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Green human resource practices and sustainable advantage: evidence from the Chilean mining sector

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This study investigates how green human resource practices (GHRP) influence green competitive advantage (GCA) in the Chilean mining sector, examining the mediating role of green intellectual capital (GIC) through its human (GHC), structural (GSC), and relational (GRC) components. Grounded in the Natural Resource-Based View and the AMO framework, the conceptual model tests direct and indirect pathways from GHRP to GCA. Using survey data from 300 managerial level participants at EXPONOR 2024, the results of the PLS-SEM show that while GHRP positively affects all three GIC dimensions, only GRC significantly predicts GCA. Mediation analysis showed that GRC partially mediated the GHRP–GCA relationship, whereas GHC and GSC did not exhibit significant indirect effects. These findings clarify that GCA emerges not from isolated green practices but from the development of specific intangible capabilities, particularly stakeholder-oriented relational capital where the organizational reputation and sustainable collaboration among strategic partners play a key role. For mining firms, aligning green HRM with stakeholder oriented relational capital is pivotal to move from compliance to sustained legitimacy and environmental leadership.

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Introduction

Environmental sustainability has become a strategic imperative for organizations worldwide, particularly in high-impact sectors such as mining. In this context, the Chilean mining industry stands out not only for its global leadership in copper production but also for its growing commitment to reducing its environmental footprint through initiatives such as *"green copper"*, a concept that reflects the integration of clean energy and environmentally responsible practices into mining operations (Guzmán et al. 2023). As regulatory pressures and global demand for sustainable production increase, mining companies must develop long-term strategies that align competitiveness with sustainability (Bintara et al. 2023). In Latin America, recent ESG policy developments—tighter sustainability disclosure requirements and sector-specific human rights due diligence expectations—have further elevated the need to translate AMO aligned GHRP into green capabilities (GIC) that underpin competitive advantage in mining (Palacios and Aninat 2023; CMF 2024; ICMM 2024; IFRS Foundation 2025). In parallel, recent scholarship underscores that people-centric green HR architectures are pivotal for converting ESG commitments into durable advantages in resource-intensive contexts (Tahir et al. 2024; Li et al. 2025).

One emerging concept in this area is the green competitive advantage (GCA), which refers to an organization's ability to achieve superior market positioning through environmental innovation, regulatory compliance, and stakeholder engagement (Chen and Chang 2013; Muisyo et al. 2022). Attaining these advantages requires not only operational changes but also a transformation in human capital management. Green Human Resource Practices (GHRP), grounded in the ability–motivation–opportunity (AMO) framework, aim to embed environmental objectives into employee training, incentives, evaluations, and recruitment processes (Renwick et al. 2013; Muisyo et al. 2022). A recent review consolidates this AMO–GHRM logic—ability via green competence-building, motivation via appraisal/rewards, and opportunity via participation—linking it to environmental performance at the organizational level (Tahir et al. 2024).

Although Green Human Resource Practices (GHRP) have been shown to positively influence organizational environmental performance, their relationship with green competitive advantage remains unclear (Aftab et al. 2023). Recent literature suggests that Green Intellectual Capital (GIC)—encompassing green human capital (GHC), green structural capital (GSC), and green relational capital (GRC)—may mediate the relationship between GHRP and sustainable outcomes (Chen 2011; Mahmood and Nasir 2023; Wang et al. 2023). However, studies analyzing the interaction of these dimensions within strategic industries remain limited, and most existing research treats GIC as a second-order construct without examining the individual contributions of its components (Kianto et al. 2017; Jirawuttinunt 2018; Nisar et al. 2021). Evidence from mining shows that GHRM enhances green innovation and, in turn, sustainable performance (Suleman et al. 2024), while multi-sector analyses, including mining, indicate that both GIC and green innovation can mediate the GHRM → sustainability link (Li et al. 2025). Simultaneously, the component-level results for GIC remain mixed or contingent on context, reinforcing the need to test disaggregated pathways.

From a practical perspective, this gap hinders decision-makers in resource-intensive sectors, such as mining, from identifying the intangible assets that should be prioritized to achieve sustainability-driven competitive advantages. Understanding whether relational capital plays a more critical role than human or structural capital can inform the allocation of training budgets, design of stakeholder engagement strategies, and development of internal environmental systems. Disaggregating the dimensions of GIC thus provides actionable insights for tailoring green human resource policies, enabling firms to comply with environmental standards and lead innovation and stakeholder trust in competitive markets. Conceptually, articulating the AMO → GIC → GCA pathway clarifies how GHRP produces advantage: ability-oriented practices nourish GHC, motivation-enhancing practices institutionalize GSC, and opportunity-creating practices expand stakeholder ties (GRC), jointly underpinning competitive differentiation under the natural resource-based view (Hart 1995; Tahir et al. 2024).

Building on this rationale, we examine the extent to which AMO aligned GHRP strengthens the three dimensions of GIC—GHC, GSC, and GRC—in mining firms; whether GIC mediates the relationship between GHRP and green competitive advantage (GCA); and which GIC component exerts the greatest relative influence on GCA. To address these questions, our study (i) tests the mediation of disaggregated GIC between GHRP and GCA, (ii) compares the relative contributions of GHC, GSC, and GRC, and (iii) assesses the model within the Chilean mining context, where heightened ESG scrutiny amplifies the strategic salience of people-driven green capability.

Literature review

Theoretical foundations: resource-based view (RBV), natural resource-based view (NRBV), and ability–motivation–opportunity (AMO). We position our model at the intersection of the resource-based view (RBV) and its natural resource-based extension (NRBV), which holds that environmentally oriented resources and capabilities can be strategically valuable, rare, and difficult to imitate, and hence potential sources of sustained advantage (Peteraf 1993; Hart 1995; Mady et al. 2023). Recent strategy work reinforces and updates this logic by integrating NRBV with dynamic capabilities and organizational governance, arguing that green strategies create durable rents when firms deliberately build environmental capabilities and align them with systems and oversight (Alkaraan et al. 2024; Befort et al. 2025). This integration makes it explicit that "green" advantage stems not only from policy compliance but also from the purposeful orchestration and renewal of eco-capabilities within the firm.

To explain how such capabilities are generated through people systems, we adopt the Ability–Motivation–Opportunity (AMO) framework, which originated in HRM and has been widely applied to green HRM (Appelbaum et al. 2000; Renwick et al. 2013). Contemporary syntheses specify the AMO levers in a green context—Ability via selection and training, Motivation via appraisal and rewards, and Opportunity via participation and voice—highlighting their relevance for environmental performance (Miah et al. 2024; San Román-Niaves et al. 2025; Paillé 2025). We conceptualize AMO as influencing the development of all three dimensions of Green Intellectual Capital (GIC)—green human capital (GHC), green structural capital (GSC), and green relational capital (GRC)—through distinct but complementary mechanisms. Ability-enhancing practices (e.g., green training and selection) directly foster GHC by building employees' environmental expertise. Motivation-enhancing practices (e.g., green KPIs, appraisals, and rewards) embed environmental values into organizational routines and systems, strengthening GSC. Opportunity-enhancing practices (e.g., participation mechanisms, employee voice, and stakeholder engagement) foster internal and external collaboration, contributing to both GSC and GRC by opening channels for knowledge sharing and stakeholder trust.

