lies in the contextual and operational extension of established multicriteria tools to Peru's formal coal subsector, rather than in presenting AHP or the GE–McKinsey matrix as new methods.

The remainder of the paper is organized as follows. Section 2 presents the methodology and data. Section 3 analyzes the results and discussion. Section 4 presents the conclusions and policy implications.

2. Methodology and data

2.1. Conceptual framework: competitiveness and attractiveness in coal mining

The strategic performance of mining companies is shaped by the interaction between internal capabilities and the external environment. In extractive industries characterized by high capital intensity, geological dependence, and exposure to institutional conditions, this interaction is essential

for explaining economic viability and competitive positioning.

2.1.1. Competitiveness: internal firm capabilities

Mining competitiveness refers to a firm's capacity to sustain or improve its relative position through efficient resource use, organizational capabilities, and commercial strategies [22]. Classical mining economics emphasizes production scale, productivity, and cost structure as key drivers of competitiveness [23], while more recent perspectives incorporate management quality, market access, and regulatory compliance as critical internal capabilities under operational uncertainty [13].

Accordingly, this study operationalizes competitiveness using four core factors: productive capacity, mineral resource base, commercial positioning, and operational management and compliance. Together, these capture differences in operational scale and continuity, geological endowment, market integration, and alignment with regulatory and environmental standards (see Table 1).

Table 1. Factors and sub-factors of competitiveness and attractiveness in coal mining companies

Dimension	Factor	Sub-factors	References
Competitiveness	Productive capacity	Production scale, operational continuity, and firm operational record	[13, 23]
	Mineral resource base	Number of mining concessions and extent of concession area as indicators of resource endowment	[23, 24]
	Commercial positioning	Export activity, diversification of destinations, and market access	[8]
	Operational management and compliance	Corporate formalization, regulatory compliance, and environmental performance	[4, 11]
Attractiveness	Geological potential of the environment	Geological endowment and mine reserve life	[8, 23]
	Territorial logistical accessibility	Distance to critical infrastructure and transport availability	[22]
	Sectoral market conditions	Industrial demand for mineral and export stability	[2, 24]
	Socio-institutional environment	Social conflicts, social license, legal security, and regulatory stability	[8, 11]

2.1.2. Attractiveness: external operating environmental conditions

Attractiveness refers to the favorability of the external environment for sustaining mining activities and attracting investment. Unlike competitiveness, it is driven by exogenous geological, institutional, logistical, and socioeconomic conditions [11]. In natural resource economics, attractiveness is part of the mining investment climate because it influences capital allocation, perceived risk, and project continuity [24]. Recent evidence also shows that, beyond geological endowment, investment sustainability depends on social conflict dynamics, permitting processes, regulatory stability, and access to critical infrastructure [8]. Accordingly, this study evaluates attractiveness through four factors: geological potential, territorial logistical accessibility, sectoral market conditions, and the socio-institutional environment (see Table 1).

2.2. Company selection and data sources

This study evaluates the competitiveness and investment attractiveness of Peru's leading formal coal mining companies. The sample was defined using three criteria: productive relevance, operational continuity, and availability of verifiable information for 2020–2025. Selection was based on cumulative production reported by the Ministry of Energy and Mines, continuity of formal activity, and active mining concessions recorded in public sectoral registers [25, 26].

Based on these criteria, six representative titleholders were selected: Obras Civiles y Mineras S.A.C., Carbonífera San Benito S.R.L., Minera Santa Mercedes E.I.R.L., San Roque F.M. S.A.C., S.M.R.L. Coal Mine, and La Estrella Trading y Logística S.A.C. Together, they account for a relevant share of formal anthracite and bituminous coal production and exhibit clear heterogeneity in production scale, mining units, territorial location, and commercial integration, making them suitable for comparative strategic assessment.

The 2024 coal-company directory identified 15 registered coal firms in Peru. Of these, six met the three inclusion criteria of productive relevance, operational continuity, and availability of comparable information for 2020–2025 and were retained for the firm-level assessment. The production shares reported in Table 2 were

calculated against total national formal coal production, not against the six-firm subtotal.

The analysis was conducted at the consolidated corporate level by aggregating production across all mining units under each titleholder. This reduces bias associated with unit-level variability and improves inter-firm comparability, consistent with corporate mining economics practice [13, 27]. As shown in Table 2, formal production is concentrated, with one firm contributing nearly one-third of the subsector's output, while all selected firms belong to the small-scale mining producer stratum.

Table 2. Leading coal mining companies in Peru: production concentration and operational characteristics (2020 - 2025)

Rank	Company	Cumulative production (TM)	Share of national formal coal production (%)	Year active	Mining units	Main region	Mining stratum
1	Obras Civiles y Mineras	348,648.49	31.69	6	3	Lima	Small-scale mining producer
2	Carbonífera San Benito	135,484.66	12.31	6	1	La Libertad	Small-scale mining producer
3	Minera Santa Mercedes	122,161.11	11.10	6	2	Lima	Small-scale mining producer
4	San Roque F.M.	92,870.38	8.44	5	2	Áncash	Small-scale mining producer
5	S.M.R.L. Coal Mine	52,007.64	4.73	6	1	Lima	Small-scale mining producer
6	La Estrella Trading y Logística	46,295.46	4.21	6	2	La Libertad	Small-scale mining producer
Selected six firms		797,467.74	72.48				
Other formal producers		302,791.28	27.52				
National formal production		1,100,259.02	100.00				

Note. Production shares were calculated against Peru's total reported formal anthracite and bituminous coal production during 2020–2025, rather than against the production of the six selected firms. The selected companies jointly produced 797,467.74 t, representing 72.48% of the approximately 1.10 million t reported nationally. The remaining 27.52% corresponds to other formal producers not included because they did not simultaneously meet the productive relevance, operational continuity, and data-availability criteria. Source: MINEM [25, 26].

Data were obtained from public, verifiable, and comparable secondary sources, including: MINEM Mining Statistical Bulletins and Yearbooks; administrative records of concessions and mining units from open sectoral platforms; and EITI Peru databases on transparency and formal extractive activity [24]. International sectoral reports and mining economics literature were also reviewed to contextualize the subsector's limited productive scale and fragmentation [5]. To reduce short-term volatility and improve temporal comparability, production indicators were consolidated as cumulative values for 2020–2025 (Figure 1). Therefore, the objective is not a simple production ranking, but a multicriteria comparison of firms' strategic positioning integrating internal and external performance dimensions.

2.3. Justification of the methodological approach

Assessing strategic positioning in coal mining requires methods that go beyond production volumes or reserve availability. In heterogeneous extractive industries, firm performance depends on the interaction of technical, economic, institutional, logistical, and market-related factors. MCDA provides a structured and transparent procedure for integrating heterogeneous evaluation dimensions [18]. Accordingly, this study adopts this approach to assess firm competitiveness and investment attractiveness.

The framework distinguishes two complementary dimensions: internal competitiveness, associated with firm capabilities such as production, resource endowment, commercial integration, and compliance; and external attractiveness, related to geological, logistical, institutional, and market conditions that influence operational viability and investment allocation. This distinction is consistent with mining economics, which recognizes that extractive performance depends on both corporate capabilities and external operating conditions [13, 23]. Both dimensions were operationalized through five-level ordinal rubrics based on literature, standards, and sectoral evidence, allowing observable information to be transformed into

comparable categories while reducing subjectivity [11].

The evaluation criteria were retained according to four requirements: conceptual relevance, applicability to small-scale coal mining, availability of verifiable and comparable information for all firms, and limited overlap among indicators. Internal criteria represent resources and capabilities under firm control, including productive scale, operational continuity, resource endowment, market integration, and compliance. External criteria capture location- and sector-dependent conditions related to geology, logistics, demand, and socio-institutional stability [13, 23]. This separation reduces double counting and preserves a clear economic interpretation of both dimensions. Variables such as operating costs, profitability, capital expenditure, and investment flows were not included because consistent firm-level information was unavailable.

