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Article

Circular Economy for Strategic Management in the Copper Mining Industry

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Abstract: This study investigates the awareness and adoption of Circular Economy (CE) principles within Chile's mining sector, the world's leading copper producer. A mixed-methods approach, combining surveys and semi-structured interviews, was utilized to assess perceptions and implementation levels of CE practices across diverse organizational contexts. The results revealed a significant knowledge gap: while 73.3% of mining professionals reported familiarity with CE, only 57.3% could accurately define it. State-owned mining companies demonstrated notably higher implementation rates of CE practices, with 36.5% engaging in eco-industrial collaborations and 51% conducting environmental audits, compared to their private counterparts. Small enterprises (1-100 employees) exhibited particularly limited engagement, as evidenced by 71.8% lacking sustainability reporting mechanisms. A substantial implementation gap was also identified; although 94.8% of respondents considered CE principles integral to business ethics and 89.6% recognized CE as crucial for securing a social license to operate, only 20.8% reported their organizations had dedicated CE units. The research concludes with actionable recommendations for policymakers, including targeted financial incentives and training programs for Small and Medium-sized Enterprises (SMEs) in mining services, the establishment of standardized CE performance metrics for the sector, and the integration of CE principles into strategic management education to accelerate sustainable transformation within Chile's critical mining industry.

Keywords: mining industry; circular economy; sustainability; environment; copper

1. Introduction

The circular economy (CE) has gained significant prominence within the global mining industry, driven by the imperative to adopt sustainable practices in a sector historically characterized by a substantial environmental footprint [1]. In Chile, the transition towards enhanced sustainability has presented multifaceted challenges across economic, social, operational, and regulatory domains [2].

Within the mining industry, sustainability principles have become increasingly integral, particularly given the sector's reliance on non-renewable natural resources. Consequently, the focus is on the progressive mitigation of environmental impacts, utilizing metrics such as efficient resource consumption, minimal land alteration, pollution reduction, and land reclamation upon operational closure [3].

It is evident that sustainability, and by extension the circular economy, are integral components of strategic management in any mining project. This entails the proficient management of resources to achieve project objectives and goals, thereby ensuring sustained business growth [4].

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Despite the recognized contemporary importance of **CE** in **mining project** development [5], a comprehensive understanding of the extent to which its significance is perceived and adopted by **mining companies** remains to be fully elucidated**.**

To investigate the nexus between CE and strategic management in the Chilean mining industry, this study employs a survey administered to industry professionals. The survey aims to gauge their perspectives on CE and its interconnections with pivotal themes in strategic management [6,7].

This study primarily aims to comprehensively assess the state of awareness and implementation of Circular Economy (CE) principles within Chile's crucial mining sector. Employing a robust mixed-methods approach, which integrates large-scale surveys with semi-structured interviews, this research not only quantifies the adoption of CE practices across various operational areas but also delves into the perception of industry professionals regarding CE and its fundamental interconnection with Business Ethics and the Social License to Operate. The distinctive and novel contribution of this work lies in its focused empirical analysis of the Chilean mining industry, a sector of vital economic and environmental importance. By offering a detailed and pioneering overview of the progress and challenges in the transition towards circular business models, this study provides critical insights for the design of strategies and public policies that can foster a more sustainable and globally competitive mining industry.

2. Mining in Chile

Mining significantly contributes to Chile's Gross Domestic Product (GDP), representing a crucial activity for the nation's socioeconomic development [8,9]. In 2022, this sector accounted for 14.2% of the Chilean GDP [10]. When considering the ancillary economic activity generated in other sectors, this contribution exceeds 20%. Furthermore, mining generates one in every ten Chilean pesos collected by the State in taxes [11].

Chilean mining is predominantly focused on copper, with the country being a current global leader in its production. In 2022, Chile was the leading copper producer, responsible for 25.4% of global output. The nation also ranks as the second-largest global producer of lithium and molybdenum, accounting for 29.6% and 17.9% of their respective global production [10].