Positioning GIC as the capability conduit between HR architecture and competitive outcomes is consistent with evidence that GIC underpins green innovation capacity and

environmental performance, that is, the translation of HR practices into hard to imitate eco-capabilities that can support advantage (Asiaei et al. 2023). Notably, Asiaei et al. (2023) show that the effect of GIC on environmental performance can operate through ambidextrous green innovation rather than directly, underscoring that capability formation and innovation are often intertwined. Meta-analytic evidence reaches a similar conclusion from the HR side: the link between green HRM and sustainable performance is frequently mediated by green innovation, reinforcing the case for modeling indirect pathways from HR practices to firm level outcomes (Bindeeba et al. 2025).

Taken together, RBV/NRBV explains the strategic value of environmental capabilities, AMO specifies how GHRP builds them through people systems, and the GIC lens clarifies the component-level pathways (GHC, GSC, and GRC) through which those practices are converted into green competitive advantage (GCA), either directly (via efficiency and differentiation) or indirectly (via capability and innovation channels).

Green competitive advantage. Michael Porter (1985) defined competitive advantage as a defensible position that rivals cannot easily replicate. Building on this foundation, Chen and Chang (2013) introduced green competitive advantage (GCA) as a firm's ability to achieve superior market positioning through environmental protection and eco-innovation, thereby creating barriers that are difficult for competitors to overcome. In practice, GCA is pursued through environmentally friendly practices, such as implementing green technologies, developing durable products, and redesigning processes to minimize environmental impact (Muisyo et al. 2022; Bintara et al. 2023). From a resource-based perspective, particularly the natural resource-based view (NRBV), these environmental capabilities can constitute valuable, rare, and hard to imitate resources that support sustained advantage.

Porter and Van der Linde (1995) further argue that well-designed environmental policies can spur innovation that offsets compliance costs, enhances corporate image, and opens up new market opportunities (Bintara et al. 2023). Empirical studies support this logic. Chen (2011) shows that environmental responsibility and leadership culture strengthen a green organizational identity, which in turn enhances GCA. In services, López-Gamero et al. (2011) find that sustainability practices in Spanish hotels improve both perceived performance and financial outcomes, consistent with gains from differentiation and cost efficiency through energy savings and waste reduction. Recent studies have also reported positive links between green practices, capability building, and competitive outcomes in resource-intensive and service settings (Muisyo et al. 2022; Bintara et al. 2023).

Overall, the literature suggests that environmental strategy and eco-innovation can translate into competitive gains through both cost (efficiency) and differentiation mechanisms under the NRBV theory. However, studies vary in terms of where the advantage actually materializes—directly from practices or indirectly via underlying capabilities—which motivates our focus on people-driven capability formation (through GHRP) and, specifically, the disaggregated roles of GIC components in converting green practices into GCA (Mustafa et al. 2023; Din et al. 2024; Akter et al. 2025).

Green human resource practices. The resource-based view (RBV) posits that organizations possess human, physical, and organizational resources that can yield sustained competitive advantages when strategically configured. In sustainability contexts, this alignment of tangible and intangible assets with environmental objectives reinforces firms' ability to adapt and lead in environmentally conscious markets (Malik et al. 2020).

Within this framework, green human resource practices (GHRP) have gained relevance as strategic tools that embed environmental values into core HR functions of organizations. Jackson and Seo (2010) critically assess traditional HRM's limitations vis-à-vis sustainability, while highlighting its latent potential to support competitive advantage through environmental alignment. Accordingly, GHRP design and implement HR policies, procedures, and strategies that jointly pursue environmental, social, and economic goals (Malik et al. 2020; Wielewska et al. 2023).

Operationally, GHRP integrates environmental concerns into recruitment, training and development, performance evaluation, and compensation so that workforce behavior aligns with ecological objectives (Bombiak 2020; Faisal 2023). A green HRM (GHRM) orientation enables organizations to use resources more efficiently and reduce environmental impact, thereby contributing to sustainable performance (Mostafa and Saleh 2023; Paillé 2025). This integration is both functional and cultural, fostering environmental awareness and a "green mindset" across the organization (Faisal 2023). Beyond internal efficiency, GHRP contributes to stakeholder value creation by embedding accountability and social responsibility into human capital management (Bombiak 2019), permeating strategic workforce planning, recruitment, environmental training, employee development, green performance appraisals, and eco-linked rewards (Dumont et al. 2017; Wielewska et al. 2023). Recent evidence consolidates this view, showing that AMO-grounded GHRM is consistently associated with improved environmental performance at the organizational level (Tahir et al. 2024).

This study adopts the Ability–Motivation–Opportunity (AMO) framework—originating in HRM (Appelbaum et al. 2000) and widely applied to GHRM (Renwick et al. 2013)—as the theoretical basis for examining GHRP. AMO clarifies how HR practices foster environmental behavior by enhancing employees' ability, motivation, and opportunity to act responsibly. Consistent with our broader model, we map AMO to the components of green intellectual capital (GIC): Ability→green human capital (GHC), Motivation→green structural capital (GSC), and Opportunity→-green relational capital (GRC). This mapping links RBV/NRBV logic, where environmentally oriented capabilities can be valuable, rare, and hard to imitate, to the specific HR mechanisms through which GHRP can ultimately support a green competitive advantage.

Conceptual and empirical work converges on GHRP as a capability-building lever: not merely a set of practices but a mechanism that shapes GHC, GSC, and GRC. However, studies differ on whether the effects are direct or indirect via these capabilities and which capability matters more in different contexts. This heterogeneity motivates our subsequent hypothesis testing of disaggregated links from the GHRP to each GIC component and, ultimately, to green competitive advantage.

Hypothesis development

Green human resource practices and green competitive advantage. Research increasingly links green human resource practices (GHRP) to a green competitive advantage (GCA). Framed by AMO, GHRP enhance employees' ability (green knowledge and skills), structure motivation (green appraisals, rewards, governance), and expand opportunity (participation and cross-boundary collaboration). These levers enable eco-efficiency and differentiation—two classic routes to advantage under the RBV/NRBV—by catalyzing green process improvements and

market-facing innovation (Muisyo et al. 2022; Bintara et al. 2023; Wang et al. 2023; Tahir et al. 2024). Green HR policies support product/process innovation and, in turn, reinforce competitive positioning. Evidence from mining indicates that GHRM fosters green innovation and improves sustainable performance (Suleman et al. 2024), while multi-sector studies—including extractives—report that both GIC and green innovation can mediate GHRM's effects on sustainability outcomes (Li et al. 2025).

Overall, the literature supports a direct GHRP → GCA link via efficiency and differentiation logic while also documenting indirect pathways through capability building (e.g., GIC) and innovation. To isolate the direct strategic effect while allowing for mediated routes to be tested later, we state the following hypothesis:

H1. Green human resource practices (GHRP) have a direct and positive effect on green competitive advantage (GCA).