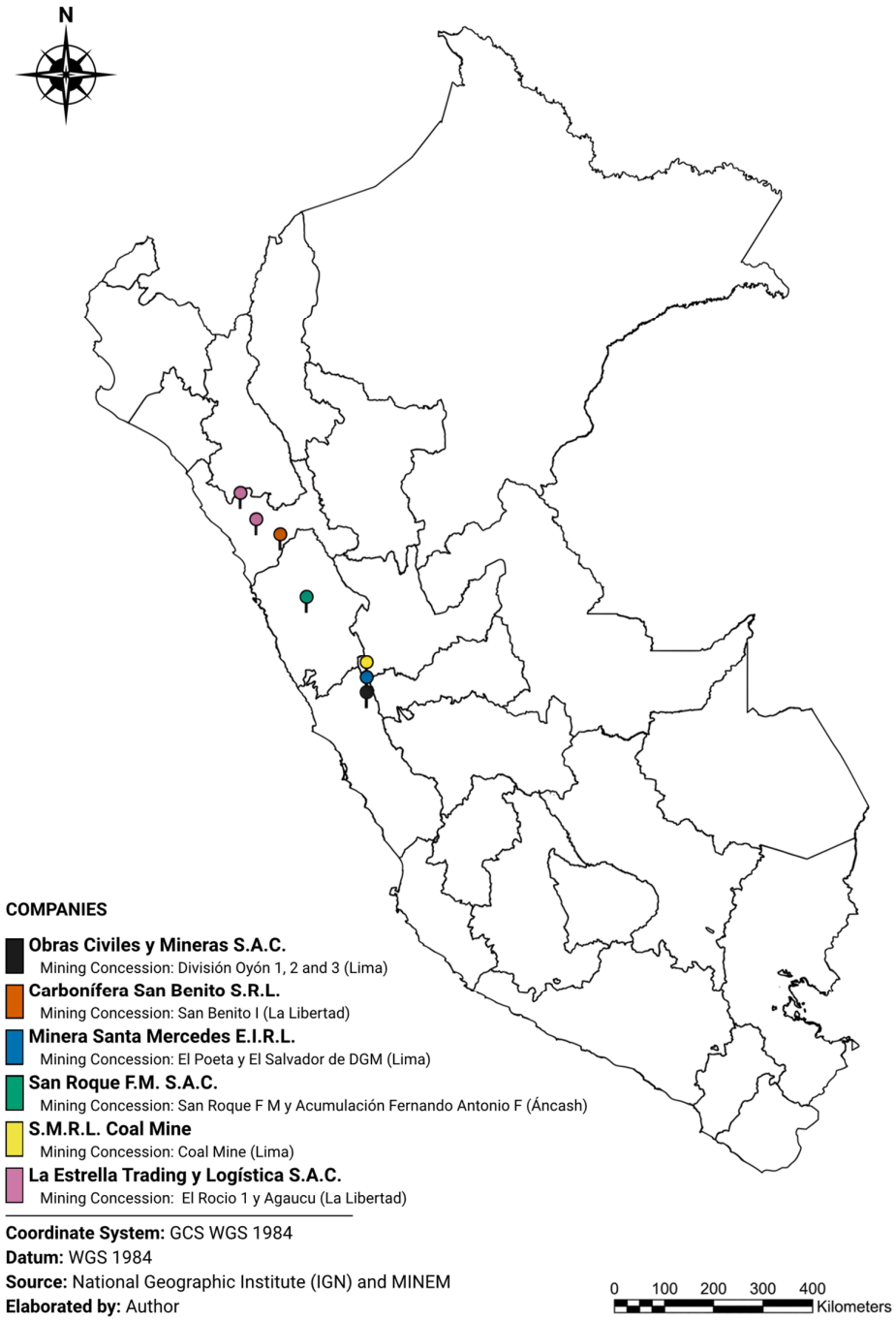

Figure 1. Geographic location of the main coal mining companies in Peru

AHP was used to derive criterion weights through pairwise comparisons, given its wide application in complex decision-making and mining-related evaluations [14, 28, 29]. These weights were used to construct composite competitiveness and attractiveness indices, while the GE-McKinsey matrix was applied to represent firms in a bidimensional strategic space. Finally, methodological consistency was assessed through AHP consistency checks and sensitivity analysis of weights [9, 30] (see Figure 2). The methodological contribution is the traceable adaptation of established multicriteria tools to fragmented small-scale coal producers, linking public evidence, observable scores, hierarchical weights, composite indices, and robustness-tested strategic positions.

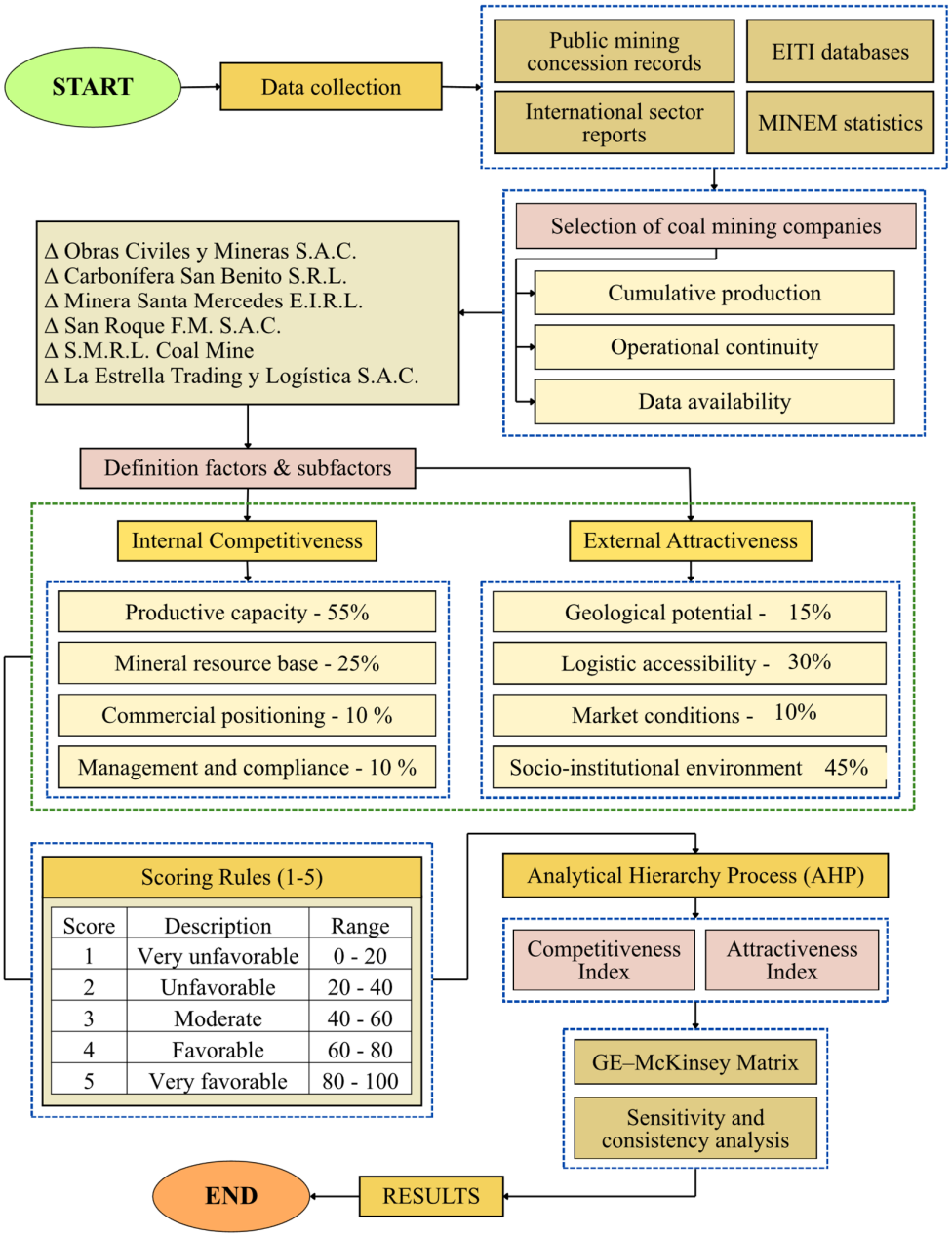

Figure 2. Methodological framework for evaluating competitiveness and attractiveness of coal mining companies in Peru. Blue dashed outlines group related sub-processes, whereas the green dashed outline identifies the two principal analytical dimensions. Light green and orange indicate process initiation and completion; pink identifies selection and intermediate outputs; and yellow–cream tones represent data inputs, criteria, analytical procedures, and results. The colors have no quantitative meaning. The percentages shown for each factor correspond to normalized AHP weights and sum to 100% within each analytical dimension.

2.4. Scoring rules

2.4.1. Scoring rules: competitiveness

Internal competitiveness was evaluated using a five-level ordinal rubric (1–5) to compare firms based on operational capabilities, resource endowment, market integration, and regulatory compliance. This rubric-based approach converts heterogeneous quantitative and qualitative information into comparable categories, improving consistency, transparency, and replicability in multicriteria evaluation [11, 18]. A score of 5 indicates the most favorable competitive condition, while 1 reflects structural constraints that limit sustained operational advantage.

The productive capacity factor captures scale, stability, and operational maturity. Production scale is measured through average annual output (t/year), where higher volumes reflect economies of scale and technical efficiency [23, 27]. Operational continuity is measured by active months per year, reflecting resilience and stability [31], and operational tenure proxies accumulated experience and organizational consolidation [32].

The mineral resource base reflects the geological assets under corporate control and long-term production sustainability. The number of concessions indicates geological diversification and flexibility [13, 23], while concession area proxies reserve potential and supply security [33].

Commercial positioning captures market integration and exposure to commercial risk. Export activity differentiates firms by their degree of integration into international value chains [34], while destination diversification reflects dependence on a limited number of markets versus greater commercial resilience [35]. Finally, management and compliance capture institutional and regulatory performance. Corporate formalization reflects governance and compliance capacity [36], and environmental sanctions provide an observable proxy of environmental management and regulatory risk exposure [37]. The full scoring criteria are summarized in Table 3.

Table 3. Scoring criteria and rubrics for evaluating internal competitiveness of coal mining companies

Factor	Sub-factor	1 (Very unfavorable)	2 (Unfavorable)	3 (Moderate)	4 (Favorable)	5 (Very favorable)
Productive capacity	Production scale (t/year)	< 5 000	5,000 - 20 000	20,000 – 50,000	50,000 - 100,000	> 100,000
	Operational continuity (months/year)	< 4 active months	4 - 6 months	7 - 9 months	10 - 11 months	12 continuous months
	Operational tenure (years)	< 5 years	5 - 10 years	10 - 20 years	20 - 30 years	> 30 years
Mineral resource base	Number of mining concessions	1 concession	2 - 3 concessions	4 - 6 concessions	7 - 10 concessions	> 10 concessions
	Concession area (ha)	< 100 ha	100 - 300 ha	300 - 800 ha	800 – 1,500 ha	> 1,500 ha
Commercial positioning	Export activity (SUNAT records)	No exports	Sporadic exports	Annual exports	Continuous exports	Consolidated exporter
	Destination diversification	1 country	2 countries	3 - 4 countries	5 - 6 countries	> 6 countries
Management and compliance	Corporate formalization	Informal or irregular	Partial registration	Basic formal status	Full formal compliance	Certifications/recognized standards
	Environmental sanctions (OEFA)	> 5 sanctions	3 - 5 sanctions	1 - 2 sanctions	1 sanction	No sanctions

2.4.2. Scoring rules: attractiveness

External attractiveness was assessed using a five-level ordinal rubric (1–5) to capture how favorable the operating environment is for investment and operational continuity. The rubric relies on observable and verifiable criteria, transforming structural external conditions into comparable and replicable categories [11]. A score of 5 indicates a highly favorable environment, while 1 reflects adverse conditions that substantially constrain continuity and investment.

The geological potential factor captures the availability and continuity of coal resources, ranging from limited endowment to extensive proven reserves [23]. Reserve life was estimated using the reserve-to-production ratio (R/P), where R represents the estimated recoverable coal reserves and P represents average annual coal production. The ratio, expressed in years, indicates the approximate period for which current reserves could sustain production at the observed annual rate. Shorter values indicate greater depletion risk, whereas longer values support operational continuity and investment planning [32]. Logistical accessibility reflects transport conditions that shape costs and operational reliability. Distance to port is measured in

kilometers and used as a proxy for logistical burden and competitiveness [31]. Infrastructure access captures the quality and availability of transport routes and supporting services that enable project viability [38].

