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Strategic Management of Sector-Specific ESG KPIs in Technology-Intensive Industries

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Abstract: The mining industry is characterized by high technological intensity, capital-intensive operations and significant environmental and social impacts. As a result, Environmental, Social and Governance (ESG) performance measurement in the sector requires indicators that reflect industry-specific technologies and operational realities. This paper examines the strategic management of sector-specific ESG KPIs in the mining industry and their role in achieving sustainable competitive advantage. Adopting a management-oriented perspective, the study analyses how mining companies align ESG KPIs with extraction and processing technologies, operational risks and strategic objectives. A conceptual framework is developed to illustrate the relationship between mining technologies, ESG KPI selection and strategic management practices. The analysis demonstrates that mining companies that effectively manage sector-specific ESG KPIs are better positioned to improve operational transparency, manage environmental and social risks and integrate sustainability into core decision-making processes. The findings suggest that sector-specific ESG KPIs function as strategic management tools in the mining industry, enabling firms to move beyond compliance and leverage sustainability as a driver of long-term competitiveness. The study contributes to the management of technology literature by addressing performance measurement and strategic control in complex, technology-intensive industrial systems.

Keywords: ESG KPIs, Mining industry, Strategic performance management, Management of technology, Technology-intensive industries.

Introduction

ESG Challenges in the Mining Industry

The mining industry occupies a structurally complex position within the sustainability discourse, as it simultaneously underpins economic development and the green transition while generating significant environmental and social externalities. Mining activities are inherently technology-intensive, capital-intensive, and site-specific, resulting in material impacts that include land disturbance, biodiversity loss, high water and energy consumption, greenhouse gas emissions, tailings generation, and elevated occupational health and safety risks. (Dimov et al, 2020) These impacts are not incidental but are intrinsically linked to extraction and processing technologies, ore characteristics, and operational scale, making sustainability performance in mining fundamentally different from that in less resource-intensive sectors (Azapagic, 2004; Hilson, 2012).

Over the past decade, stakeholder expectations toward the mining industry have intensified considerably. Regulators, investors, financial institutions, downstream manufacturers, and local communities increasingly demand transparent, credible, and decision-useful information on how mining companies identify, manage, and mitigate ESG-related risks. This shift reflects a broader transformation in corporate sustainability governance, whereby ESG considerations are no longer treated as peripheral reputational concerns but as determinants of

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operational continuity, access to finance, and long-term competitiveness (Eccles et al., 2014; Friede et al., 2015). In mining, this transformation is particularly pronounced due to the sector's exposure to high-consequence environmental and social risks and its reliance on long-lived assets with irreversible impacts. Good practices and approaches aimed at enhancing innovation potential contribute to the more efficient use of natural resources and to reducing resource depletion. They are included in the policies for social, corporate and environmental responsibility of the mining companies (Galabova & Trifonova, 2018).

The institutionalization of ESG expectations has further accelerated through the expansion and consolidation of sustainability reporting and disclosure frameworks. At the global level, the emergence of investor-oriented standards such as the IFRS Sustainability Disclosure Standards has reinforced the integration of ESG considerations into corporate governance, strategy, and risk management, while explicitly encouraging the use of industry-based guidance to enhance relevance and comparability (IFRS Foundation, 2023). In parallel, the European Union has introduced an extensive regulatory architecture through the Corporate Sustainability Reporting Directive and the European Sustainability Reporting Standards, which require companies to disclose sustainability information based on a double materiality perspective, linking impact materiality with financial materiality (European Commission, 2023; European Union, 2023).

For the mining industry, these developments have profound implications. Sector-specific sustainability standards, most notably the GRI 14: Mining Sector 2024 standard, explicitly acknowledge that generic sustainability disclosures are insufficient to capture the industry's impact profile. Instead, they emphasize the need for disclosures and indicators that reflect mining-specific technologies, operational risks, and lifecycle considerations, including site-level impacts and long-term liabilities (Global Reporting Initiative, 2024). This recognition aligns with earlier scholarship highlighting that sustainability challenges in mining are best understood as sociotechnical systems in which environmental, social, and governance outcomes are co-produced by engineering design, operational practices, and institutional arrangements (Azapagic & Perdan, 2000; Jenkins & Yakovleva, 2006).

A particularly illustrative example is tailings management, which has emerged as a critical ESG issue following several high-profile failures with catastrophic environmental and social consequences. The Global Industry Standard on Tailings Management frames tailings governance as a zero-harm aspiration supported by integrated technical, environmental, and social requirements throughout the facility lifecycle (UNEP, 2020). The existence of such sector-specific standards underscores a central argument of this study: in mining, ESG performance is inseparable from technological choices and operational controls, and therefore requires measurement systems that are explicitly aligned with these determinants.

Why Universal KPIs Do Not Work

Despite growing recognition of sectoral specificities, ESG measurement in practice continues to rely heavily on universal, cross-sector key performance indicators. These indicators are often designed to facilitate comparability across industries and geographies, yet their applicability to mining is increasingly contested. Research on ESG metrics and ratings consistently demonstrates substantial heterogeneity in indicator selection, weighting, and aggregation methods, leading to divergent assessments of corporate ESG performance even for the same firm (Berg et al., 2022; OECD, 2020). Such divergence reflects deeper methodological tensions between financially oriented ESG metrics and impact-oriented sustainability measurement, with significant implications for managerial decision-making.

In the mining industry, the limitations of universal ESG KPIs are particularly acute for several reasons. First, mining impacts are technologically mediated and highly site-specific. Universal indicators often obscure critical differences arising from extraction methods, processing technologies, ore grades, and local environmental conditions. For example, a single water-use or emissions intensity metric may fail to distinguish between operations facing fundamentally different hydrological constraints or energy systems, thereby providing limited insight into actual environmental risk exposure or improvement potential (Azapagic, 2004).