Green human resource practices and green human capital. Green intellectual capital (GIC) is an intangible asset for organizations pursuing sustainability-driven competitive advantages. The resource-based view (RBV) and its natural resource-based extension (NRBV) explain how environmentally oriented resources and capabilities can underpin long-term advantages when they are valuable, rare, and hard to imitate (Peteraf 1993; Hart 1995; Mady et al. 2023). Within this logic, disaggregating GIC into green human capital (GHC), green structural capital (GSC), and green relational capital (GRC) clarifies the specific capability bundles through which firms adapt and perform (Soo et al. 2017).

Focusing on GHC, green human resource practices (GHRP) are a primary lever for building employees' environmental knowledge, skills, and problem-solving abilities—the ability component in AMO. Empirical evidence supports the HRM/GHRP → GHC linkage. In Chinese firms, Song et al. (2020) show that HRM practices strengthen GHC and spur green innovation. In Taiwanese samples, Chen et al. (2021) find that human resource development directly enhances human capital, improving performance; and in Malaysian hotels, Nisar et al. (2021) reported that green training fosters pro-environmental behavior consistent with GHC accumulation. Recent syntheses further consolidate the AMO-grounded mechanism, reporting consistent associations between GHRM practices and environmental performance at the organizational level, which is coherent with GHC formation (Tahir et al. 2024) and capability-mediated pathways observed across sectors, including extractives (Li et al. 2025).

Under AMO, Ability-enhancing GHRP (targeted green training, competency-based selection, and developmental pathways) should directly build GHC, which later supports green process and product innovation. While contexts and measures vary across studies, the convergent pattern justifies testing the direct GHRP → GHC link in our mining setting.

H2. Green human resource practices (GHRP) have a direct and positive effect on green human capital (GHC).

Green human resource practices and green structural capital. Green structural capital (GSC) comprises organizational systems, routines, databases, environmental management systems, and process standards that embed sustainability into day-to-day operations. Under AMO, Motivation-enhancing GHRP (e.g., green KPIs, appraisal and reward systems, governance, and auditing) should institutionalize these routines and information flows, thereby strengthening GSC.

Empirical research supports the HR–structure linkage in various contexts. In Taiwan, Chen et al. (2021) show that human resource development positively affects structural capital. Using data from Spanish firms, Kianto et al. (2017) find that knowledge-based HR practices directly enhance structural capital. In Malaysian hotels, Nisar et al. (2021) reported that green-oriented HR practices strengthen green intellectual capital, with GSC as a key component. Complementing these findings, Jirawuttinunt (2018) observes a positive and significant GHRP → GSC relationship in Thai firms. Recent syntheses further consolidate the AMO-grounded mechanism linking GHRM practices to environmental outcomes (Tahir et al. 2024) and document capability-mediated pathways across sectors, including extractives, where structural routines are central (Li et al. 2025).

Motivation-focused GHRP provide performance controls and incentives that lock in green routines, data systems, and process discipline—features of GSC that, under the NRBV, are valuable, hard to imitate (path dependent, socially complex), and thus strategically consequential in mining. This motivates the testing of the direct formation of GSC via GHRP.

H3. Green human resource practices (GHRP) have a direct and positive effect on green structural capital (GSC).

Green human resource practices and green relational capital. Green relational capital (GRC) captures a firm's external relationships with key stakeholders—suppliers, customers, regulators, and local communities—embodying trust, legitimacy, and channels for environmental knowledge exchange that are difficult for rivals to replicate (Zhang et al. 2022). Under AMO, Opportunity-enhancing GHRP (e.g., employee voice, participation in cross-functional "green teams," boundary-spanning roles, stakeholder engagement training and KPIs) should directly strengthen GRC by institutionalizing regular interaction and collaboration with external partners and enhancing organizational reputation.

Empirical research supports the HR–HR-relational capital link across various contexts. Using survey data from Taiwanese firms, Chen et al. (2021) showed that human resource development positively influences relational capital. In Spanish firms, Kianto et al. (2017) find that knowledge-based HR practices significantly enhance relational capital. In Malaysian hotels, Nisar et al. (2021) report that green-oriented HR practices strengthen relational capital, consistent with the accumulation of GRC. Complementing these findings, Jirawuttinunt (2018), using data from HR managers in Thailand, observed a positive and significant relationship between GHRP and GRC, highlighting its role in competitive outcomes. Recent multi-sector evidence further indicates that intellectual capital pathways—including the relational dimension—mediate the effects of GHRM on sustainability performance, a pattern that plausibly extends to extractive settings where stakeholder legitimacy and a "social license to operate" are pivotal (Li et al. 2025).

In line with the AMO, opportunity-focused GHRP provide the organizational mechanisms (voice, participation, and engagement routines) through which firms build GRC—a VRIN consistent asset under the NRBV that confers legitimacy, facilitates compliance and co-innovation, and thereby supports competitive positioning in mining. This logic motivates a direct test of the GHRP → GRC link.

H4. Green human resource practices (GHRP) have a direct and positive effect on green relational capital (GRC).

Green human capital and green competitive advantage. Green human capital (GHC) refers to the collective environmental knowledge, skills, and experience of employees (Chen 2008; Mustafa et al. 2023). GHC is foundational for developing green research and development (R&D), process innovation, sustainable production and effective environmental management

(Huang et al. 2021). When organizations face environmental constraints or regulatory shifts, the ability to mobilize GHC supports differentiation (e.g., eco-innovation and superior environmental quality) and cost/efficiency gains (e.g., resource conservation and waste minimization)—two classic routes to advantage under the natural resource-based view (NRBV) (Obeidat et al. 2020). By equipping employees with the ability to proactively apply environmental expertise, GHC facilitates continuous improvement and strengthens a sustainability-oriented culture (Yong et al. 2019; Astuti and Datrini 2021). Empirical studies have also associated GHC with idea generation, ecological competencies, and advantages in technological and environmental domains (Yusliza et al. 2020; Bombiak 2023).

Under NRBV, GHC is a VRIN-consistent capability bundle (knowledge, skills, experience) that enables both efficiency and differentiation, making a direct positive link to GCA theoretically plausible—even as complementary pathways via innovation can further amplify effects in some contexts.

H5. Green human capital (GHC) has a direct and positive effect on green competitive advantage (GCA).

Green structural capital and green competitive advantage. Green structural capital (GSC) comprises organizational systems, routines, environmental management systems, databases, and process standards that embed sustainability into day-to-day operations (Chen 2008; Akter et al. 2025). In practice, this organizational infrastructure supports core activities such as environmental management, R&D, and sustainable operations by codifying procedures, monitoring, and reporting (Wang et al. 2019). Under AMO, Motivation-enhancing GHRP (e.g., green KPIs, appraisals, rewards, governance, and audits) institutionalizes these routines and information flows, thereby strengthening GSC. From an NRBV standpoint, such routinized systems are valuable and difficult to imitate (path dependence, causal ambiguity) and, therefore, strategically consequential for GCA.

By improving operational processes, optimizing systems, and reinforcing environmental standards, GSC contributes to a durable competitive advantage via both efficiency (cost savings, reliability, compliance) and differentiation (credible environmental quality and reputation) (Dang and Wang 2022). As GSC capabilities mature, organizations are better positioned to innovate and implement sustainable initiatives, enhancing their environmental performance and securing a strategic edge in sustainability-driven markets (Yong et al. 2019; Astuti and Datrini 2021; Bombiak 2023).