Market conditions represent demand depth and stability. Sectoral demand is proxied by the number of consumer industries, where higher diversification reduces vulnerability [39]. Export stability was measured using the coefficient of variation of annual export volume during 2020–2025. For each firm, the coefficient was calculated as $CV_i = (\sigma_i/\bar{E}_i) * 100$, where $\bar{E}_i$ is the mean annual export volume and σ_i is its standard deviation over the six-year period. Years without exports were retained as zero because they represent commercial discontinuity. Lower coefficients indicate more stable export activity. Firms with no exports throughout the assessment period were assigned the lowest score [22]. The resulting values were classified as follows: CV > 50% = score 1; 30–50% = score 2; 20–30% = score 3; 10–20% = score 4; and CV < 10% = score 5.

Finally, the socio-institutional environment captures social and regulatory conditions influencing continuity. Social conflicts and social license reflect the stability of community relations and the feasibility of sustained operations [6, 7]. Environmental permits (EIA status) proxy regulatory readiness [11], and legal security reflects the degree of certainty over concession rights, which shapes the investment climate [40]. The full scoring criteria are summarized in Table 4.

Table 4. Scoring criteria and rubrics for evaluating external attractiveness in the coal mining sector

Factor	Sub-factor	1 (Very unfavorable)	2 (Unfavorable)	3 (Moderate)	4 (Favorable)	5 (Very favorable)
Geological potential	Geological potential	Very limited resources	Limited resources	Moderate resources	Significant reserves	Extensive proven reserves
	Reserve life (R/P years)	< 5 years	5 - 10 years	10 - 20 years	20 - 30 years	> 30 years
Logistical accessibility	Distance to port (km)	> 500 km	300 - 500 km	150 - 300 km	50 - 150 km	< 50 km
	Infrastructure access	No adequate transport routes	Limited access	Functional access	Adequate infrastructure	Strategic infrastructure
Market conditions	Sectoral demand (No. of consumer industries)	1 sector	2 sectors	3 sectors	4 sectors	> 4 sectors
	Export stability (coefficient of variation, CV %)	> 50 %	30 - 50 %	20 - 30 %	10 - 20 %	< 10 %
Socio-institutional environment	Social conflicts	> 5 cases	3 - 5 cases	1 - 2 cases	0 - 1 case	No conflicts
	Social acceptance/documented social license	Community rejection	Low acceptance	Partial acceptance	Formal acceptance	Sustained acceptance
	Environmental permits	No EIA	Under review	In process	Approved	Approved + authorized expansions
	Legal stability of concession rights	High uncertainty	Moderate instability	Moderate stability	Legal stability	Very high legal stability

Note. Social acceptance and legal stability were scored using documented evidence for 2020–2025. Social acceptance was based on opposition events, complaints, dialogue processes, agreements, and evidence of their implementation. Legal stability was based on concession validity, continuity of rights, overlaps, disputes, and administrative or judicial proceedings. Mixed evidence was classified using the lower supported score.

Qualitative socio-institutional subfactors were operationalized through documentary evidence rather than social acceptance as a direct perception measure. Social acceptance was assessed as a documentary proxy. A score of 1 was assigned when active community rejection, blockades, stoppages, or formal complaints threatened operational continuity. Score 2 indicated recurrent opposition or unresolved grievances without an effective agreement. Score 3 represented mixed evidence, where dialogue or limited agreements existed but relevant tensions remained unresolved. Score 4 required documented agreements or formal dialogue mechanisms with no major unresolved conflict affecting operations. Score 5 required evidence of sustained agreement implementation, stable cooperation, and absence of material conflict throughout 2020–2025.

Legal stability was assessed through concession validity, continuity of mining rights, documented overlaps, ownership disputes, and administrative or judicial proceedings. Score 1 represented inactive, expired, or materially disputed rights that could

prevent operations. Score 2 indicated valid rights affected by substantial unresolved overlaps, restrictions, or proceedings. Score 3 represented valid and operational rights with minor non-critical observations or pending procedures. Score 4 required active rights without material disputes or proceedings affecting current operations. Score 5 required continuous and updated rights, absence of material overlaps or disputes, and no adverse administrative or judicial proceedings during the assessment period.

Evidence was obtained from official concession records, conflict reports, regulatory documents, and institutional or company disclosures. When the available evidence supported more than one level, the lower category was assigned as a conservative rule. The absence of reported conflict or litigation alone was not sufficient for the highest score.

2.5. AHP weighting

To avoid arbitrary assignment of relative importance across criteria, this study applies the Analytic Hierarchy Process (AHP) at the factor and subfactor levels. No external expert questionnaire or independent elicitation panel was used. Pairwise judgments were formulated jointly by the research team, acting as the decision-making group, based on the cited mining-economics literature, official sectoral evidence, and the structural characteristics of Peru's small-scale coal industry [18, 41, 42, 48]. Accordingly, the resulting weights represent context-specific analytical priorities rather than consensus estimates from a broader expert population. Their internal coherence was assessed through the consistency ratio, and their stability was examined through sensitivity analysis.

The decision-making group comprised all six study authors. Collectively, the group had postgraduate training and professional experience in mineral economics, economics, mining engineering, and multicriteria decision analysis, representing both academic and mining-sector perspectives. Individual identities and institutional affiliations are not disclosed in the anonymized manuscript to preserve the double-blind review process.

The percentages displayed in Figure 2 represent factor-level AHP weights rather than observed performance shares. They were estimated through pairwise comparison matrices using Saaty's 1–9 fundamental scale. The judgments reflected the relative influence of each factor on operational continuity, cost exposure, competitiveness, and investment risk, based on the cited mining-economics literature and the structural characteristics of Peru's small-scale coal industry. The normalized principal eigenvector of each comparison matrix produced the final weights. For internal competitiveness, productive capacity, mineral resource base, commercial positioning, and management and compliance received weights of 0.55, 0.25, 0.10, and 0.10, respectively. For external attractiveness, geological potential, logistical accessibility, market conditions, and the socio-institutional environment received weights of 0.15, 0.30, 0.10, and 0.45. The weights sum to 1.00 within each dimension. The corresponding consistency ratios were 0.063 and 0.017, both below the accepted threshold of 0.10. Their stability was subsequently evaluated through the ±20% sensitivity analysis.

The hierarchy is structured around two dimensions: internal competitiveness (firms' ability to sustain productive, commercial, and organizational advantages) and external attractiveness (geological, logistical, institutional, and market conditions shaping operational viability and the investment climate). These dimensions and their factors are consistent with established natural resource economics and extractive competitiveness literature [13, 23, 43].

In coal mining, competitiveness and attractiveness are strongly influenced by logistics costs, territorial accessibility, and industrial market conditions, and given the predominance of small- and medium-scale operations by institutional risks, formalization capacity, and socio-environmental stability [39, 44]. Equal weighting was not adopted because the criteria differ in their direct influence on operational continuity, cost exposure, and investment risk. AHP was selected because it makes these priorities explicit, preserves hierarchical traceability through local and global weights, and allows judgment consistency to be verified [18, 41, 42].

Methodologically, AHP is implemented through a pairwise comparison matrix $A = [a_{ij}]$, from which the dominant eigenvector w_i is obtained and normalized such that:

$$\sum w_i = 1 \quad (1)$$

Judgment consistency is verified using the Consistency Index (CI) and Consistency Ratio (CR), computed from the maximum eigenvalue of the comparison matrix:

$$CI = \frac{\lambda_{max} - n}{n - 1}, \; CR = \frac{CI}{RI} \quad (2)$$

where λ_{max} is the principal eigenvalue, n is matrix size, and RI is the random index. Values of

$CR < 0.10$ indicate acceptable consistency in pairwise comparisons [18, 45, 46].

For the internal competitiveness dimension, four factors were considered. The resulting normalized weights were: productive capacity (PC) = 0.55, mineral resource base (MRB) = 0.25, commercial positioning (CP) = 0.10, and management and compliance (M&C) = 0.10. The corresponding pairwise comparison matrix is shown in Table 5. These weights indicate that productive capacity is the dominant driver of competitiveness in coal mining due to its direct link to operational scale, technical efficiency, and unit extraction costs. The mineral resource base is the second most important factor, reflecting its role in long-term sustainability and supply security, while commercial positioning and management/compliance act as complementary determinants [23, 33]. The consistency ratio for this matrix was CR = 0.063, within the acceptable threshold. The pairwise comparisons presented in Table 5 were established by consensus among the four-author decision-making group previously described, using Saaty's 1–9 scale. Reciprocal values were assigned to the inverse comparisons.

Table 5. Consensus AHP pairwise-comparison matrix and normalized weights for internal competitiveness factors

Code	Factor	Normalized weight	PC	MRB	CP	M&C
PC	Productive capacity	0.55	1	3	5	5
MRB	Mineral resource base	0.25	1/3	1	3	3
CP	Commercial positioning	0.10	1/5	1/3	1	2
M&C	Management and compliance	0.10	1/5	1/3	1/2	1

Note. Normalized weights were obtained from the principal eigenvector. The consistency ratio was 0.063.

For external attractiveness, four factors were also evaluated. The normalized weights were: geological potential of the environment (GP) = 0.15, territorial logistical accessibility (LA) = 0.30, sectoral market conditions (MC) = 0.10, and socio-institutional environment (SIE) = 0.45. The corresponding AHP matrix is presented in Table 6. The highest weight assigned to the socio-institutional environment reflects the sensitivity of coal operations to social conflict, regulatory stability, and concession security conditions that directly affect operational continuity. Logistical accessibility ranks second, consistent with coal's bulky nature and relatively low unit value, which makes transport costs a decisive determinant of profitability. By comparison, geological potential and market conditions, while relevant, receive lower weights than institutional and territorial constraints [39, 44, 47]. The consistency ratio for this matrix was CR = 0.017, also within the acceptable threshold. The pairwise comparisons presented in Table 6 were established using the same consensus procedure previously described for the four-author decision-making group, following Saaty's 1–9 scale and reciprocal judgments.

Table 6. AHP weighting matrix for external attractiveness factors

Code	Factor	Normalized weight	PC	MRB	CP	M&C
GP	Geological potential	0.15	1	1/2	2	1/3
LA	Logistic accessibility	0.3	2	1	3	1/2
MC	Market conditions	0.1	1/2	1/3	1	1/4
SIE	Socio-institutional environment	0.45	3	2	4	1

Note. Normalized weights were obtained from the principal eigenvector. The consistency ratio was 0.017.