Second, material ESG issues in mining are unevenly distributed across environmental, social, and governance dimensions and vary significantly across commodities, jurisdictions, and project lifecycles. Sector-focused standards such as GRI 14 explicitly reflect this logic by prioritizing material topics that are likely to be significant for mining organizations and their stakeholders, rather than prescribing a uniform set of indicators applicable to all sectors (Global Reporting Initiative, 2024). The very existence of such standards constitutes an implicit critique of universal KPI approaches, suggesting that sectoral impact logic must precede indicator selection.

Third, mining operates under a pronounced legitimacy constraint shaped by social license to operate considerations. Community acceptance, trust in risk management practices, and perceptions of procedural fairness play a decisive role in project viability and operational continuity. While these dimensions are difficult to quantify, their strategic relevance is well documented in the mining and development literature (Prno & Slocombe, 2012; Owen & Kemp, 2013). Universal ESG KPIs frequently underrepresent these relational and process-oriented aspects, focusing instead on simplified output metrics that may inadequately capture social risk dynamics.

Fourth, and most critically from a management perspective, universal ESG KPIs often fail to support strategic decision-making. While such indicators may satisfy external disclosure requirements, they are not necessarily designed to guide internal resource allocation, technology selection, or risk governance. Empirical studies of ESG ratings in the mining sector indicate weak or inconsistent relationships between aggregated ESG scores and financial performance, suggesting that these metrics may reflect disclosure intensity or firm size rather than underlying operational performance (Fikru, 2021). This disconnect undermines the utility of universal KPIs as instruments of strategic management in technology-intensive industries.

Motivation and Contribution of the Study

Against this backdrop, this paper advances the argument that ESG KPIs in the mining industry should be conceptualized primarily as strategic management instruments, rather than as standardized reporting artifacts. While contemporary regulatory and voluntary frameworks increasingly acknowledge the importance of industry-based disclosures, a gap remains between disclosure-oriented indicator systems and KPI frameworks explicitly designed for strategic integration into mining governance, investment decisions, and operational control.

This study addresses this gap by proposing a sector-specific, management-oriented perspective on ESG KPIs grounded in the technological characteristics of mining operations. It contends that mining technologies constitute first-order determinants of ESG materiality and performance and must therefore serve as the starting point for KPI design and strategic management. By articulating a conceptual framework that links mining technologies, sector-specific ESG KPI design, and strategic management practices, the paper contributes to the literature on management of technology and sustainability by demonstrating how ESG KPIs can support sustainable competitive advantage in a sector increasingly defined by sustainability constraints and stakeholder scrutiny.

This Study Makes Three Distinct Contributions to Literature

First, it reframes ESG KPIs in the mining industry from disclosure-oriented metrics to *strategic management instruments* explicitly shaped by extraction and processing technologies. Second, it advances the management of technology literature by conceptualizing ESG KPIs as mediating mechanisms between technological systems and competitive outcomes in high-risk industrial environments. Third, the paper develops a sector-specific framework that links technological determinants, ESG KPI design, and strategic performance management, thereby addressing a gap between sustainability measurement and strategic decision-making in technology-intensive industries.

Literature Review

ESG KPIs in the Mining Sector

The academic literature on ESG performance in the mining sector consistently emphasizes the inadequacy of generic sustainability indicators to capture the sector's distinctive impact profile. Early contributions in the field of sustainability assessment in mining already highlighted that environmental and social impacts are deeply embedded in extraction and processing technologies, site-specific geological conditions, and long project lifecycles (Azapagic, 2004; Azapagic & Perdan, 2000). As a result, ESG performance measurement in mining has long been recognized as fundamentally different from that in manufacturing or service-oriented industries.

Subsequent research has expanded this perspective by examining how ESG indicators are operationalized through corporate reporting and performance management systems. Studies on sustainability disclosure in the mining industry reveal significant variation in the scope, depth, and consistency of ESG metrics used by firms, even within the same commodity group or jurisdiction (Jenkins & Yakovleva, 2006; Fonseca et al., 2014). This variation is often attributed to differences in operational technologies, regulatory environments, and stakeholder

pressures, suggesting that ESG KPIs in mining are shaped as much by technological and institutional contexts as by managerial intent.

More recent literature has focused on the growing formalization of ESG measurement through sector-specific standards and guidance. The introduction of mining-focused disclosure frameworks reflects a recognition that sectoral materiality must precede indicator selection. These frameworks emphasize ESG topics such as tailings management, water stewardship, occupational health and safety, community engagement, and mine closure, which are directly linked to mining technologies and operational risks (Global Reporting Initiative, 2024). Academic analyses interpret this sectoral turn as an attempt to enhance the decision-usefulness of ESG information by aligning indicators with the underlying drivers of impact and risk (Sullivan & Gouldson, 2017).

Despite these advances, a recurring critique in the literature is that ESG KPIs in mining remain predominantly disclosure-oriented. Empirical studies show that many indicators are selected to satisfy external reporting expectations rather than to support internal decision-making, resulting in limited integration of ESG KPIs into strategic planning and operational control (Lodhia & Hess, 2014; Fonseca, 2010). This critique is reinforced by research on ESG ratings in the mining sector, which demonstrates weak correlations between aggregated ESG scores and financial or operational performance, raising questions about the managerial relevance of widely used metrics (Fikru, 2021; Berg et al., 2022).

Collectively, the literature suggests that while ESG KPIs are increasingly institutionalized in the mining sector, their strategic potential remains underdeveloped. Existing studies tend to focus on what is disclosed rather than on how ESG indicators are managed, governed, and used as instruments of strategic control. This gap provides a critical entry point for research that repositions ESG KPIs as elements of strategic management rather than as static reporting artifacts.