Consistent with AMO → GIC and NRBV, GSC operationalizes green intent into repeatable, scalable routines that competitors find hard to replicate, making a direct link to GCA theoretically plausible.

H6. Green structural capital (GSC) has a direct and positive effect on green competitive advantage (GCA).

Green relational capital and green competitive advantage. Green relational capital (GRC) captures a firm's externally oriented ties with suppliers, customers, regulators, and local communities—relationships that embody trust, legitimacy, and channels for environmental knowledge exchange (Chen 2008). Built over time and shaped by context, these ties are difficult for competitors to replicate because of path dependence and exclusivity (Dang and Wang 2022). Through these networks, firms access critical environmental resources and expertise, enhancing their ecological capabilities and creating sustainable value (Yusliza et al. 2020). By deepening stakeholder engagement, companies can respond more effectively to rising sustainability expectations and reinforce their competitive position in environmentally conscious markets (Astuti and Datrini 2021; Sadiq et al. 2022; Bombiak 2023). Under the AMO, opportunity-enhancing GHRP (e.g., employee voice, cross-functional "green teams," stakeholder engagement training, and KPIs) institutionalize boundary-spanning interactions, thereby strengthening GRC—a VRIN-consistent asset under the NRBV, especially salient in mining, where the social license to operate and regulatory relationships are pivotal.

GRC channels legitimacy, co-innovation, and information exchange that competitors cannot easily imitate, providing both differentiation (credible environmental engagement) and efficiency (smoother compliance and collaboration). This makes a direct positive link between GRC and GCA theoretically plausible in the mining context.

H7. Green relational capital (GRC) has a direct and positive effect on green competitive advantage (GCA).

Mediation of dimensions of green intellectual capital. Research on mining remains limited regarding how each component of green intellectual capital (GIC)—green human capital (GHC), green structural capital (GSC), and green relational capital (GRC)—mediates the relationship between green human resource practices (GHRP), and green competitive advantage (GCA). Building on the natural resource-based view (NRBV), we argue that environmentally oriented capabilities that are valuable, rare, and hard to imitate provide a sustained advantage (Hart 1995; Mady et al. 2023). Within the AMO framework, GHRP enhances employees' Ability, structure Motivation, and expand Opportunity, which we map to GHC, GSC, and GRC, respectively; consequently, we conceptualize parallel mediating pathways from GHRP to GCA through each GIC component. GHRP enhances employees' Ability, structures Motivation, and expands Opportunity, capability levers that influence the formation of GHC, GSC, and GRC through distinct but complementary mechanisms (Suleman et al. 2024; Tahir et al. 2024; Li et al. 2025).

GHC comprises employees' environmental knowledge and skills that enable problem-solving, clean-technology adoption, and process/product eco-innovation—mechanisms that improve efficiency (resource conservation, waste reduction) and differentiation (credible environmental quality), thereby supporting GCA (Ahmad Yahya et al. 2019; Astuti and Datrini 2021; Naseem et al. 2024). Ability-enhancing GHRP (targeted green training, competency-based selection, and developmental pathways) should therefore increase GHC, which in turn elevates GCA.

GSC captures codified systems, routines, environmental management systems, databases, and standards that routinize green behaviors. Motivation-enhancing GHRP (green KPIs, appraisals, rewards, governance, audits) institutionalizes these routines and information flows, scaling compliance, reliability, and eco-efficiency—features that are path dependent and causally ambiguous under the NRBV and thus supportive of GCA (López-Gamero et al. 2011; Cahyono and Hakim 2020; Bombiak 2023).

GRC reflects boundary-spanning ties with suppliers, customers, regulators, and communities. Opportunity-creating GHRP (voice, cross-functional "green teams," stakeholder engagement training, and KPIs) expand collaboration, legitimacy, and knowledge exchange—particularly salient in mining via social license to operate—which enhances GCA through co-innovation and smoother compliance (López-Gamero et al. 2011; Ahmad Yahya et al. 2019; Naseem et al. 2024).

Taken together, AMO-consistent GHRP should build GIC and thereby convert HR policies into competitive advantages via three parallel capability channels (GHC, GSC, and GRC). While we acknowledge complementary routes via green innovation reported in recent studies (Suleman et al. 2024; Li et al. 2025),

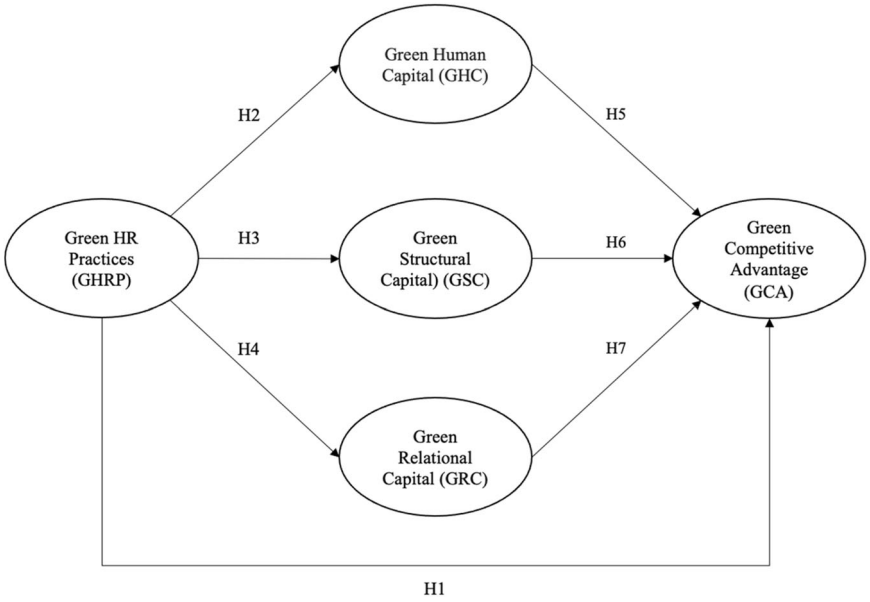

Fig. 1 Arrows indicate the hypothesized relationships (H1–H7). GHRP Green HR Practices, GHC Green Human Capital, GSC Green Structural Capital, GRC Green Relational Capital, GCA Green Competitive Advantage.

our primary mediation tests focus on disaggregated GIC dimensions.

H8. GIC (via GHC, GSC, and GRC) mediates the positive effect of GHRP on GCA.

The conceptual model is presented in Fig. 1.

Methodology

Sampling and data collection. Data were collected via an in-person survey from June 3–6, 2024, during EXPONOR in Antofagasta, Chile (EXPONOR 2025)—a major international mining exhibition in one of the world's leading mining hubs, with investments exceeding US$65.7 billion and, in 2024, more than 1000 exhibitors, 15 international pavilions, and 40,000+ attendees. The target population comprised managerial personnel from Chile's mining ecosystem (core mining firms and suppliers). We focused on managerial level informants because they are key decision-makers and knowledgeable about firm-level HR architectures, capability building, and competitive positioning, making them appropriate key informants for GHRP, GIC, and GCA constructs at the organizational level. This alignment of the unit of analysis (organization) and the informant level (managers) enhances construct validity and is standard in green HRM/strategy research, which commonly relies on managerial samples to capture organization-level practices and outcomes (Renwick et al. 2013; Asiaei et al. 2023; San Román-Niaves et al. 2025; Paillé 2025).