Beyond factor-level weights, subfactor weights were estimated using hierarchical (nested) AHP, avoiding the simplifying assumption of uniform subfactor importance and preserving full traceability of the weighting process. Pairwise comparisons among subfactors followed Saaty's fundamental 1–9 scale and reciprocal values, ensuring internal consistency [48]. For a factor f with global weight w_f and a subfactor j with local weight $w_{j|f}|$, the total (global) weight of subfactor j is:

$$w_j = w_f \cdot w_{j|f} \tag{3}$$

Finally, the composite index for firm i is computed as the weighted sum of the ordinal scores assigned to each subfactor:

$$I_i = \sum_f \sum_{j \in f} (w_f \cdot w_{j|f}) s_{ij}, \;\; s_{ij} \in [1,5] \tag{4}$$

where s_{ij} is the score of firm i in subfactor j. This formulation integrates heterogeneous variables into a single synthetic measure while maintaining a transparent economic interpretation and enabling strategic representation through the GE-McKinsey matrix [13, 49, 50, 51].

2.6. Scaling and evaluation procedure

The evaluation consisted of two stages: (i) transforming ordinal scores into comparable quantitative values and (ii) aggregating results using AHP-derived weights at the subfactor, factor, and dimensional levels. This structure allows heterogeneous information to be integrated in a consistent, traceable, and comparable manner across firms [18, 48].

First, each subfactor was rated on a five-level ordinal scale (1–5) defined by objective thresholds. To enable aggregation, scores were linearly converted to a 0–100 scale as:

$$s_{ij}{}^{(100)} = 20 * s_{ij}, s_{ij} \in 1,2,3,4,5 \quad (5)$$

where s_{ij} is the ordinal score assigned to firm i on subfactor j, and $s_{ij}^{(100)}$ is its normalized value. This transformation preserves proportional performance differences and reduces aggregation distortions [53].

Second, for each factor f, a factor-level score F_{if} was computed as the weighted sum of its normalized subfactor scores:

$$\mathrm{F_{if}} = \sum_{\mathrm{j \in f}} w_{j|f} s_{ij}^{(100)}, \sum_{j \in f} w_{j|f} = 1 \quad (6)$$

where $w_{j|f}$ denotes the local weight of subfactor j within factor f, obtained through nested AHP using pairwise comparisons validated by the AHP consistency criterion ($CR < 0.10$) [18, 48]. The resulting local and global subfactor weights are reported in Table 7 and Table 8.

Table 7. Nested AHP weights for internal competitiveness subfactors

Factor	Sub-factor	Local weight $(w_{j\|f})$	Global weight $(w_f w_{j\|f})$
Productivity capacity (0.55)	Production scale (t/year)	0.40	0.22
	Operational continuity (months/year)	0.35	0.19
	Operational tenure (years)	0.25	0.14
Mineral resource base (0.25)	Number of mining concessions	0.45	0.11
	Concession area (ha)	0.55	0.14
Commercial positioning (0.1)	Export activity (SUNAT records)	0.60	0.06
	Destination diversification	0.40	0.04
Management and compliance (0.1)	Corporate formalization	0.55	0.06
	Environmental sanctions (OEFA)	0.45	0.05

Table 8. Nested AHP weights for external attractiveness subfactors

Factor	Sub-factor	Local weight $(w_{j\|f})$	Global weight $(w_f w_{j\|f})$
Geological potential (0.15)	Geological potential	0.55	0.08
	Reserve life (R/P years)	0.45	0.07
Logistic accessibility (0.3)	Distance to port (km)	0.45	0.14
	Infrastructure access	0.55	0.17
Market conditions (0.1)	Sectoral demand (No. of consumer industries)	0.60	0.06
	Export stability (annual variability %)	0.40	0.04
Socio-institutional environment (0.45)	Social conflicts	0.25	0.11
	Social license	0.30	0.14
	Environmental permits	0.20	0.09
	Legal security	0.25	0.11

Finally, the overall composite index for firm i was obtained by aggregating factor scores using the global factor weights w_f:

$$Index_i = \sum_{j \in f} w_f F_{if}, \qquad \sum_f w_f = 1 \quad (7)$$

Since all subfactors are normalized to 0–100, the composite index also lies within:

$$Index_i \in [0, 100] \quad (8)$$

This procedure supports a direct interpretation of relative firm performance, enables the identification of strengths and weaknesses across strategic dimensions, and facilitates graphical representation through the GE-McKinsey matrix, which is commonly used in extractive industry strategy analysis [13, 49, 53].

2.7. GE-McKinsey matrix: construction and interpretation

The GE-McKinsey matrix was used to position firms based on two dimensions: internal competitiveness and external attractiveness. This tool is suitable for mining because it summarizes multidimensional information in a clear strategic format, especially in capital-intensive and high-risk sectors [49, 54].

In this study, the matrix was constructed using the AHP-based competitiveness and attractiveness indices, both normalized on a 0–100 scale. Competitiveness was placed on the horizontal axis and attractiveness on the vertical axis. The matrix was divided into low, medium, and high levels using cut-off points of 33 and 67, resulting in nine strategic zones [51].

The interpretation was defined as follows: high–high positions indicate consolidation and selective growth; high competitiveness with low attractiveness suggests optimization and risk control; low competitiveness with high attractiveness indicates the need for internal strengthening; and low–low positions suggest restructuring or rationalization. Thus, the matrix facilitates strategic comparison, investment prioritization, and sectoral decision-making by integrating firm capabilities with external operating conditions [50, 51, 53] (see Figure 3).

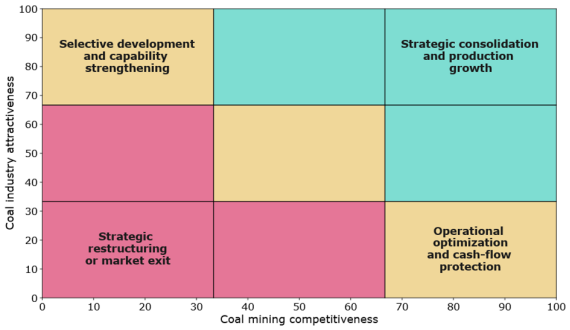

Figure 3. GE-McKinsey matrix for strategic positioning of coal mining companies in Peru. Competitiveness is represented on the horizontal axis and investment attractiveness on the vertical axis. Both dimensions are divided into low, medium, and high levels using thresholds of 33 and 67. Teal indicates investment, consolidation, or growth; yellow represents selective development, capability strengthening, or optimization; and pink indicates restructuring, risk reduction, or possible market exit. The colors provide strategic orientation only and do not represent additional quantitative variables.

3. Results and Discussion

3.1. Competitiveness analysis

The internal competitiveness of the analyzed coal mining companies was assessed using the ordinal rubrics defined in Table 3, considering four dimensions: productive capacity, mineral resource base, commercial positioning, and operational management and compliance. This approach captures the main endogenous capabilities that shape firm performance in Peru's formal coal subsector, which is dominated by small-scale producers and characterized by technological and organizational heterogeneity [23, 55].

Productive capacity shows clear differences among firms. During 2020–2025, Obras Civiles and Mineras S.A.C. recorded the highest average annual output, with 58,108 t/year, followed by Carbonífera San Benito S.R.L. and Minera Santa Mercedes E.I.R.L., with 22,581 and 20,360 t/year, respectively. The remaining firms reported lower production volumes, reflecting a more limited operational scale [26]. This pattern supports the relevance of production scale as a determinant of efficiency, unit costs, and labor productivity [13, 56]. Operational continuity was high across the sample, as five of the six firms remained active throughout the six-year period, indicating relative stability despite market and logistical constraints [26, 57]. Most firms also reported more than a decade of activity, suggesting accumulated experience and institutional maturity [58].

The mineral resource base also differentiates competitiveness. Obras Civiles and Mineras show the broadest geological position, with three active mining units and more than 2,000 ha of concession area [59]; Minera Santa Mercedes, San Roque F.M., and La Estrella Trading operate with two concessions, whereas Carbonífera San Benito and S.M.R.L. Coal Mine depend on a single concession, implying greater geological concentration [25, 26]. These differences are relevant because resource endowment influences production continuity, expansion capacity, and resilience to market fluctuations [23].

Commercial positioning shows moderate differentiation. Obras Civiles and Mineras and Minera Santa Mercedes maintained continuous export activity, while Carbonífera San Benito and San Roque F.M. reported annual exports, and the remaining firms showed more limited export presence [26, 34]. This suggests that market access and destination diversification remain uneven across the subsector, despite evidence of increasing

international integration of Peruvian coal exports [8].

Management and compliance also influence relative competitiveness in small-scale formal mining, where legal and environmental conditions affect operational continuity [11]. All firms are registered as formal small-scale producers, although they differ in administrative capacity, infrastructure, and compliance standards. Obras Civiles and Mineras and S.M.R.L. Coal Mine show stronger industrial and logistical infrastructure, while most firms reported between zero and one minor environmental sanction according to available OEFA records [37, 60, 61].

Overall, competitiveness in Peru's formal coal subsector is mainly driven by production scale, operational continuity, and resource endowment, while commercial positioning and compliance capacity introduce additional differences among firms. Obras Civiles and Mineras present the strongest competitive profile, followed by Carbonífera San Benito and Minera Santa Mercedes. By contrast, S.M.R.L. Coal Mine, San Roque F.M., and La Estrella Trading show more constrained profiles associated with smaller scale, narrower geological diversification, and limited commercial integration. Table 9 reports the consolidated subfactor scores used to compute the composite competitiveness index.