Technology-Intensive Industries and Sustainability Measurement

The concept of technology-intensive industries is well established in the management and industrial economics literature, where such industries are characterized by high capital intensity, complex production systems, long asset lifecycles, and strong path dependencies shaped by technological choices (Pavitt, 1984; Tidd & Bessant, 2018). Mining is frequently cited as a paradigmatic example of a technology-intensive industry, given its reliance on specialized extraction and processing technologies, large-scale infrastructure, and irreversible environmental interventions.

Within this body of literature, technology is not treated merely as an operational input but as a structural determinant of organizational behavior, risk exposure, and performance outcomes. Research on management of technology emphasizes that technological systems constrain and enable strategic choices, influencing cost structures, flexibility, learning trajectories, and competitive positioning (Grant, 2016). From this perspective, sustainability performance in technology-intensive industries cannot be decoupled from the technological architectures through which value is created.

Studies examining sustainability in technology-intensive sectors highlight that environmental and social impacts are often non-linear, cumulative, and characterized by high uncertainty. In mining, these characteristics are evident in areas such as tailings storage, groundwater interactions, and occupational safety, where technological failures can result in disproportionate consequences (Prior et al., 2012). As a result, performance measurement systems in such industries must be capable of capturing risk dynamics and long-term liabilities, rather than relying solely on short-term efficiency indicators.

The literature further indicates that technology-intensive industries face heightened scrutiny from regulators and investors precisely because of these risk characteristics. This has contributed to the proliferation of sector-based sustainability standards and the increasing expectation that firms demonstrate robust governance of technology-related ESG risks (UNEP, 2020; OECD, 2020). However, scholars note that the translation of these expectations into effective performance measurement remains uneven, with many firms struggling to align sustainability metrics with technological realities (Schaltegger et al., 2017).

Importantly, research on technology-intensive industries underscores the limits of cross-sector comparability in performance measurement. Indicators designed for broad applicability often obscure critical differences in technological risk profiles and impact pathways, thereby reducing their explanatory and managerial value (Kaplan

& Norton, 2001). This insight reinforces the argument that ESG KPIs in mining must be explicitly grounded in sector-specific technologies if they are to support meaningful management decisions.

Strategic Performance Management and ESG Integration

Strategic performance management (SPM) literature provides a critical lens for understanding how ESG KPIs can move beyond disclosure to become instruments of strategic control. Classical contributions to SPM conceptualize performance measurement systems as mechanisms for translating strategy into operational terms, aligning organizational behavior with strategic objectives, and enabling feedback and learning (Kaplan & Norton, 1996; Neely et al., 2005). Within this framework, KPIs are not neutral metrics but selective representations of what organizations choose to value and manage.

Recent extensions of SPM theory explicitly incorporate sustainability considerations, arguing that environmental and social performance must be integrated into core management systems to achieve long-term value creation (Schaltegger & Wagner, 2011; Gond et al., 2012). This stream of literature emphasizes that sustainability-oriented KPIs should be embedded in strategic planning, capital allocation, and risk management processes, rather than treated as parallel or supplementary reporting tools.

However, empirical evidence suggests that such integration remains limited, particularly in technology-intensive industries. Studies examining ESG integration into performance management systems find that while firms increasingly monitor ESG indicators, these metrics are often decoupled from strategic decision-making and incentive structures (Crutzen et al., 2017). In mining, this decoupling is exacerbated by the dominance of externally driven ESG requirements, which prioritize comparability and disclosure over internal controllability and strategic relevance.

The strategic management literature also highlights the importance of context-specific KPIs in environments characterized by high uncertainty and irreversible investments. In such settings, performance indicators must support risk-informed decision-making and long-term planning, rather than short-term optimization (Simons, 1995; Grant, 2016). Applied to mining, this implies that ESG KPIs should reflect technological risk profiles, lifecycle considerations, and stakeholder dependencies, enabling managers to anticipate and mitigate sustainability-related constraints on competitiveness.

Taken together, the literature on strategic performance management suggests that ESG KPIs can contribute to sustainable competitive advantage only when they are strategically designed, contextually grounded, and actively managed. Yet, existing research rarely examines how these principles apply in the mining industry, where technological intensity and sustainability risks intersect most strongly. This gap underscores the need for a sector-specific, management-oriented framework that connects mining technologies, ESG KPI design, and strategic performance management—an objective directly addressed by the present study.

Methodology

Research Design and Conceptual Orientation

This study adopts a conceptual and qualitative research design, appropriate for addressing research questions that are exploratory, theory-building, and integrative in nature. The objective is not to test predefined hypotheses or quantify causal effects, but to develop a theoretically grounded framework that explains how sector-specific ESG KPIs can be strategically managed in the mining industry, given its technology-intensive characteristics. Such an approach is well established in the management and sustainability literature, particularly where existing empirical evidence is fragmented and where conceptual clarification is required to advance understanding (Eisenhardt, 1989; Meredith, 1993; Jaakkola, 2020).

Conceptual research is especially relevant in the context of ESG KPIs in mining for two reasons. First, the rapid evolution of ESG-related standards, regulations, and practices has outpaced the development of stable, cumulative theory, resulting in a body of literature that is rich in descriptive insights but limited in integrative frameworks. Second, ESG KPIs operate at the intersection of technology, governance, and strategy, making them difficult to analyze through single-method empirical designs without prior conceptual structuring. Accordingly, this study positions conceptual development as a necessary precursor to future empirical testing and model refinement.