We used a non-probability convenience sampling approach at the venue to access a broad cross-section of the firms. To mitigate common-method concerns and venue-specific clustering, interviews were distributed across multiple days/times and different company stands. The initial contact list included 320 managers. After screening and data checks, the final sample comprised 300 valid responses collected by trained surveyors through face-to-face interviews. The respondents were 82.4% men and 17.6% women, broadly mirroring the gender distribution of the Chilean mining industry (Consejo Minero and Fundación Chile 2023). The mean age was 45 years, and the average industry tenure was 18 years. Of these, 47.8% were employed directly by mining companies and 52.2% by suppliers/clients. Participation was voluntary and anonymous. Written informed consent was obtained by trained surveyors immediately prior to survey administration. Participation was voluntary and anonymous, and no personally identifiable data were collected.

The questionnaire adapted established multi-item scales to the mining context and was pre-tested for content validity and clarity. A pilot test with 50 mining workers (non-overlapping with the main sample) assessed the comprehension, wording, and completion time. Based on pilot feedback, we (i) refined item wording to remove industry jargon and double-barreled phrasing, (ii) standardized anchors, and (iii) reordered items to reduce context effects. No constructs were dropped, and minor wording adjustments improved readability and reduced ambiguity. We separated the predictor and criterion blocks in the questionnaire, used neutral headers, assured anonymity to reduce evaluation apprehension, and varied the item stems and directions. Pilot participants included a balanced mix of operators and suppliers and completed the instrument under supervised conditions, providing written and verbal feedback on clarity, redundancy, and terminology. The average completion time was ~12 min, and no systematic missing data patterns were observed. The 7-point response format and the sequence between constructs were confirmed as appropriate. These refinements enhanced content validity, respondent comprehension, and the instrument's internal consistency prior to field deployment.

Measurement scales. The GHRP scale, consisting of six items, was adapted from Dumont et al. (2017), who assessed the impact of green human resource practices on employees' environmentally friendly behaviors in China. The GCA scale, comprising ten items, was adapted from Chen (2008), who examined the effect of green human capital on the competitive advantages of small and medium-sized enterprises.

The Green Intellectual Capital (GIC) scale includes 18 items covering its three dimensions—Green Human Capital (GHC), Green Relational Capital (GRC), and Green Structural Capital (GSC)—and was adapted from Yusoff et al. (2019), originally based on the work of Huang and Kung (2011), who analyzed green intellectual capital and business sustainability in Taiwan.

All items were measured using a 7-point Likert scale ranging from "strongly disagree" to "strongly agree," except for the sociodemographic variables.

Statistical tools. We employed a structural equation modeling (SEM) approach, specifically partial least squares (PLS), to test the measurement reliability, validity, and hypothesized relationships. PLS-SEM allows researchers to estimate both the causal relationships between indicators and their latent constructs and the causal relationships among the latent constructs themselves (Gudergan et al. 2008).

The choice of PLS-SEM over covariance-based SEM (CB-SEM) is theoretically and methodologically justified. First, the model's primary goal is prediction and variance explanation rather than strict theory confirmation, which aligns with the strengths of PLS as a component-based approach (Hair et al. 2019). Second, the proposed framework includes multiple mediators operating in parallel (green human, structural, and relational capital) and numerous indicators, which increases the model complexity and favors PLS-SEM for robust estimation (Sarstedt et al. 2017). Third, the sample size ($N = 300$) met the power requirements recommended for PLS-SEM based on the maximum number of arrows pointing at a construct (Hair et al. 2022). Fourth, the use of perceptual survey data introduces potential non-normality, for which PLS-SEM offers greater robustness. Finally, this approach is widely adopted in green management and HRM research, particularly when the focus is on explaining organizational capabilities and indirect effects rather than model fit.

To evaluate the measurement and structural models, the procedures recommended in the literature were followed (Fornell and Larcker 1981; Henseler et al. 2016). All analyses were conducted using SmartPLS 4 (Ringle et al. 2022).

Results

Measurement model evaluation. To analyze the instrument, the criteria for reliability, convergent validity, and discriminant validity were evaluated. The Cronbach's alpha coefficient (CA), composite reliability (CR), the average variance extracted (AVE) for each construct are presented in Table 1. The results of Cronbach's alpha (CA) and composite reliability (CR) ensured the reliability of the scales. The Cronbach's alpha results ranged from 0.932 to 0.954, surpassing the recommended scale robustness value of 0.7 (Henseler et al., 2016). Similarly, the composite reliability of the proposed model varied from 0.941 to 0.955, surpassing the recommended value of 0.7. This indicates that the constructs have high internal consistency. To assess convergent validity, the loadings of each item and the average variance extracted (AVE) were examined. Each item had loadings greater than 0.7 (Fornell and Larcker, 1981). The average variance extracted ranged between 0.705 and 0.832, which was higher than the accepted level of 0.5 (Chin 1998). These results suggest adequate convergent validity for all latent constructs.

To assess discriminant validity, the Fornell–Larcker criterion (Fornell and Larcker 1981) and HTMT ratio (Voorhees et al. 2016) were used. First, Fornell and Larcker (1981) suggested that discriminant validity can be evaluated by examining whether the square roots of the AVE are greater than the correlations with other constructs. As shown in Table 2, all values on the diagonal exceed the correlations between the constructs. Table 3 shows the HTMT criterion, which is the ratio of within-construct correlations to between-construct correlations. The HTMT values were below the required value of 0.9 (Henseler et al. 2016). In conclusion, the results indicate adequate discriminant validity.

Structural model evaluation. In the structural model, we treat Green Intellectual Capital (GIC) as three parallel, first-order mediators—Green Human Capital (GHC), Green Structural Capital (GSC), and Green Relational Capital (GRC)—consistent with the mediation logic outlined in Section 3.8. Accordingly, we estimate and report component-wise indirect effects from GHRP to GCA via each GIC dimension, alongside direct paths and R^2.

We evaluated the model fit prior to examining the structural relationships (Henseler et al. 2016). Using SmartPLS 4 (Ringle et al. 2022), the standardized root mean square residual (SRMR) for the proposed model was 0.041, which is acceptable for a prediction-oriented PLS model. The structural model was then assessed using path coefficients and R^2 values. We applied PLS bootstrapping with 10,000 subsamples (Streukens and Leroi-Werelds 2016) to obtain the coefficients and p-values for the hypothesized relationships. Figure 2 displays the model estimates, and Table 4 reports the results of the hypotheses.

The results show that GHRP significantly affect the three dimensions of GIC—GHC, GSC, and GRC—and have a direct, positive effect on GCA. Regarding the effects of GIC dimensions on GCA, only GRC exhibited a significant positive effect, whereas GHC and GSC were not significant. The R^2 values indicated that the model explained 56.1% of GHC, 68.8% of GSC, 70.6% of GRC, and 75.6% of GCA.