Table 9. Comparative assessment of internal competitiveness of Peruvian coal mining companies

Factor	Sub-factor	Obras Civiles y Mineras	Carbonífera San Benito	Minera Santa Mercedes	San Roque F.M.	S.M.R.L. Coal Mine	La Estrella Trading & Logistics
Productivity capacity	Production scale	4	3	3	2	2	2
	Operational continuity	5	5	5	4	5	5
	Operational tenure	4	4	4	3	3	3
Mineral resource base	Number of mining concessions	2	1	2	2	1	2
	Concession area	5	4	4	3	3	3
Commercial positioning	Export activity	4	3	4	3	2	2
	Market diversification	4	3	3	3	2	3
Management & compliance	Corporate formalization	5	3	4	3	5	4
	Environmental sanctions	5	5	5	5	5	5

3.2. Attractiveness analysis

The external attractiveness of Peru's formal coal mining subsector was assessed using the ordinal rubrics defined in Table 4, considering four dimensions: geological potential, logistical accessibility, market conditions, and the socio-institutional environment. This approach identifies how external conditions facilitate or constrain coal mining viability, particularly in a subsector dominated by small-scale producers and institutional heterogeneity [23, 43].

The results show clear territorial differences in coal resource endowment. Carbonífera San Benito S.R.L. and La Estrella Trading y Logística S.A.C. operate in La Libertad, within the Alto Chicama coal basin, widely recognized as Peru's main coal district and characterized by high-energy anthracite and the largest share of recoverable coal resources in the country [62]. In contrast, firms operating in Oyón (Lima) and Yungay (Áncash), such as Obras Civiles y Mineras S.A.C., Minera Santa Mercedes E.I.R.L., S.M.R.L. Coal Mine, and San Roque F.M. S.A.C., are located in more fragmented basins, although they demonstrate stronger formal production continuity and operational stability [26].

Geological potential therefore favors Carbonífera San Benito and La Estrella Trading, which receive the highest scores (Level 5), while Obras Civiles y Mineras and Minera Santa Mercedes obtain favorable ratings due to proven continuity in Oyón [59, 61]. Reserve life remains favorable for Oyón operations, with estimated horizons exceeding 20–30 years, whereas La Estrella Trading, S.M.R.L. Coal Mine, and San Roque F.M. show more moderate production horizons [63, 64].

Logistical accessibility shows more balanced but still constrained conditions. Firms in Lima benefit from paved-road connectivity to Lima and the Port of Callao, while San Roque F.M. has intermediate access to northern coastal ports. In La Libertad, Carbonífera San Benito and La Estrella Trading are closer to the Port of Salaverry, but unpaved roads reduce effective accessibility [65, 66, 67]. This confirms that distance alone does not determine logistics quality; road conditions and transport reliability are also decisive.

Market conditions indicate a relatively diversified demand base. Peruvian coal supplies cement, steel, and brick manufacturing industries, including Cementos Pacasmayo, UNACEM, and

Aceros Arequipa, which support favorable sectoral demand scores across all firms [68]. However, export stability varies: Obras Civiles y Mineras shows lower interannual variability; Carbonífera San Benito, Minera Santa Mercedes, and La Estrella Trading show intermediate stability; while S.M.R.L. Coal Mine and San Roque F.M. present higher variability (see Table 9).

The socio-institutional environment is one of the main differentiating factors of attractiveness [11]. Carbonífera San Benito and La Estrella Trading face greater exposure to social conflict due to tensions associated with informal mining and territorial disputes, while firms in Oyón report more stable community relations and fewer preventive incidents [69]. Environmental permitting also favors Obras Civiles y Mineras and Minera Santa Mercedes, which hold approved and updated instruments under the MINEM framework, whereas other firms operate mainly under simplified instruments [60, 61, 70]. Legal security is stronger in Oyón, while overlap with informal mining reduces stability in parts of La Libertad.

Overall, external attractiveness in Peru's formal coal subsector is shaped mainly by the interaction of geological potential, logistics, and socio-institutional stability. Alto Chicama offers the strongest geological advantages, but these are partly offset by logistical limitations, territorial conflict, and informal mining. By contrast, Oyón and Yungay show more balanced conditions, supported by better infrastructure, stronger formalization, and lower socio-environmental risk. At the firm level, Obras Civiles y Mineras leads the attractiveness profile, followed by Minera Santa Mercedes and S.M.R.L. Coal Mine, while Carbonífera San Benito and La Estrella Trading face stronger socio-institutional constraints. Table 10 reports the consolidated subfactor scores used to compute the composite external attractiveness index.

Table 10. Nested AHP weights for external attractiveness subfactors

Factor	Sub-factor	Obras Civiles y Mineras	Carbonífera San Benito	Minera Santa Mercedes	San Roque F.M.	S.M.R.L. Coal Mine	La Estrella Trading & Logistics
Geological potential	Geological potential	4	5	4	3	3	5
	Reserve life (R/P)	4	4	4	3	3	3
Logistic accessibility	Distance to port	3	4	3	3	3	4
	Infrastructure access	4	3	4	3	4	3
Market conditions	Sector demand	4	4	4	4	4	4
	Export stability	4	3	3	2	2	3
Socio-institutional environment	Social conflicts	4	2	4	4	4	2
	Social license	4	3	4	3	4	4
	Environmental permits	4	3	4	3	3	3
	Legal security	4	3	4	3	4	3

3.3. Summary of scores and strategic interpretations using AHP and the GE-McKinsey matrix

Table 11 reports the AHP-based competitiveness index. Productive capacity is the dominant driver of competitiveness, with a weight of 0.55, confirming the importance of operational scale, continuity, and technical efficiency in solid mineral industries [13]. This result is consistent with the structure of Peru's formal coal segment, where small-scale producers face constraints in scaling output and maintaining stable production.

Table 11. Competitiveness Index (AHP) of coal mining companies in Peru

Companies	Productive capacity (0.55)	Mineral resource base (0.25)	Commercial positioning (0.10)	Management & compliance (0.10)	Competitiveness index
Obras Civiles y Mineras	47.9	18.3	8.0	10.0	84.1
Carbonífera San Benito	43.5	13.3	6.0	7.8	70.5
Minera Santa Mercedes	43.5	15.5	7.2	8.9	75.1
San Roque F.M.	32.5	12.8	6.0	7.8	59.0
S.M.R.L. Coal Mine	36.3	10.5	4.0	10.0	60.8
La Estrella Trading & Logistics	36.3	12.8	4.8	8.9	62.8

Obras Civiles and Mineras S.A.C. obtains the highest competitiveness score (84.1), supported by stronger productive performance, a broader resource base, and a more consolidated export

positioning. Minera Santa Mercedes E.I.R.L. (75.1) and Carbonífera San Benito S.R.L. (70.5) form a second group, with relatively high competitiveness supported by operational continuity and formalization but limited by smaller production scale. La Estrella Trading y Logística S.A.C. (62.8), S.M.R.L. Coal Mine (60.8), and San Roque F.M. S.A.C. (59.0) show lower scores, mainly due to smaller scale, narrower geological diversification, and weaker commercial integration. These results suggest that productivity improvements and cost-reducing operational strategies are central for strengthening small-scale formal coal producers [71].

Table 12 presents the external attractiveness index. The socio-institutional environment is the most influential factor, with a weight of 0.45, highlighting the relevance of legal stability, conflict management, and environmental compliance for mining investment viability in Peru [11, 71]. Logistical accessibility is the second most important factor, with a weight of 0.30, reflecting the high transport-cost sensitivity of coal.

Table 12. External attractiveness index (AHP) of the coal mining subsector

Companies	Geological potential (0.15)	Logistic accessibility (0.30)	Market conditions (0.10)	Socio-institutional environment (0.45)	Attractivenes s index
Obras Civiles y Mineras	12.0	21.3	8.0	19.8	61.1
Carbonífera San Benito	13.7	20.7	7.2	12.6	54.2
Minera Santa Mercedes	12.0	21.3	7.2	19.8	60.3
San Roque F.M.	9.0	18.0	6.4	17.1	50.5
S.M.R.L. Coal Mine	9.0	21.3	6.4	19.8	56.5
La Estrella Trading & Logistics	12.3	20.7	7.2	15.3	55.5

Obras Civiles and Mineras S.A.C. (61.1) and Minera Santa Mercedes E.I.R.L. (60.3) obtain the highest attractiveness scores, supported by better logistics, lower exposure to social conflict, and stronger concession security. S.M.R.L. Coal Mine (56.5) occupies an intermediate position, while La Estrella Trading y Logística S.A.C. (55.5) and Carbonífera San Benito S.R.L. (54.2) are constrained by more complex socio-institutional conditions in the Alto Chicama basin. San Roque F.M. S.A.C. records the lowest attractiveness score (50.5), mainly due to weaker geological conditions and less favorable logistics.

Using the GE-McKinsey framework, firms were positioned according to their competitiveness and attractiveness indices (Figure 4). Obras Civiles and Mineras occupy the strongest relative position, combining high competitiveness with medium attractiveness, which supports strategies of production consolidation and selective growth. Minera Santa Mercedes and Carbonífera San Benito are located in an upper-intermediate zone, where relatively high competitiveness coexists with external constraints, particularly socio-institutional and logistical conditions. For these firms, strategic priorities should focus on capability consolidation, territorial risk reduction, and institutional stability.

La Estrella Trading and S.M.R.L. Coal Mine are positioned closer to the central area, reflecting moderate competitiveness and attractiveness. Their strategic priorities should emphasize operational optimization, commercial diversification, and institutional strengthening. San Roque F.M. occupies the lower-middle area, suggesting the need to improve scale, continuity, and risk management before considering expansion. Overall, the matrix indicates that, within Peru's formal coal subsector, competitiveness differences are more decisive than attractiveness gaps. This highlights production consolidation, formalization, and operational efficiency as core strategic challenges, consistent with the view that internal capability building often precedes the full capture of external opportunities in emerging extractive industries [50].

The common color scheme facilitates direct comparison between the conceptual matrix and the empirical results. Obras Civiles y Mineras, Minera Santa Mercedes, and Carbonífera San Benito are located in the teal high-competitiveness and medium-attractiveness zone, indicating scope for selective consolidation and growth, subject to improvements in external conditions. La Estrella Trading, S.M.R.L. Coal Mine, and San Roque F.M. occupy the yellow medium–medium zone, where capability strengthening and operational optimization are more appropriate than immediate expansion. No firm is positioned in the high–high or pink strategic zones.