Development of the Conceptual Framework

The conceptual framework proposed in this study was developed through an iterative process of analytical abstraction and synthesis of insights from three interrelated bodies of literature:

1. ESG measurement and reporting in the mining sector,
2. management of technology and technology-intensive industries, and
3. strategic performance management.

Following established principles of conceptual framework development, the process involved identifying key constructs, clarifying their boundaries, and specifying theoretically plausible relationships among them (Whetten, 1989; Miles et al., 2014). Rather than aggregating variables in a statistical sense, the framework organizes analytical layers that reflect different levels of decision-making and causality: technological determinants, ESG KPI design, strategic management practices, and competitive outcomes.

Mining technologies are positioned as the foundational layer of the framework, reflecting insights from technology management theory that technological systems shape organizational constraints, risk profiles, and strategic options (Grant, 2016; Tidd & Bessant, 2018). ESG KPIs are conceptualized as a translation mechanism that converts technology-driven impacts and risks into measurable indicators suitable for managerial use. Strategic management practices constitute the central mediating layer, where ESG KPIs are integrated into planning, investment appraisal, and risk governance processes. The framework culminates in sustainable competitive advantage as an outcome, consistent with strategic management literature that links performance measurement systems to long-term value creation when they are aligned with organizational context and strategy (Kaplan & Norton, 1996; Neely et al., 2005).

Importantly, the framework is analytical rather than prescriptive. It does not propose a universal set of KPIs or managerial actions, but instead provides a structured logic for understanding how ESG KPIs can be designed and managed in a sector where technology is a primary driver of sustainability performance. This orientation aligns with calls in the sustainability and management literature for theory-building approaches that respect sectoral heterogeneity and contextual specificity (Schaltegger et al., 2017; Jaakkola, 2020).

Qualitative Analysis of Standards, Reports, and Sectoral Practices

To ground the conceptual framework in real-world practices and enhance its analytical robustness, the study employs a qualitative document-based analysis of selected standards, sustainability reports, and sectoral practices relevant to the mining industry. Qualitative analysis of documentary sources is a well-established method in sustainability and management research, particularly where the objective is to interpret institutional logics, governance arrangements, and performance measurement practices rather than to generate statistically generalizable results (Bowen, 2009; O'Dwyer, 2004). The analysis focuses on three categories of sources.

First, sustainability standards and regulatory frameworks relevant to ESG measurement in mining were examined. These include global and sector-specific standards that articulate material ESG topics, disclosure expectations, and performance indicators for the mining industry. Such standards are treated as institutionalized expressions of collective expectations regarding what constitutes relevant and credible ESG performance in the sector (Global Reporting Initiative, 2024; IFRS Foundation, 2023). The analysis concentrates on how these frameworks address sector specificity, technological impacts, and the role of KPIs in governance and risk management, rather than on detailed compliance requirements.

Second, corporate sustainability reports of mining companies were reviewed to identify prevailing practices in ESG KPI selection and presentation. Sustainability reports are widely recognized as key artifacts through which organizations communicate their sustainability priorities and performance, while simultaneously revealing internal measurement logics and managerial emphases (Jenkins & Yakovleva, 2006; Fonseca, 2010). The analysis does not seek to evaluate the credibility or completeness of individual reports, but rather to observe patterns in how ESG KPIs are framed, linked to operations, and embedded (or not embedded) in strategic narratives.

Third, sectoral practices and industry initiatives were analyzed to capture how ESG risks and performance are addressed beyond formal reporting. This includes industry-level guidance on critical issues such as tailings management, occupational health and safety, and community engagement, which often reflect tacit knowledge and shared norms within the sector (UNEP, 2020; Owen & Kemp, 2013). These sources provide insight into how

ESG KPIs are implicitly shaped by technological risk domains and operational priorities, even when not explicitly labeled as “KPIs” in corporate disclosures.

The qualitative analysis followed a structured interpretive approach, involving iterative reading, thematic coding, and comparison across different categories of documentary sources (Miles et al., 2014). The analysis focused on identifying recurring patterns in how ESG KPIs are linked to technological processes, risk management structures, and strategic narratives within the mining sector. Particular attention was paid to cross-document consistency and divergence, as well as to the stated purposes of ESG KPIs, including reporting, risk management, and performance improvement. The insights derived from this analysis informed the specification of KPI categories and managerial linkages presented in Table 1, ensuring that the proposed conceptual framework is grounded in observed sectoral practices rather than normative or abstract assumptions.

Methodological Rigor and Limitations

The methodological rigor of the study is ensured through theoretical triangulation and transparent articulation of analytical assumptions. By integrating insights from multiple literature streams and documentary sources, the study reduces the risk of overreliance on a single perspective or normative framework. At the same time, the conceptual and qualitative nature of the research entails inherent limitations. The proposed framework is not empirically tested and does not claim statistical generalizability. Instead, it is intended as a theory-building and sense-making device, suitable for guiding future empirical research and informing managerial practice in the mining industry.

Such limitations are consistent with the aims of conceptual research in management and sustainability studies, where the development of coherent explanatory frameworks is recognized as a valuable scholarly contribution in its own right (Whetten, 1989; Jaakkola, 2020). Future research may build on this study by empirically testing the framework through case studies, surveys, or mixed-method designs across different mining contexts and commodities.

Strategic Management of ESG KPIs in the Mining Industry

The strategic management of ESG KPIs in the mining industry requires a deliberate shift from disclosure-oriented measurement toward decision-oriented performance management. In technology-intensive sectors such as mining, ESG KPIs acquire strategic relevance only when they are explicitly linked to operational processes, technological constraints, and governance mechanisms. This section operationalizes the proposed conceptual framework by examining how environmental, social, and governance KPIs function as strategic management instruments in the mining context, rather than as isolated reporting metrics. To operationalize the proposed conceptual framework and to illustrate the strategic role of ESG KPIs in the mining industry, Table 1 presents a set of sector-specific ESG KPIs aligned with key technological drivers, managerial relevance, and potential contributions to sustainable competitive advantage. The table provides an integrative overview of how environmental, social, and governance KPIs translate technology-driven impacts into strategic management instruments, which are subsequently discussed in detail in the following subsections.