Mediation results. We assessed the indirect effects using bias-corrected bootstrap confidence intervals with 10,000 subsamples. Following Nitzl et al. (2016), an indirect effect is statistically significant when its confidence interval excludes zero. The total effect of GHRP on GCA was significant; when introducing the mediators, the direct effect remained significant with a reduced magnitude, indicating complementary partial mediation.

As reported in Table 5, only the GHRP → GRC → GCA indirect path was statistically significant (97.5% CI = [0.017; 0.275]). In contrast, mediation via GHC was not significant because its confidence interval included zero (97.5% CI = [−0.010; 0.177]). Likewise, the GHRP → GSC → GCA path was positive but not significant at the 97.5% level (CI = [−0.031; 0.256]).

Regarding magnitude, the total VAF indicates that 40.12% of the effect of GHRP on GCA occurs indirectly through the three mediators, which supports partial mediation when considering all mediators jointly. However, at the component level, the VAF values are below 20% for each mediator—GRC = 17.51%, GSC = 12.66%, and GHC = 9.94%—a range typically interpreted as weak mediation. Following common VAF thresholds, values below 20% denote weak mediation; therefore, only GRC exhibits a statistically significant but weak-in-magnitude mediation effect, whereas GHC and GSC are not significant.

Discussion

This study examined, in the Chilean mining context, the extent to which AMO aligned Green Human Resource Practices (GHRP) strengthen the three disaggregated dimensions of Green Intellectual Capital (GIC)—GHC, GSC, and GRC—and whether these dimensions mediate the translation of GHRP into Green Competitive Advantage (GCA), identifying which component exerts the greatest relative influence.

The results confirm that GHRP exerts both direct and indirect effects on GCA, consistent with prior studies linking green-oriented HR practices to competitive advantage through innovation and environmental performance (Muisyo et al. 2022; Bintara et al. 2023). Recent evidence further shows that GHRM enhances sustainability performance with partial mediation by green innovation and GIC, reinforcing the integrative role of

Table 1 Convergent validity.

Construct	Item	Loading	CA	CR	AVE
Green HR Practices (GHRP)	This company sets goals related to environmental protection for its staff	0.874	0.954	0.955	0.813
	This company trains the staff on environmental issues to promote ecological values	0.899			
	This company provides its staff with training in ecological topics to develop the knowledge and skills necessary for environmental management	0.935			
	This company takes into account the ecological behavior of its staff in performance evaluations	0.909			
	This company provides rewards and compensation to the staff for implementing eco-friendly behaviors within their work activities	0.894			
	This company takes into account the ecological behaviors of its staff in promotions and advancements	0.896			
Green Human Capital (GHC)	The employees of this company produce with a contribution to environmental protection in mind	0.882	0.932	0.941	0.788
	The employees of this company have adequate competence in environmental protection	0.913			
	The employees of this company offer high-quality products and services for environmental protection.	0.920			
	In this company the level of cooperation and teamwork towards environmental protection is carried out at high levels	0.930			
	Managers can fully support their employees in carrying out their environmental protection tasks	0.786			
Green Structural Capital (GSC)	This company has management processes aligned with environmental protection	0.832	0.951	0.951	0.746
	This company has a high percentage of environmental management employees compared to the total number of employees	0.843			
	This company makes an adequate investment in environmental protection facilities	0.895			
	The general operational processes towards environmental protection in this company operate efficiently	0.907			
	The knowledge management system in this company is favorable for the accumulation and exchange of knowledge on environmental management	0.905			
	This company has formed a committee to advance key issues in environmental protection	0.884			
	This company has established detailed environmental protection standards and regulations	0.852			
	This company has established a system of rewards/incentives for the fulfillment of environmental tasks	0.784			
Green Relational Capital (GRC)	This company develops its products or services respecting the environmental wishes of the community where it operates	0.899	0.949	0.950	0.832
	The community is satisfied with the environmental protection actions carried out by this company	0.913			
	The cooperative relationships of this company with the community for environmental protection are stable	0.928			
	The cooperation relationships of this company with its clients are oriented towards environmental protection	0.919			
	The cooperation relationships of this company with its strategic partners are oriented towards environmental protection	0.906			

Table 1 (continued)

Construct	Item	Loading	CA	CR	AVE
Green Competitive Advantage (GCA)	This company has a low-cost competitive advantage in terms of environmental protection or green innovation over its major competitors.	0.840	0.953	0.955	0.705
	This company offers better quality products or services based on respect for the environment	0.884			
	This company has a greater capacity to carry out R&D (research and development) in environmental protection or green innovation	0.821			
	This company has environmental management skills	0.853			
	This company is achieving greater profitability compared to previous years	0.750			
	The growth of this company is due to its activities being environmentally friendly	0.878			
	This company is a pioneer in several important areas of environmentally friendly products or services	0.890			
	This company has an adequate environmental reputation	0.851			
	This company has an important competitor that cannot easily replicate its production or services in an environmentally respectful manner and/or with environmental ideas	0.819			
	This company has significant competitors who cannot easily replace its distinctive position in environmental management or green innovation	0.799			

Table 2 Discriminant validity Fornell-Larcker criterion.

	GSC	GHC	GRC	GHRP	GCA
GSC	0.864				
GHC	0.829	0.888			
GRC	0.839	0.770	0.912		
GHRP	0.829	0.749	0.840	0.901	
GCA	0.789	0.733	0.795	0.824	0.839

Table 3 Discriminant validity Heterotrait-monotrait ratio HTMT.

	GSC	GHC	GRC	GHRP
GHC	0.882			
GRC	0.884	0.818		
GHRP	0.869	0.789	0.881	
GCA	0.829	0.776	0.834	0.884

intangible green assets (Li et al. 2025). At the field level, bibliometric mapping indicates a sharp rise in publications since 2016 on GHRM and environmental performance, signaling the theoretical and empirical consolidation of this stream (Tahir et al. 2024).

Overall, GHRP significantly enhanced all three GIC dimensions, showing that human resource practices oriented toward environmental goals strengthen the organizational foundations of green capability. However, their effects on GCA differ across dimensions. The combined results suggest that GIC operates as a multidimensional capability bundle in line with the Natural Resource-Based View (NRBV), where human, relational, and structural assets jointly form the basis for sustainable advantage (Hart 1995; Chen 2008).

The non-significant effect of GHC on GCA suggests that developing employees' environmental skills alone may be insufficient to yield competitive differentiation in mining. Outsourcing specialized environmental services is one explanation (Yusliza et al. 2020; Endiana et al. 2023), but a complementary interpretation is that green competencies remain individual rather than systemic—not yet embedded in collective routines or incentive systems (Ahmad Yahya et al. 2019). From an NRBV/VRIO lens, resources generate an advantage only when they are valuable, rare, inimitable, and organizationally embedded; here, organizational embedding appears to be the missing condition. Cross-industry evidence also shows that the performance impact of GIC depends on organizational conditions (e.g., ownership structures), underscoring that capabilities must be internalized and aligned with governance to become strategically consequential (Akter et al. 2025).