In 2022, mining sector exports reached USD 58,151.5 million (USD 58.15 billion), with a detailed breakdown by mineral type provided in Table 1 [10].

Notably, 5% of global metal exploration occurs in Chile, positioning the country as having the highest intensity of mine prospecting activity relative to its territorial area [11].

Table 1. Chilean mining export values [10].

Produced item	2022	
	US$	%
Total mining	58.151,5	100,0%
Copper	43.830,6	75,4%
Iron	1.681,7	2,9%
Saltpeter & iodine	1.253,0	2,2%
Lithium carbonate	7.762,7	13,3%
Molybdenum	1.833,0	3,2%
Gold	867,1	1,5%
Plate	398,1	0,7%
Other	525,3	0,9%

3. A Brief Look at the Circular Economy

The prevailing economic production model is linear, characterized by the extraction, fabrication, and subsequent disposal of materials lacking economic value or utility at the end of their service life [12]. This linear approach to production and resource management has engendered adverse

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economic, environmental, and social consequences [13], presenting challenges of escalating pollution and global resource scarcity. Within a linear economy, resources are depleted more rapidly, and waste generation is accelerated compared to a circular system [14].

To counteract this, materials and resources must be maintained within the economy for as long as possible, thereby extending their service life and minimizing waste [15]. This objective can be achieved through a Circular Economy (CE), a term originated by Pearce and Turner [16]. Geissdoerfer et al. [17] define CE as "a regenerative system wherein the entry of resources and wastes, emissions, and energy leaks are minimized by slowing down, closing, and narrowing energy and material flows. This can be achieved via long-life designs, maintenance, repairs, reuse, remanufacturing, renovation, and recycling." Academic publications on CE have proliferated, with a significant geographical concentration of research in Europe and China [18]. A consensus among academics is that CE adheres to the "Reduce, Reuse, and Recycle" (3R) principles. 'Reduce' aims to curtail energy and material flows, 'Reuse' focuses on extending the utilization period of products and components, and 'Recycle' involves processing used materials for reintegration into production cycles or as new resources [19]. The systematic adoption of CE within industrial systems can foster a more sustainable industrial ecosystem and enhance corporate performance [20].

4. Mining – Environment – Circular Economy

Consistent with the preceding discussion, Chilean mining generates substantial environmental liabilities. For each ton of total material exploited, only 6 kg of copper are obtained [10,11]. Given that 5.588 billion tons of copper were extracted in Chile during 2021 [10], this implies the generation of approximately 931.333 billion tons of mining waste in Chile alone, with an estimated 14 trillion tons generated globally. According to Fundación Chile [21], the country possesses 757 tailings deposits, of which 112 are active and 467 are inactive. Among the inactive sites, 173 are abandoned, and 5 are currently under construction. These deposits and accumulated wastes represent a significant environmental challenge, primarily due to issues such as soil degradation, pollution, and water contamination [22–24].

These environmental burdens are compounded by other factors. The extraction of metals from the Earth's crust necessitates intensive consumption of resources like fossil fuels and generates environmentally harmful substances, including heavy metals and contaminating wastes [22,23]. Nevertheless, the industry has made notable advancements in other areas, such as water management and consumption, where its impact is considerably lower than that of other industrial activities like agriculture [25]. The Mining Council, an organization representing major copper-producing companies in Chile, reports that mining consumes 4% of the country's water, whereas agriculture accounts for a significantly higher 72% [26]. Furthermore, the mining sector achieves a 76% water recirculation rate in its processes [27].

These factors underscore the critical importance of the mining sector's future development for both Chile and the global economy, particularly its role in advancing non-conventional renewable energy and new technologies, including electromobility and digitalization. Mining activity is projected to continue for at least another 25 years at production levels equal to or exceeding current rates [28,29]. The sector plays a pivotal role in the transition towards a low-carbon economy, and the adoption of Circular Economy (CE) principles can mitigate the negative impacts of its productive activities [30]. This transition necessitates significant efforts in environmental protection, given the profound environmental alterations caused by mining.