Illustrative Application of Strategic ESG KPIs in a Mining Context

Consider a large-scale copper mining operation characterized by energy-intensive comminution processes and long-life tailings facilities. In this context, energy intensity per unit of output functions not only as an environmental indicator but as a strategic KPI informing investment decisions related to equipment modernization and energy sourcing. Simultaneously, tailings management efficiency operates as a governance-critical KPI, supporting board-level oversight of long-term environmental liabilities and risk exposure. Social KPIs related to occupational health and safety further interact with technological choices, as higher levels of mechanization reduce accident rates while altering workforce skill requirements. This illustrative example demonstrates how sector-specific ESG KPIs translate technological characteristics into strategic management signals, reinforcing the framework proposed in this study.

Strategic Management of Environmental KPIs

Table 1. Strategic ESG KPIs in mining

<i>ESG Dimension</i>	<i>Strategic KPI</i>	<i>ESG</i>	<i>Technological Driver</i>	<i>Managerial Relevance</i>	<i>Contribution to Competitive Advantage</i>
<i>Environmental</i>	Energy intensity of extraction and processing		Extraction method; processing technology; equipment efficiency	Supports strategic decisions on technology upgrades and energy sourcing	Cost efficiency; reduced exposure to energy price volatility
	Water use efficiency		Ore processing technology; water recycling systems	Guides investment in water-saving technologies and operational planning	Reduced operational risk; improved license to operate
	Tailings and waste management efficiency		Tailings storage technology; waste treatment systems	Enables proactive risk management and long-term liability control	Lower environmental risk; enhanced stakeholder trust
	Emissions intensity per unit of output		Fuel mix; processing routes; operational scale	Informs decarbonization strategies and compliance planning	Regulatory resilience; improved market positioning
	Occupational health and safety performance		Level of mechanization; automation; workplace technology	Supports workforce safety strategies and technology adoption	Reduced downtime; higher productivity
<i>Social</i>	Workforce stability and skills intensity		Technological complexity; training requirements	Informs human capital planning and skills development	Knowledge retention; operational continuity
	Community impact intensity (e.g., grievance rate; local employment share; land-use footprint)		Scale of operations; land use technologies	Guides stakeholder engagement and community investment strategies	Social acceptance; reduced project delays
	ESG risk integration into strategic planning		Technological risk profile; operational complexity	Supports board-level oversight and risk governance	Improved decision quality; long-term resilience
<i>Governance</i>	Transparency of ESG performance management		Monitoring and reporting systems	Enhances internal control and accountability	Investor confidence; reputational advantage
	Alignment of ESG KPIs with investment decisions		Capital allocation processes; technology lifecycle	Enables capital prioritization based on ESG performance	Efficient capital deployment; sustainable growth

Environmental performance constitutes the most visible and technologically mediated dimension of ESG in the mining industry. Environmental KPIs are directly shaped by extraction and processing technologies and therefore offer significant potential for strategic intervention when integrated into managerial decision-making.

Energy Intensity

Energy intensity—typically measured as energy consumption per unit of output—represents a critical environmental KPI in mining due to the sector’s reliance on energy-intensive extraction, hauling, crushing, and processing activities. The literature consistently identifies energy use as a major driver of both operating costs and greenhouse gas emissions in mining operations (Azapagic, 2004; Prior et al., 2012). From a strategic management perspective, energy intensity is not merely an efficiency indicator but a technology-contingent KPI that reflects choices regarding mining methods, equipment configuration, and processing routes.

When managed strategically, energy intensity informs long-term investment decisions, including technology upgrades, electrification strategies, and the integration of alternative energy sources. Studies on sustainability-oriented performance management emphasize that such KPIs become strategically meaningful when they guide capital allocation and operational redesign rather than serving as static performance benchmarks (Schaltegger & Wagner, 2011). In mining, reducing energy intensity can simultaneously enhance cost competitiveness and mitigate regulatory and transition risks associated with decarbonization policies (IEA, 2021).

Water Balance

Water balance KPIs capture the relationship between water withdrawal, consumption, recycling, and discharge across mining operations. Given the site-specific nature of water availability and the high sensitivity of mining projects to hydrological conditions, water-related KPIs are among the most context-dependent indicators in the ESG landscape (Mudd, 2008). Universal water metrics often fail to reflect local scarcity, competing uses, and contamination risks, limiting their managerial usefulness.

Strategically managed water balance KPIs enable mining companies to align operational planning with local environmental constraints and stakeholder expectations. Research on mining sustainability highlights that water stewardship is increasingly linked to social license to operate, particularly in arid regions and water-stressed basins (Owen & Kemp, 2013). When embedded in strategic management systems, water KPIs support proactive risk management, long-term resource security, and investment prioritization in water-saving and recycling technologies.

Waste and Tailings Management

Waste and tailings KPIs occupy a central position in mining ESG management due to the sector’s exposure to high-consequence environmental and social risks. Tailings generation, storage, and long-term stability are intrinsically linked to processing technologies, ore characteristics, and facility design. The literature underscores that failures in tailings management represent not only environmental disasters but also profound governance and legitimacy failures (Prior et al., 2012; UNEP, 2020).