In contrast, GRC significantly influences GCA, highlighting the importance of trust-based relationships with external stakeholders, such as local communities, suppliers, and regulators. In industries where a social license to operate is essential, relational assets constitute a hard to imitate source of advantage (Hart and Dowell 2011; Bombiak 2023). GRC enhances legitimacy, mitigates social conflict, and facilitates collaboration in sustainability initiatives (Cahyono and Hakim 2020; Ahmar and Astuti 2023). Its mediating role further confirms that the pathway from GHRP to GCA materializes primarily through relational channels, suggesting that HR-driven environmental values are most impactful when they are diffused beyond organizational boundaries.

Although GSC did not show a significant direct link to GCA, its potential remains promising. Current practices often frame GSC in terms of compliance—ISO certifications, audits, and

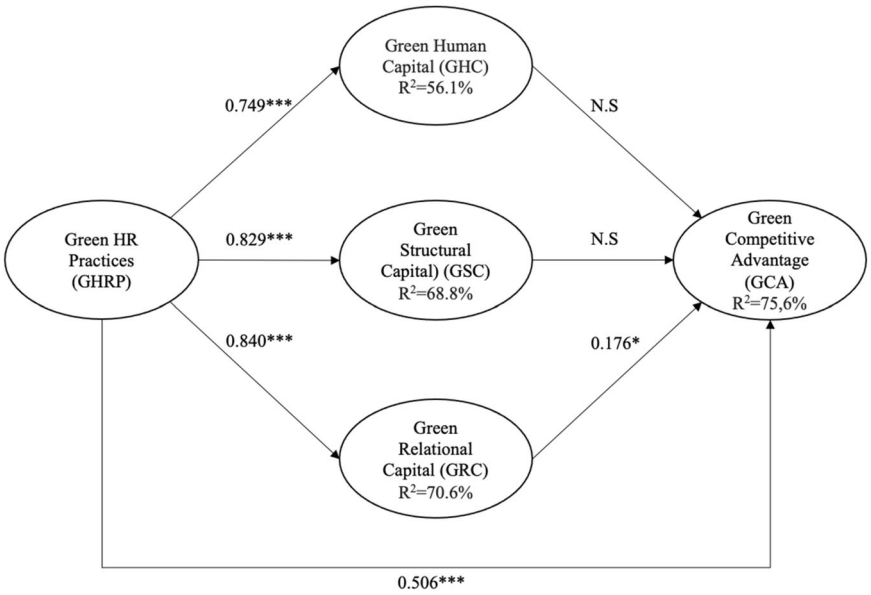

Fig. 2 Numbers on the arrows represent standardized path coefficients (β). Values inside endogenous constructs indicate explained variance (R^2). Significance is denoted by asterisks (*p 0.05; **p 0.01; ***p 0.001), and "N.S" indicates non-significant paths. GHRP Green HR Practices, GHC Green Human Capital, GSC Green Structural Capital, GRC Green Relational Capital, GCA Green Competitive Advantage.

Table 4 Hypothesis testing.

Hypothesis	Path	Coefficient (β)	p-value	Result
H1	GHRP- > GCA	0.506	0.000	Supported
H2	GHRP- > GHC	0.749	0.000	Supported
H3	GHRP- > GSC	0.829	0.000	Supported
H4	GHRP- > GRC	0.840	0.000	Supported
H5	GHC- > GCA	0.112	0.074	Not supported
H6	GSC- > GCA	0.129	0.140	Not supported
H7	GRC- > GCA	0.176	0.024	Supported

reporting—rather than as dynamic systems enabling green innovation (Dang and Wang 2022). To activate GSC's impact, mining firms should strengthen the infrastructure for knowledge sharing, cross-functional coordination, and digitalization of environmental processes to transform compliance-oriented systems into learning-oriented systems. This shift aligns with NRBV principles by converting structural resources into innovation platforms that sustain a competitive advantage (Ahmad Yahya et al. 2019; Wang et al. 2019). Complementary recent work shows the growing centrality of GHRM in broader sustainability architectures, offering a bridge to embed environmental knowledge into systems and routines (Tahir et al. 2024).

When integrated, the three GIC dimensions form a complementary configuration rather than being isolated drivers. GHC provides the foundation for expertise, GSC embeds this knowledge in systems and routines, and GRC extends it through collaborative networks—together constituting a "green capability bundle." This interaction explains the partial mediation observed: GHRP directly influences GCA while also operating indirectly through the synergy of GIC dimensions, particularly via GRC. The evidence supports the complementary role of GIC proposed by the NRBV, in which firms achieve sustainable competitiveness when human, relational, and structural resources co-evolve to reinforce their environmental strategy.

In summary, this study extends the NRBV theory by empirically demonstrating that green competitive advantage in resource-intensive contexts emerges not from isolated green capabilities but from their integration. Therefore, mining firms seeking to strengthen GCA should pursue a dual strategy: intensifying green HR practices while simultaneously developing interconnected human, structural, and relational capital. By embedding environmental knowledge into organizational routines and stakeholder relationships, firms can move from regulatory compliance to proactive sustainability, transforming green capabilities into enduring sources of competitive advantage. Recent empirical contributions converge with this view, showing that GHRM's effects on sustainability performance are amplified when mediated by green innovation and intellectual capital (Li et al. 2025) and that the research domain has matured rapidly, offering tested levers for practice (Tahir et al. 2024).

Implications

The Ability–Motivation–Opportunity (AMO) model (Appelbaum et al. 2000; Renwick et al. 2013) provides the theoretical foundation for interpreting the study's findings. Consistent with the AMO framework, the results reveal that ability-oriented practices enhance Green Human Capital (GHC), motivation-driven practices institutionalize Green Structural Capital (GSC), and opportunity-focused practices expand Green Relational Capital (GRC). This alignment clarifies that Green Human Resource Practices (GHRP) generate Green Competitive Advantage (GCA) not through isolated actions but by jointly shaping the organizational, human, and relational capabilities that constitute the firm's "green capability bundle" (Tahir et al. 2024). Through this lens, AMO explains how and why GHRP influences GIC dimensions and, consequently, sustainable competitiveness in the Chilean mining context.

For HR professionals, the findings emphasize the need to internalize environmental expertise rather than rely on external consultants. This reinforces the "ability" pillar of the AMO model. Recent evidence shows that when firms invest in employees' environmental skills—through green-skills certification, eco-efficiency workshops, and innovation challenges—they increase their absorptive capacity and environmental responsiveness (Endiana et al. 2023). In Chile's mining industry,

Table 5 Mediation results.

Model A Total effect (c)			Model B Direct effect (c′)			Model B Indirect effect				
Path	Coefficient	t-value	Path	Coefficient	t-value	Path	Point estimate	Bias-corrected bootstrap 97.5% confidence interval		VAF
								Lower	Upper	
GHRP →GCA	0.845	4.2511	GHRP →GCA	0.506	7.739	Total	0.339	0.224	0.461	40.12%
						GHRP→GHC→GCA	0.084	-0.010	0.177	9.94%
						GHRP→GSC→GCA	0.107	-0.031	0.256	12.66%
						GHRP→GRC→GCA	0.148	0.017	0.275	17.51%

programs focused on renewable energy management, waste reduction, and circular economy design can reduce dependency on specialized contractors while enhancing resilience. Linking incentive systems to environmental performance indicators, such as water-use reduction or energy efficiency, can embed sustainability into a firm's internal capability structure (Ahmad Yahya et al. 2019).