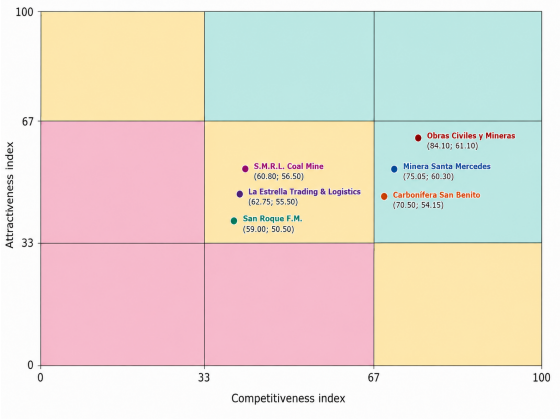

Figure 4. Strategic positioning of Peruvian coal mining companies using the GE-McKinsey matrix. Teal indicates investment, consolidation, or growth; yellow represents selective development or optimization; and pink indicates restructuring, risk reduction, or possible market exit. Marker colors distinguish the individual firms only and have no strategic or quantitative meaning.

3.4. Sensitivity analysis and statistical validation

The sensitivity assessment was conducted at two levels. First, weighting uncertainty was examined by varying one AHP factor weight at a time by ±20%, keeping all firm scores unchanged and renormalizing the complete weight vector to sum to 1.00. Sensitivity effects were calculated as signed deviations from the baseline index, where $\Delta I = I_{scenario} - I_{baseline}$. This analysis tests whether the composite indices and rankings depend excessively on the assumed relative importance of the factors. Second, input and scoring uncertainty were examined for selected subfactors. Average annual production was varied by ±20%, after which the production-scale rubric was reapplied and the competitiveness index was recalculated. Because export activity and corporate formalization are ordinal rather than continuous variables, percentage changes were not applied directly. Instead, their scores were shifted by one adjacent rubric level upward and downward, within the 1–5 scale, and the resulting indices and rankings were recomputed.

For the competitiveness index, productive capacity generated the largest variations, confirming that operational scale is the main structural determinant of competitiveness in Peru's formal coal subsector. Carbonífera San Benito and S.M.R.L. Coal Mine showed the highest sensitivity to this factor, indicating a stronger dependence on scale-related performance. By contrast, Obras Civiles and Mineras showed lower sensitivity, suggesting a more balanced competitive structure supported not only by production scale but also by management, resource base, and commercial positioning. Changes in the mineral resource base weight did not modify the underlying number or area of concessions. Increasing the weight only strengthened the contribution of the existing resource-base scores to the competitiveness index. Consequently, firms with more concessions and larger concession areas gained relative influence, whereas firms with fewer concessions or smaller areas received a lower relative contribution after weight renormalization. Reducing the weight had the opposite effect by decreasing the influence of resource-base differences and increasing the relative contribution of the remaining factors. Thus, the sensitivity result reflects a change in criterion importance, not a reduction in geological diversification.

Commercial positioning and management/compliance produced smaller changes. For Obras Civiles y Mineras, increasing the commercial-positioning weight by 20% reduced the index by 0.08 points, whereas decreasing it increased the index by 0.08 points because its commercial-positioning score was below its overall competitiveness index. For San Roque F.M., the corresponding effects were +0.02 and −0.02 points because its commercial-positioning score was slightly above its overall index. The same-sign values previously displayed in Figure 5 resulted from a plotting error and were corrected.

For the attractiveness index, the socio-institutional environment was the most influential factor, consistent with its highest weight (0.45). Perturbations in this factor produced the largest index changes, especially for Carbonífera San Benito and La Estrella Trading y Logística, whose operations are more exposed to territorial conflicts, informal mining, and governance constraints. Firms located in Oyón, such as Obras Civiles and Mineras and Minera Santa Mercedes, showed lower sensitivity, reflecting more stable institutional settings and fewer territorial disputes. Logistical accessibility was the second most influential factor, although its impact was lower than that of socio-institutional conditions. Geological potential and market conditions generated smaller changes, generally below ±0.5 points.

These results indicate that attractiveness differences are driven less by resource endowment alone and more by institutional stability, logistics, and territorial governance. The relative ranking of firms remained unchanged under the ±20% factor-

weight perturbations (Figure 6), supporting the stability of the attractiveness model and highlighting the importance of policies aimed at reducing informality, improving legal security, and strengthening territorial governance.

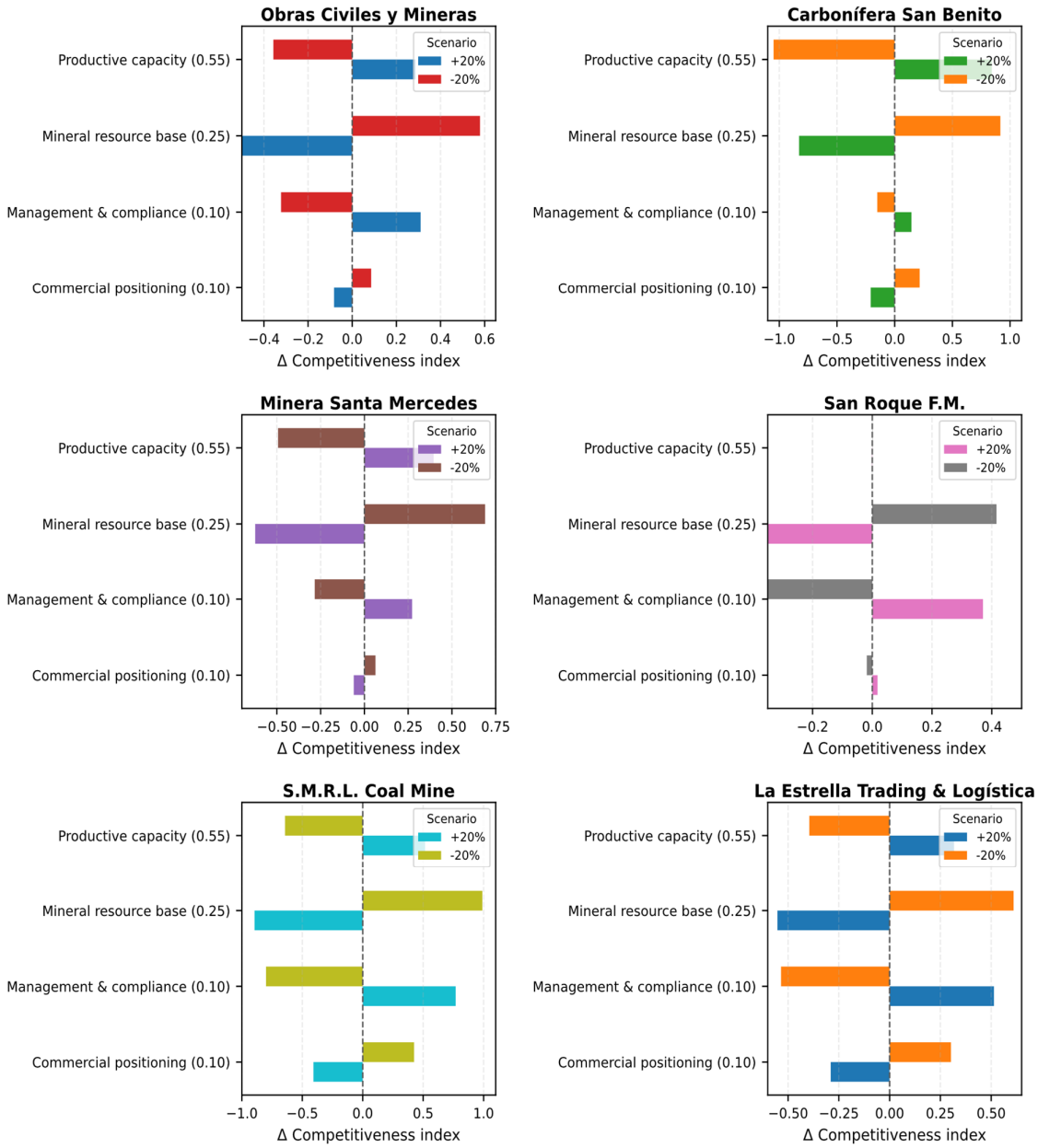

Figure 5. Sensitivity analysis of the competitiveness index

The production-input sensitivity analysis reveals a limited but relevant threshold effect. A 20% production decrease moved Obras Civiles y Mineras, Carbonífera San Benito, and Minera Santa Mercedes down by one rubric level, reducing their competitiveness indices by approximately 4.4 points, although the ordering of the three leading firms remained unchanged. Conversely, a 20% increase moved San Roque F.M. from production level 2 to level 3, increasing its index from 59.0 to 63.4 and shifting its relative position from sixth to fourth. S.M.R.L. Coal Mine and La Estrella Trading remained within the same production category under both scenarios. Thus, the ranking is stable under factor-weight perturbations but may show local changes when continuous inputs cross predefined rubric thresholds (see Table 13).