From a strategic perspective, waste and tailings KPIs should be designed to support lifecycle risk management rather than short-term output monitoring. Indicators related to tailings stability, facility integrity, and closure readiness enable boards and senior management to oversee risk exposure associated with long-lived assets. Empirical research suggests that mining firms with more robust tailings governance frameworks are better positioned to manage regulatory scrutiny and reputational risk, reinforcing the strategic value of such KPIs (Lodhia & Hess, 2014).

Strategic Management of Social KPIs

Social KPIs in the mining industry reflect the sector’s deep entanglement with labor-intensive operations and geographically embedded communities. Unlike environmental KPIs, social indicators often capture relational and process-oriented dimensions of performance, requiring careful integration into management systems to retain strategic relevance.

Health and Safety

Occupational health and safety (OHS) is a foundational social KPI in mining, given the sector’s historically high accident rates and exposure to hazardous working conditions. The literature consistently identifies OHS performance as both a moral imperative and a determinant of operational efficiency, workforce morale, and

productivity (Hilson, 2012). Safety KPIs—such as injury frequency rates or lost-time incidents—are widely reported, yet their strategic value depends on how they are interpreted and acted upon.

Strategic management of health and safety KPIs involves linking performance indicators to technological choices, training systems, and organizational culture. Research in performance management demonstrates that safety KPIs contribute to competitive advantage when they are integrated into continuous improvement processes and incentive structures, rather than treated as compliance indicators (Simons, 1995). In mining, improvements in safety performance are often associated with higher levels of mechanization and process control, underscoring the interplay between technology and social performance.

Local Communities

Community-related KPIs address the mining industry's dependence on social acceptance and stakeholder trust. Concepts such as social license to operate highlight that community relations are not peripheral but central to project continuity and risk management (Prno & Slocombe, 2012). However, translating community impacts into measurable KPIs remains challenging due to their qualitative and context-specific nature.

The strategic management literature suggests that community-related KPIs should focus on processes and outcomes that are within managerial influence, such as grievance resolution mechanisms, local employment, and community investment effectiveness (Owen & Kemp, 2013). When systematically monitored and reviewed at the strategic level, such KPIs enable mining companies to anticipate social risks, reduce conflict-related disruptions, and strengthen long-term stakeholder relationships. In this sense, social KPIs function as early-warning indicators rather than retrospective performance measures.

Strategic Management of Governance KPIs

Governance KPIs provide the structural backbone for effective ESG management in the mining industry by shaping how environmental and social risks are identified, assessed, and addressed within organizational decision-making processes.

Risk Management

Risk management KPIs capture the extent to which ESG-related risks are systematically integrated into corporate governance and strategic planning. In mining, risk exposure is strongly influenced by technological complexity, asset longevity, and regulatory uncertainty, making robust governance structures essential (Grant, 2016). Governance KPIs related to risk identification, escalation, and oversight enable boards and senior executives to monitor the alignment between operational realities and strategic objectives. The literature on strategic risk management emphasizes that performance indicators are most effective when they facilitate dialogue and learning rather than mechanistic control (Simons, 1995). In mining, governance KPIs that link ESG risks to investment decisions and project approvals enhance organizational resilience by ensuring that sustainability considerations are embedded in core management processes rather than treated as external constraints.

Transparency

Transparency-related KPIs reflect the quality, consistency, and credibility of ESG performance management and communication. While transparency is often discussed in the context of external reporting, its strategic importance lies in supporting internal accountability and stakeholder trust (Eccles et al., 2014). In the mining sector, transparency is particularly salient due to heightened scrutiny from regulators, investors, and civil society organizations.

Strategically managed transparency KPIs enable mining companies to demonstrate control over complex ESG risk domains and to reduce information asymmetries with key stakeholders. Research on sustainability governance suggests that transparency contributes to competitive advantage when it reinforces internal discipline and supports informed decision-making, rather than merely increasing disclosure volume (Schaltegger et al., 2017). In this respect, governance KPIs act as enabling mechanisms that connect environmental and social performance to strategic oversight.

Synthesis: ESG KPIs as Strategic Management Instruments

Across environmental, social, and governance dimensions, the literature converges on a central insight: ESG KPIs in the mining industry create strategic value only when they are actively managed within an integrated performance management system. Environmental KPIs translate technology-driven impacts into actionable efficiency and risk indicators; social KPIs capture workforce and community dynamics that shape operational continuity; and governance KPIs ensure that ESG considerations are embedded in strategic decision-making and oversight structures.

This integrative perspective reinforces the argument advanced in this study that sector-specific ESG KPIs, when strategically managed, function as instruments of sustainable competitive advantage rather than as passive reporting tools. By aligning ESG KPIs with mining technologies, operational realities, and governance processes, mining companies can enhance resilience, improve decision quality, and navigate the growing sustainability constraints that define the sector's competitive landscape.

Discussion

ESG KPIs as a Strategic Resource

The findings of this study support a growing body of literature suggesting that ESG KPIs should be interpreted not merely as measurement or disclosure tools, but as strategic resources embedded within organizational decision-making systems. From a strategic management perspective, resources become sources of advantage when they are valuable, context-specific, and difficult to substitute or imitate (Barney, 1991). In the mining industry, sector-specific ESG KPIs exhibit these characteristics precisely because they are closely aligned with proprietary technologies, site-specific conditions, and firm-specific governance arrangements.

Unlike generic ESG indicators, which primarily facilitate external comparability, sector-specific ESG KPIs translate technologically driven impacts and risks into managerially actionable signals. As demonstrated in the preceding sections, environmental KPIs such as energy intensity, water balance, and tailings management are directly shaped by extraction and processing technologies, while social and governance KPIs reflect organizational capabilities related to workforce management, community engagement, and risk oversight. When these KPIs are strategically managed, they enable firms to identify inefficiencies, anticipate constraints, and prioritize interventions that would otherwise remain obscured by aggregated or standardized metrics.