For sustainability and community relations managers, GRC emerges as the most influential mediator between GHRP and GCA. Mining firms operate under constant scrutiny from regulators and local communities, making stakeholder collaboration essential for maintaining their social license to operate. Thus, strengthening relational capital operationalizes the "opportunity" dimension of AMO, as employees are empowered to engage externally and co-create solutions. Concrete actions include joint environmental monitoring committees, supplier development programs for low carbon logistics, and transparent ESG communication platforms (Dang and Wang 2022; Bombiak 2023). These initiatives enhance legitimacy, reduce social conflict, and create trust-based partnerships, which are key resources that are valuable, rare, and difficult to imitate under the NRBV (Hart and Dowell 2011; Mady et al. 2023).

Executives and operations leaders should reinterpret GSC not merely as a compliance requirement but as a potential source of innovation and a long-term advantage. Recent studies indicate that digitalization and AI driven environmental management systems can convert GSC into a dynamic capability that supports eco-innovation (Hoang and Ha 2025). In the Chilean mining context, firms could implement blockchain based traceability for "green copper", AI enabled environmental monitoring platforms, and cross-functional innovation hubs linking HR, energy, and production departments. These systems exemplify the AMO model's *"motivation/structure"* component by embedding sustainability goals into decision-making processes and transforming compliance-oriented systems into learning-oriented platforms (Tahir et al. 2024; Li et al. 2025).

The implications are particularly salient for Chile's mining sector, a global leader in copper production now under increasing ESG scrutiny and decarbonization pressure (Guzmán et al. 2023). The development of internal GHC reduces vulnerability to external shocks and talent shortages. Enhancing the GRC strengthens social legitimacy and ensures project continuity in territories with strong community oversight. Innovating through GSC aligns with national goals for "green copper" and renewable-powered operations, transforming sustainability from a regulatory obligation into a strategic advantage. By aligning AMO-based HR practices with the three dimensions of GIC, mining firms can transition from reactive compliance to proactive sustainability, positioning Chile as a benchmark for low carbon and high responsibility mining in Latin America.

Conclusions

This study demonstrates that in the Chilean mining sector, AMO aligned Green Human Resource Practices (GHRP) enhance Green Competitive Advantage (GCA) both directly and indirectly through Green Intellectual Capital (GIC). By disaggregating GIC into its human (GHC), structural (GSC), and relational (GRC) dimensions, we show that GHRP contributes to sustainable competitiveness by developing employees' environmental capabilities, embedding sustainability into organizational systems, and fostering trust-based collaboration with stakeholders. However, the relative influence of these dimensions varies: GRC emerges as the only significant mediator between GHRP and GCA, whereas GHC and GSC exhibit weaker or statistically insignificant effects. This suggests that environmental advantage in resource-intensive contexts is realized primarily when green values and competencies diffuse beyond organizational boundaries through stakeholder engagement.

These findings highlight that GIC functions as a capability bundle, a synergistic configuration of human expertise, structural systems, and relational networks. While GHC builds internal knowledge, its impact depends on its integration into organizational routines and incentives. Although often compliance-driven, GSC has the potential to evolve into a dynamic capability when supported by digital systems and cross-functional coordination. In contrast, GRC directly reinforces competitiveness by sustaining legitimacy, mitigating social risks, and enabling collaborative innovation. Together, these dimensions reveal that the pathway from GHRP to GCA operates through both internal capability building and external relationship management, underscoring the complementary logic of the Natural Resource-Based View (NRBV) and the AMO framework.

From a managerial perspective, this study advances a dual strategic implication: mining firms should intensify green HR practices while aligning them with GIC development, embedding environmental knowledge into people, systems, and stakeholder networks. Such alignment enables a shift from regulatory compliance to proactive sustainability, positioning Chilean mining firms as regional leaders in "green copper" and low carbon competitiveness.

This study had several limitations. It focuses exclusively on the Chilean mining sector, which restricts the generalizability of the findings to other industries or countries with different institutional and cultural contexts. The use of convenience sampling at a single industry event (EXPONOR) may introduce selection bias toward firms and individuals already engaged in sustainability topics. However, EXPONOR's broad representation of operators, EPCs, OEMs, and service providers offers comprehensive coverage of the Chilean mining value chain. To mitigate bias, we benchmarked the respondent profiles against sectoral data and conducted robustness checks by firm type to assess model

stability. Although these procedures enhance transparency, they do not eliminate bias. Additionally, the cross-sectional design limits the ability to capture the temporal evolution of the GHRP–GIC–GCA relationship. Longitudinal research would better reflect the dynamic effects of regulatory pressure, digital transformation, and innovation. The reliance on perceptual, interviewer-administered survey measures may introduce key-informant and social desirability bias, which future studies could address through qualitative approaches, such as interviews or focus groups, to deepen the understanding of how GHRP are implemented and perceived in practice.

Future research should extend this model across sectors undergoing sustainability transitions, such as renewable energy or manufacturing, to test the boundary conditions of the observed relationships. Comparative studies in contexts with weaker environmental regulations could reveal how institutional environments moderate the effectiveness of the GHRP and GIC in generating competitive advantages. Moreover, longitudinal designs can trace how GHRP evolve and interact with GIC and GCA over time, providing insights into capability accumulation and path dependence. Finally, integrating complementary theoretical perspectives, such as Resource Dependence Theory or Dynamic Capabilities, would enrich our understanding of how organizations leverage human and intellectual capital to build enduring green competitiveness in complex, resource-intensive environments.

Data availability

The datasets and materials supporting the conclusions of this study are available in a public repository. The repository includes the study dataset, the survey instrument, a codebook/data dictionary (variable definitions and coding schemes), and supporting documentation for the analysis. Materials can be accessed at: https://github.com/jserranomalebran/green_hrm_mining_chile.

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Author contributions

JS-M, CM, and OO-R developed the research model and wrote the main manuscript text. FG-L and SA-A conducted the literature review and contributed to the interpretation of results. All authors reviewed and approved the final version of the manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval statement

The study protocol was reviewed and approved by the Scientific Ethics Committee of the Colegio Profesional de Economistas de la Región Cajamarca (Peru) (Report No. 004/2024; Protocol 004/2024; approval date: March 3, 2024). All procedures were conducted in accordance with relevant guidelines and regulations for research involving human participants. The committee's review covered the study protocol and materials, including the informed consent procedure.

Informed consent statement

Written informed consent to participate and for the use of anonymised data for research and publication purposes was obtained from all adult participants. Consent was obtained on-site by trained field staff immediately prior to survey administration during data collection at EXPONOR (Antofagasta, Chile) on June 3–6, 2024. Participants received a written information sheet describing the study purpose, procedures, expected duration, voluntary nature of participation, confidentiality/anonymity safeguards, and the right to refuse or withdraw at any time without consequences. No personally identifying information was collected.

Additional information

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