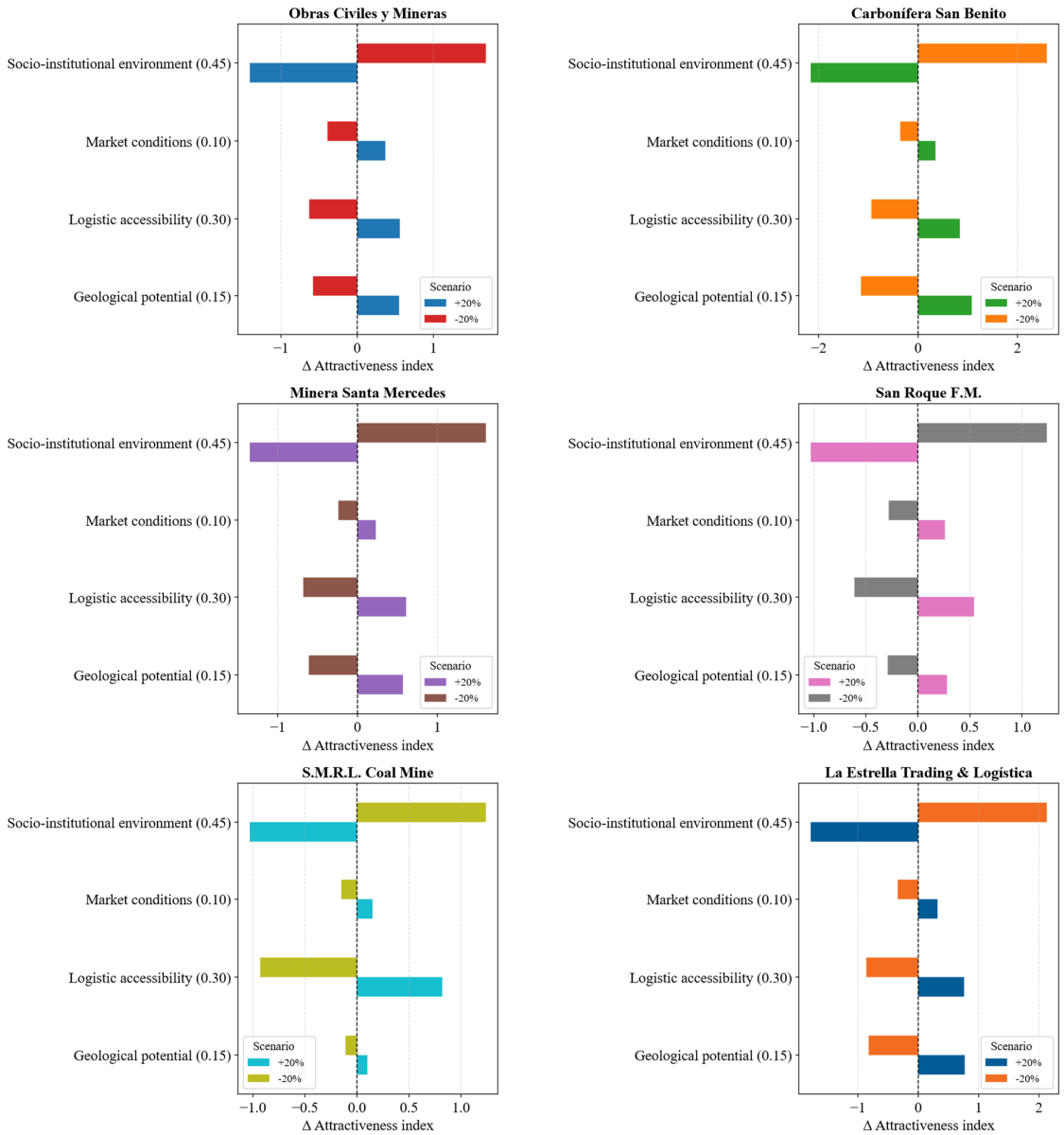

Figure 6. Sensitivity analysis of the attractiveness index

Table 13. Sensitivity of the competitiveness index to ±20% changes in annual production

Company	Baseline production (t/year)	Baseline rubric	-20% rubric	+20% rubric	Index under -20%	Baseline index	Index under +20%
Obras Civiles y Mineras	58,108.00	4	3	4	79.70	84.10	84.10
Carbonífera San Benito	22,581.00	3	2	3	66.10	70.50	70.50
Minera Santa Mercedes	20,360.00	3	2	3	70.70	75.10	75.10
San Roque F.M.	18,574.00	2	2	3	59.00	59.00	63.40
S.M.R.L. Coal Mine	8,668.00	2	2	2	60.80	60.80	60.80
La Estrella Trading & Logistics	7,716.00	2	2	2	62.80	62.80	62.80

Note. Annual production was varied before applying the rubric thresholds. A change of one production-scale category modifies the normalized score by 20 points and the overall competitiveness index by approximately 4.4 points, given the global production-scale weight of 0.22.

For ordinal indicators, a direct percentage perturbation would incorrectly treat qualitative categories as continuous measurements. Therefore,

export activity and corporate formalization were evaluated through one-level upward and downward scenarios. A one-level change in export activity modified the competitiveness index by a maximum of 1.2 points, while a one-level change in corporate formalization produced a maximum variation of 1.1 points. Neither scenario altered the firm ranking, indicating that these subfactors have a limited individual effect under the adopted weighting structure.

The internal statistical validation of the composite AHP model was based on three elements: AHP consistency, sensitivity stability, and structural coherence. First, the pairwise comparison matrices reported acceptable consistency ratios, with CR = 0.063 for competitiveness and CR = 0.017 for attractiveness, both below the 0.10 threshold proposed by Saaty. This indicates internal coherence in the weighting procedure [9, 52]. Second, the model remained stable under ±20% factor-weight perturbations, with no changes in firm rankings and only limited variation in index values. Third, internal correlations between composite indices and factor blocks were consistent with the theoretical structure of the model (Figure 7).

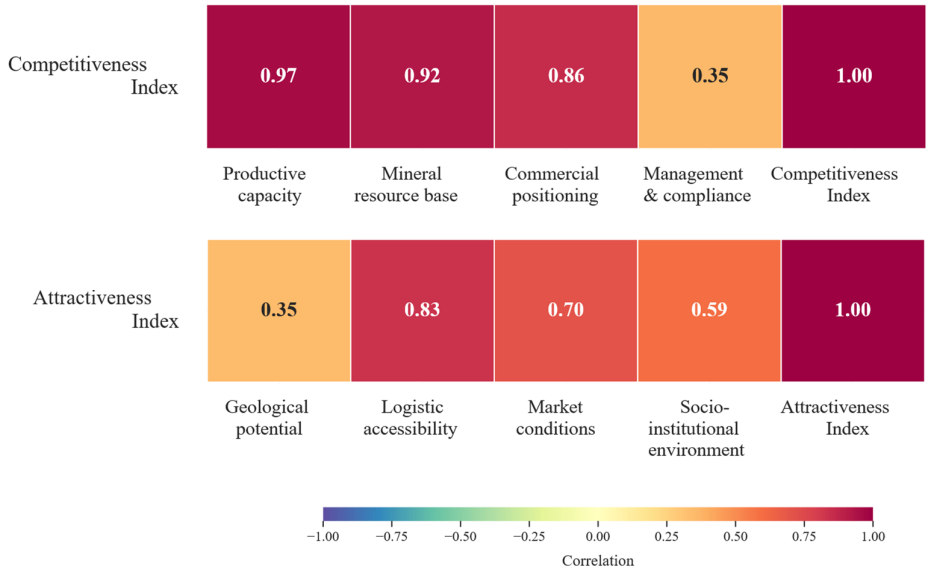

Figure 7. Internal structural correlations between competitiveness and attractiveness drivers

For competitiveness, strong associations were observed with productive capacity ($\rho = 0.97$), mineral resource base , ($\rho = 0.92$)and commercial positioning ($\rho = 0.86$), confirming the predominance of operational and geological drivers. Management and compliance showed a more moderate association ($\rho = 0.35$), suggesting a complementary role. For attractiveness, stronger associations were observed with logistical accessibility ($\rho = 0.83$), market conditions , ($\rho = 0.70$)and the socio-institutional environment ($\rho = 0.59$), while geological potential showed a lower association ($\rho = 0.35$). Given the small sample size ($n = 6\ firms$), these coefficients should be interpreted as indicators of internal coherence rather than population-level inference. Overall, the convergence of acceptable AHP consistency, stable rankings, and theoretically coherent correlations supports the methodological reliability of the proposed composite indices for strategic analysis of Peru's formal coal subsector. Table 14 shows the convergent comparison between competitiveness and cumulative production rankings.

Table 14. Convergent comparison between competitiveness and cumulative production rankings

Company	Competitiveness index	Competitiveness rank	Cumulative production (t)	Production rank	Absolute rank difference
Obras Civiles y Mineras	84.10	1	348,648.49	1	0
Carbonífera San Benito	70.50	3	135,484.66	2	1
Minera Santa Mercedes	75.10	2	122,161.11	3	1
San Roque F.M.	59.00	6	92,870.38	4	2
S.M.R.L. Coal Mine	60.80	5	52,007.64	5	0
La Estrella Trading & Logistics	62.80	4	46,295.46	6	2

As a convergent validity check, the competitiveness ranking was compared with cumulative formal production during 2020–2025. The rankings showed positive agreement (Spearman's $\rho = 0.714$; $p = 0.111$; n = 6). Obras Civiles and Mineras ranked first in both measures, and the same three firms occupied the leading group, although their internal order differed. This result supports directional coherence but does not constitute independent external validation because production scale is one component of the competitiveness index, and the small sample limits statistical inference. An equivalent comparison was not feasible for attractiveness because comparable firm-level data on investment flows, profitability, operating costs, or capital expenditure are not publicly available. Therefore, the validation should be interpreted as internal and convergent rather than predictive or causal.

3.5. Comparative synthesis and scientific interpretation of strategic positioning

The GE-McKinsey matrix reveals not only differences in firm rankings but also a structural asymmetry between internal competitiveness and external attractiveness. Competitiveness scores range from 59.0 to 84.1, a difference of 25.1 points, whereas attractiveness varies from 50.5 to 61.1, a narrower interval of 10.6 points. Within the analyzed sample, this greater dispersion indicates that firm-controlled capabilities differentiate strategic positions more strongly than the external environment, which remains partly shared through common national market and regulatory conditions. Nevertheless, the narrower attractiveness range should not be interpreted as evidence that external factors are unimportant, because logistical and socio-institutional constraints determine whether productive and geological advantages can be converted into viable investment conditions [11, 23, 72].

Obras Civiles and Mineras occupy the strongest relative position because their productive scale is reinforced by resource availability, export integration, and comparatively favorable institutional conditions. Minera Santa Mercedes also combines solid internal capabilities with a balanced external environment. Carbonífera San Benito presents a different configuration: despite its favorable geological potential and relatively strong competitiveness, its attractiveness is reduced by logistical limitations and socio-institutional exposure. This contrast suggests that geological endowment is not sufficient to generate a favorable strategic position when territorial governance, infrastructure, and legal certainty remain constrained.

The middle-lower positions also reflect different combinations of weaknesses rather than a single pattern of underperformance. La Estrella Trading shows moderate competitiveness and geological advantages but faces stronger territorial constraints. S.M.R.L. Coal Mine benefits from comparatively stable external conditions and formalization, although its limited scale and commercial integration restrict competitiveness. San Roque F.M. combines the lowest competitiveness and attractiveness scores, indicating simultaneous internal and external constraints. These configurations show that firms within the same small-scale subsector may require different improvement pathways depending on whether their main limitation arises from productive capability, market integration, logistics, or institutional conditions.