This resource-based interpretation of ESG KPIs aligns with strategic performance management theory, which emphasizes that performance indicators derive their strategic value not from their existence, but from their integration into planning, control, and learning processes (Kaplan & Norton, 1996; Simons, 1995). In mining, where technological lock-in and long asset lifecycles limit managerial flexibility, ESG KPIs function as boundary-spanning instruments that connect operational realities with strategic intent. They inform capital allocation decisions, shape technology adoption pathways, and support risk-informed governance at board and executive levels.

Importantly, the strategic value of ESG KPIs in mining is cumulative rather than static. Over time, firms that systematically manage sector-specific ESG KPIs develop organizational routines, data infrastructures, and governance practices that enhance their ability to respond to regulatory change, stakeholder scrutiny, and technological disruption. This path-dependent accumulation of ESG-related capabilities reinforces the argument that ESG KPIs constitute a strategic resource whose value increases as they become embedded in core management systems (Schaltegger & Wagner, 2011; Gond et al., 2012).

Competitive Advantage in the Mining Sector

The relationship between ESG performance and competitive advantage in mining has been widely debated, with empirical findings often yielding mixed results. However, much of this ambiguity can be attributed to the reliance on aggregated ESG scores or universal indicators that inadequately capture the sector's technological and risk characteristics (Fikru, 2021; Berg et al., 2022). The present study contributes to this debate by reframing competitive advantage not as a direct outcome of ESG "performance" per se, but as the result of strategically managing ESG KPIs in alignment with sector-specific technologies and governance structures.

In the mining sector, competitive advantage is increasingly shaped by a firm's ability to operate under tightening environmental and social constraints. Regulatory developments, investor expectations, and downstream supply chain requirements impose explicit and implicit costs on firms that fail to manage ESG risks effectively. Within this context, sector-specific ESG KPIs support competitive advantage through several interrelated mechanisms.

First, strategically managed ESG KPIs enhance operational resilience. Environmental indicators that reflect energy efficiency, water stewardship, and tailings stability enable firms to reduce exposure to resource scarcity, regulatory intervention, and catastrophic failures. Social KPIs related to health and safety and community relations reduce the likelihood of work stoppages, project delays, and reputational damage. Governance KPIs strengthen oversight and coordination across complex organizational structures, improving decision quality in high-risk environments (Grant, 2016; UNEP, 2020).

Second, ESG KPIs contribute to cost and risk differentiation rather than simple cost reduction. Mining firms that effectively manage technology-linked ESG risks are better positioned to internalize sustainability-related costs proactively, avoiding reactive expenditures associated with non-compliance, accidents, or social conflict. This differentiation is particularly relevant in capital-intensive projects with long payback periods, where unanticipated ESG disruptions can materially undermine project economics (Prior et al., 2012).

Third, sector-specific ESG KPIs support strategic legitimacy and access to critical resources, including capital, permits, and skilled labor. The literature on social license to operate underscores that sustained community acceptance and stakeholder trust are prerequisites for long-term competitiveness in mining (Prno & Slocumbe, 2012; Owen & Kemp, 2013). By embedding social and governance KPIs into strategic management processes, firms can demonstrate control over ESG risks in a manner that is credible to external stakeholders, thereby strengthening their competitive positioning.

Finally, ESG KPIs enable strategic alignment across organizational levels. When environmental, social, and governance indicators are integrated into performance management systems, they facilitate coherence between corporate strategy, operational execution, and governance oversight. This alignment is particularly important in multinational mining firms operating across diverse regulatory and socio-environmental contexts, where fragmented ESG management can erode both efficiency and legitimacy.

Importantly, competitive advantage in the mining industry should not be interpreted as short-term financial outperformance, but as enhanced resilience, risk-adjusted stability, and sustained operational viability under increasing ESG constraints. From this perspective, strategically managed ESG KPIs contribute to competitive advantage by enabling firms to anticipate constraints, internalize risks, and maintain legitimacy in environments characterized by high technological and regulatory uncertainty.

Implications for Management and Theory

The discussion yields several implications for both managerial practice and academic theory. From a management perspective, the findings suggest that mining companies should prioritize the strategic design and governance of ESG KPIs, rather than expanding the volume of reported indicators. Emphasis should be placed on selecting KPIs that reflect technological realities, material risks, and decision-making needs at different organizational levels.

From a theoretical standpoint, the study advances the literature on management of technology and sustainability by demonstrating that ESG KPIs function as mediating mechanisms between technological systems and competitive outcomes. This perspective extends existing ESG-performance debates by highlighting the role of strategic management processes in converting ESG measurement into competitive advantage. It also reinforces calls for sector-specific and context-sensitive approaches to sustainability performance measurement, particularly in technology-intensive industries.

Overall, the discussion supports the central proposition of this paper: in the mining industry, ESG KPIs create competitive advantage not by signaling compliance, but by enabling strategic control over technology-driven environmental and social risks. This insight provides a coherent explanation for why universal ESG metrics often fail to predict performance in mining and underscores the value of sector-specific, strategically managed ESG KPI frameworks.

While this study focuses empirically on the mining industry, the proposed conceptual framework is applicable to other technology-intensive industries characterized by capital-intensive assets, complex process technologies, and

elevated environmental and social risk profiles, such as energy production, metals processing, and chemical manufacturing. In these sectors, sector-specific ESG KPIs similarly mediate the relationship between core technologies, risk management structures, and strategic performance outcomes.