From a scientific perspective, the findings support a conditional relationship between internal capabilities and external operating conditions. Strong firm capabilities improve relative positioning, but their strategic value depends on an enabling territorial and institutional environment. Conversely, favorable external conditions cannot fully compensate for limited scale, weak market integration, or a narrow resource base. The results therefore extend firm-level competitiveness analysis by showing that strategic position emerges from the configuration of both dimensions rather than from any isolated indicator, consistent with evidence from other Peruvian mining segments [9].

These interpretations remain comparative rather than causal. The matrix identifies observable strategic configurations within the selected firms, but it does not demonstrate that changes in a specific factor will necessarily produce improvements in profitability, investment, or production. Consequently, the strategic orientations associated with each matrix zone should be understood as diagnostic orientations for managerial and policy assessment, not as validated forecasts or prescriptive decisions [46, 68, 69].

3.6. Global context and comparative interpretation

Peru's formal coal subsector operates in a global market dominated by large-scale producers. In 2023, China, India, Indonesia, the United States, and Australia accounted for more than 80% of global coal production, while Peru's cumulative

formal coal output during 2020–2025 was approximately 1.10 Mt [73]. This contrast confirms the very small international scale of Peru's formal coal segment.

This scale gap matters because coal competitiveness depends strongly on production volume, logistics integration, and the capacity to reduce unit transport costs. Large producers benefit from rail networks, high-capacity ports, and broad domestic markets, whereas Peruvian formal coal firms depend more on road access, territorial conditions, and institutional stability [74].

However, scale alone does not explain strategic performance. International studies show that legal security, infrastructure quality, institutional stability, and social acceptance strongly influence mining investment decisions [74]. Coal-sector research further incorporates socioeconomic, health, and environmental effects when evaluating long-term sustainability [75]. These contributions broaden the analysis beyond production and geological endowment, but they mainly operate at national, regional, or sectoral levels and therefore provide limited evidence on why firms exposed to similar market conditions occupy different strategic positions.

Mining-related MCDM studies offer greater methodological structure by weighting criteria and comparing alternatives under technical, economic, environmental, and territorial considerations [76–78]. Nevertheless, their decision units are generally projects, processing locations, sustainability scenarios, or strategic alternatives rather than operating firms. Research on developing mining economies also confirms the importance of governance and environmental constraints [79], but it commonly provides qualitative or sector-wide diagnoses without translating these conditions into comparable competitiveness and attractiveness indices.

Recent studies confirm both the relevance and the limitations of these approaches. Kouskoura et al. [15] applied AHP to sustainable regional competitiveness, Singh et al. [16] combined AHP and TOPSIS to prioritize alternatives for repurposing abandoned surface coal mines, and Yu et al. [17] compared multiple MCDM methods to evaluate mining-area sustainability. Although these studies strengthen criterion selection, weighting, and multidimensional assessment, their units of analysis remain regions, sites, or alternatives. The present study differs by evaluating formal operating firms, separating internal capabilities from external conditions, and connecting observable evidence with nested weights, composite indices, strategic positioning, and robustness analysis.

4. Conclusion and policy implications

4.1. Conclusions

This study provides comparative evidence on the strategic positioning of six formal coal firms in Peru using an integrated AHP–GE-McKinsey framework. Within the adopted criteria and weighting structure, productive capacity makes the largest contribution to the competitiveness index, while the socio-institutional environment and logistical accessibility contribute most strongly to investment attractiveness. Obras Civiles and Mineras occupy the strongest joint position, followed by Minera Santa Mercedes and Carbonífera San Benito, whereas the remaining firms present different combinations of productive, commercial, logistical, and institutional constraints.

The findings indicate that internal capabilities generate greater differentiation among the analyzed firms, while external conditions shape the extent to which productive and geological advantages can be translated into favorable strategic positions. In particular, the comparison between geological potential and final attractiveness suggests that resource endowment alone does not offset infrastructure deficiencies, territorial conflict, or legal uncertainty. These results support the analytical relevance of evaluating competitiveness and attractiveness jointly rather than relying exclusively on production or reserves.

The consistency ratios and ±20% factor-weight perturbations support the internal coherence and local stability of the weighting structure, while the production-input and ordinal scoring scenarios identify limited threshold sensitivity in selected subfactors. The comparison with cumulative production provides additional convergent evidence under the tested assumptions. However, they do not constitute independent predictive validation. The production comparison provides convergent evidence only because productive scale is already included in the competitiveness index. Accordingly, the rankings should be interpreted as comparative strategic benchmarks for the selected firms, not as causal estimates of performance or forecasts of future investment outcomes.

The findings are bounded by the small sample, reliance on public secondary information, rubric-based scoring, context-specific weights, and the absence of comparable data on costs, profitability,

capital expenditure, and investment flows. Therefore, they should not be generalized beyond the selected firms and study period without additional evidence.

Overall, the demonstrated contribution is the development of a traceable firm-level procedure that separates internal capabilities from external operating conditions and converts heterogeneous public records into comparable strategic positions. Its application to benchmarking, investment screening, or other extractive industries remains a potential extension that would require sector-specific recalibration, independent expert assessment, and external validation.

4.2. Policy implications

The following implications should be interpreted as priorities suggested by the observed strategic patterns rather than as evidence of the causal effectiveness of specific policies. Their implementation would require additional economic appraisal, stakeholder consultation, and evaluation of firm- and territory-specific conditions.

The findings suggest that Peru's formal coal industry could benefit from coordinated actions addressing both firm-level capabilities and the broader investment climate. Since socio-institutional and logistical factors carry the greatest weight in the attractiveness index, three areas warrant consideration. First, territorial governance and formalization could be supported through clearer concession enforcement, credible permitting processes, and stronger coordination between national and subnational institutions. Second, conflict-prevention and social-licence mechanisms could be reinforced through early-warning systems, community engagement, and transparent grievance-resolution channels. Third, logistical constraints could be addressed through road improvements, reduced bottlenecks to ports and industrial consumers, and better access to reliable transport services.

From a business strategy perspective, productivity improvement, technical assistance, compliance capacity, and commercial diversification may warrant greater attention than production expansion alone. For managers and investors, the framework may support preliminary benchmarking, investment screening, and identification of firm-specific weaknesses. For policymakers, the results suggest that competitiveness in small-scale resource-based industries is associated not only with firm capabilities but also with the institutional and logistical conditions surrounding their operations.

4.3. Limitations and future research

This study is limited to six formal coal firms and relies on rubric-based scores constructed from public secondary sources. The findings are therefore not statistically generalizable beyond the selected firms and the 2020–2025 study period. The absence of comparable firm-level information on operating costs, profitability, capital expenditure, and investment flows prevented independent external validation of the rankings. The comparison with cumulative production provides only convergent evidence because production scale is already included in the competitiveness construct.

No external expert questionnaire was administered; consequently, the AHP judgments reflect the evidence-informed priorities of the author decision-making group rather than consensus from an independent multidisciplinary panel. The ordinal scoring thresholds, linear normalization procedure, and fixed 33/67 boundaries of the GE–McKinsey matrix simplify continuous variation and may affect the classification of firms located near strategic-zone limits. Although acceptable consistency ratios and sensitivity analysis support internal robustness, the results should be interpreted as comparative strategic benchmarks rather than causal or predictive measures.

Social license was assessed through documentary proxies and may therefore not fully capture current community perceptions, informal relationships, or changes not reflected in public records. Future research should validate this subfactor through interviews, community surveys, and participatory stakeholder assessments; recalibrate the AHP weights through independent multidisciplinary elicitation; incorporate longitudinal financial and operational outcomes; compare alternative multicriteria methods; and test whether strategic positions are associated with subsequent investment, export continuity, profitability, or compliance performance.

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رقابت پذیری و جذابیت سرمایه گذاری در سطح شرکت در صنعت رسمی زغال سنگ پرو: یک رویکرد موقعیت یابی استراتژیک چند معیاره

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ماتریس GE-McKinsey

چکیده

این مطالعه، موقعیت استراتژیک شرکت‌های اصلی معدن زغال سنگ رسمی پرو را با ادغام رقابت‌پذیری در سطح شرکت و جذابیت سرمایه‌گذاری در یک چارچوب چندمعیاره شفاف ارزیابی می‌کند. شش دارنده سند مالکیت نماینده با استفاده از معیارهای عینی مربوط به ارتباط تولیدی، تداوم عملیاتی و در دسترس بودن اطلاعات قابل تأیید برای سال‌های ۲۰۲۰-۲۰۲۵ انتخاب شدند. رقابت‌پذیری از طریق ظرفیت تولیدی، پایگاه منابع معدنی، موقعیت تجاری و مدیریت و انطباق ارزیابی شد، در حالی که جذابیت سرمایه‌گذاری از طریق پتانسیل زمین‌شناسی، دسترسی لجستیکی، شرایط بازار و محیط اجتماعی-نهادی ارزیابی شد. روبریک‌های ترتیبی به مقیاس ۰-۱۰۰ تبدیل شدند، با استفاده از فرآیند سلسله مراتبی تحلیلی وزن‌دهی شدند و از طریق شاخص‌های ترکیبی و ماتریس جنرال الکتریک-مک‌کینزی (GE-McKinsey) ترکیب شدند. نتایج، یک صنعت زغال سنگ رسمی تکه‌تکه شده را نشان می‌دهد که تحت سلطه تولیدکنندگان کوچک با پروفایل‌های استراتژیک ناهمگن است. ظرفیت تولیدی محرک اصلی رقابت‌پذیری شرکت است، در حالی که محیط اجتماعی-نهادی و لجستیک عوامل اصلی تعیین‌کننده جذابیت سرمایه‌گذاری هستند. شرکت‌های Obras Civiles و Mineras قوی‌ترین موقعیت‌های استراتژیک کلی را ثبت کرده‌اند و پس از آنها Minera Santa Mercedes و Carbonífera San Benito قرار دارند. آزمون‌های حساسیت بر اساس آشفتگی‌های وزنی ±۲۰٪، رتبه‌بندی‌های پایداری را نشان می‌دهند که از استحکام ارزیابی چندمعیاره پشتیبانی می‌کند. این مطالعه، تطبیق قابل ردیابی در سطح شرکت از چارچوب AHP-GE-McKinsey را برای صنایع استخراجی کوچک و پراکنده، با ترکیب روبریک‌های مخصوص زغال‌سنگ، وزن‌های تو در تو و آزمایش استحکام، ارائه می‌دهد.

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