Conclusions and Future Research

Conclusions

This study set out to examine the strategic role of ESG KPIs in the mining industry through the lens of management of technology and strategic performance management. Responding to the growing recognition that generic ESG metrics are insufficient for technology-intensive sectors, the paper developed a sector-specific, management-oriented conceptual framework that positions ESG KPIs as strategic instruments rather than as compliance-driven reporting tools.

The analysis demonstrates that ESG KPIs in the mining industry derive their relevance and managerial value from their alignment with core extraction and processing technologies, site-specific operational conditions, and governance structures. Environmental KPIs such as energy intensity, water balance, and waste and tailings management were shown to be directly shaped by technological choices and therefore critical for strategic decision-making related to capital allocation, risk mitigation, and long-term operational resilience. Similarly, social KPIs related to occupational health and safety and local communities reflect the labor-intensive and geographically embedded nature of mining operations, while governance KPIs associated with risk management and transparency provide the institutional foundation for integrating ESG considerations into strategic oversight.

By conceptualizing ESG KPIs as strategic resources, the study advances existing debates on the relationship between ESG performance and competitive advantage in the mining sector. Rather than treating ESG outcomes as exogenous reputational signals or as aggregated scores detached from operational realities, the proposed framework emphasizes the role of strategic management practices in transforming ESG measurement into a source of sustainable competitive advantage. This perspective helps explain why empirical studies relying on universal ESG indicators often yield inconclusive results for mining firms: such indicators frequently fail to capture the sector's technological risk profile and managerial control mechanisms.

From a theoretical standpoint, the paper contributes to the literature on sustainability management and management of technology by integrating three previously fragmented streams of research: ESG performance measurement in mining, technology-intensive industries, and strategic performance management. The resulting framework offers a coherent explanation of how technology-driven impacts are translated into ESG KPIs and how these KPIs, when strategically managed, can support long-term competitiveness in a sector increasingly constrained by environmental, social, and governance considerations.

Managerial and Policy Implications

The findings carry several implications for managerial practice in the mining industry. First, managers should prioritize the strategic design and governance of ESG KPIs, focusing on indicators that are materially linked to mining technologies and operational risks rather than expanding the breadth of reported metrics. Second, ESG KPIs should be explicitly integrated into strategic planning, investment appraisal, and risk governance processes to ensure that sustainability considerations inform core managerial decisions. Third, boards and senior executives should treat ESG KPIs as dynamic tools for learning and adaptation, capable of supporting long-term resilience in the face of regulatory tightening, technological change, and stakeholder scrutiny.

At the policy and standard-setting level, the study reinforces the importance of sector-specific sustainability frameworks that recognize technological heterogeneity and impact pathways. While harmonization and comparability remain important objectives, excessive reliance on universal indicators may undermine the decision-usefulness of ESG information in high-impact sectors such as mining. Policymakers and standard setters may therefore benefit from further strengthening industry-based guidance that supports strategic ESG management rather than solely disclosure compliance.

Limitations and Directions for Future Research

As a conceptual and qualitative study, this research is subject to several limitations that also point to avenues for future inquiry. First, the proposed framework has not been empirically tested. Future research could examine its explanatory and predictive power through in-depth case studies of mining firms, comparative analyses across commodities, or survey-based studies of ESG KPI integration into strategic management systems. Such empirical work would allow for refinement of the framework and assessment of its applicability across different mining contexts and regulatory environments.

Second, while this study focused on the mining industry as a technology-intensive sector, future research could explore the transferability of the framework to other resource- and capital-intensive industries, such as energy, metals processing, or heavy manufacturing. Comparative studies could shed light on how differences in technological architectures and risk profiles influence ESG KPI design and strategic use.

Third, further research is needed to investigate the dynamic dimension of ESG KPI management. Longitudinal studies could examine how ESG KPIs evolve over project lifecycles, how firms adapt their KPI systems in response to technological innovation or regulatory change, and how such adaptations affect competitive outcomes over time.

In conclusion, this study underscores that the strategic value of ESG KPIs in the mining industry lies not in standardization, but in contextualization and technological alignment. By grounding ESG performance measurement in sector-specific technologies and embedding ESG KPIs within strategic management and governance processes, mining companies can move beyond compliance-oriented sustainability practices and position ESG performance measurement as a core instrument of strategic control in technology-intensive industrial systems, supporting long-term competitiveness and resilience.

Recommendations

Mining companies should design ESG KPI systems around the specific technological and operational characteristics of their activities rather than relying on uniform reporting templates. Different extraction methods, processing routes, tailings systems, and energy configurations create different sustainability risks and therefore require differentiated KPI architectures.

Managers should establish explicit links between ESG KPIs and key decision points across the mining project lifecycle, including feasibility studies, technology selection, mine planning, expansion projects, and closure strategies. This would allow ESG information to support forward-looking decisions rather than serving only retrospective reporting purposes.

The mining sector should also increase the use of leading indicators in addition to lagging indicators. For example, indicators related to tailings monitoring, workforce training, equipment modernization, grievance management, and water recycling capacity may provide earlier signals of emerging risks than traditional incident-based metrics. In addition, companies should strengthen cross-functional coordination in ESG KPI management. Environmental, social, operational, engineering, and financial teams should jointly participate in KPI selection and review processes to ensure that ESG indicators reflect both technical realities and strategic priorities.

From a governance perspective, boards and senior management should regularly review whether existing KPI systems remain aligned with changing regulatory expectations, stakeholder concerns, and technological developments. ESG KPIs should be periodically updated to reflect shifts in climate policy, resource availability, automation, digitalization, and new industry standards.

Finally, future sectoral guidance for the mining industry should place greater emphasis on the distinction between externally reported ESG indicators and internally managed strategic KPIs. Not all indicators that are useful for disclosure are equally useful for strategic control, and mining companies should avoid treating reporting metrics and management metrics as interchangeable.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest.

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