The mining sector, as the initial stage for most product value chains, contributes to the depletion of non-renewable mineral resources [31]. However, implementing CE in the mining industry offers a substantial opportunity to address natural resource scarcity, waste generation, and environmental pollution [19]. The industry is also increasingly focused on phasing out fossil fuel-based transportation and minimizing mining waste to prevent the associated environmental disturbances. These imperatives have driven legislative changes within the mining industry, fostering a shift towards CE [30].

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For the successful implementation of CE in mining, five major categories of barriers must be considered, which can impede its adoption [32]:

- **Financial:** Insufficient economic resources for CE-related operations, encompassing a lack of initial capital, inadequate funding for training, and limited investment in research and development.
- **Market:** A general reluctance or unpreparedness in the market to accept products derived from CE-aligned operations.
- **Government Policies and Regulation:** Deficiencies in infrastructure, inadequate regulatory frameworks, insufficient government promotion of CE operations, and weak compliance mechanisms.
- **Organizational:** A lack of requisite skills, internal support, relevant experience, an appropriate corporate culture, and established metrics for CE within corporate management and organizational structures.

5. Circular Economy: Barriers to Its Implementation in Mining

The circular economy (CE) is an economic model designed to minimize waste generation and maximize resource utilization [15]. Achieving a CE necessitates the integration of innovative product design and business model strategies [33]. The CE is proposed as a novel sustainability paradigm capable of addressing certain deficiencies inherent in the current linear economic model, such as excessive waste generation [17]. However, the implementation of circular business models within small and medium-sized enterprises (SMEs) encounters several barriers, including insufficient access to supplies, limited capital, and inadequate government support, among other factors. Conversely, enabling factors include a strong environmental stewardship culture within the company and robust support networks [34].

Considering the aforementioned points, implementing CE principles in the extraction and processing stages of mining presents considerable challenges. Mining inherently generates substantial waste (tailings) from ore selection and beneficiation processes, as only small quantities (ounces or pounds) of economically valuable metals are typically extracted per ton of processed ore. In 2022, over 14 billion metric tons of mining tailings were produced globally from metal and mineral extraction [22].

These tailings are predominantly stored in tailings dams, reservoirs, and waste dumps. The challenge of achieving sustainable disposal methods for these accumulated wastes is becoming increasingly critical [35].

Production volumes in the metallurgical and copper mining industries are projected to increase by 300% by 2050 [36], which will inevitably lead to a corresponding rise in tailings generation if adequate waste management strategies are not implemented. This situation is further compounded by the progressively stringent ecological and environmental standards being established in most countries worldwide [37].

6. Circular Economy and Strategic Management

Barros et al. [38] emphasize the importance of organizations recognizing the Circular Economy (CE) as integral to their strategic development. This necessitates addressing circularity principles across various domains, including strategic planning, cost management, supply chain management, logistics management, and service administration, among others. Consequently, organizations should understand that internalizing circularity principles within strategic plans can significantly enhance the achievement of strategic objectives.

Indeed, CE is considered fundamental for value generation within a company. A strategic re-envisioning of the business model, incorporating principles of reduction, reuse, and recycling, can positively influence Environmental Management System (EMS) certification and contribute to the establishment of a sustainable business model [39].

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Therefore, the benefits of CE and its implementation warrant careful consideration within Strategic Administration. Adopting CE can provide a distinct competitive advantage and favorable positioning, particularly for an industry frequently scrutinized by society due to its environmental impact [40].

7. Methodology

7.1. Data collection and search design

7.1.1. Literature Review

Existing studies have utilized surveys to explore individual and organizational-level understanding of the Circular Economy (CE). Over the past decade, several initiatives have been undertaken to assess the extent of CE adoption [41].

Goyal et al. [42] report that studies focusing on CE adoption within specific regions or states constituted 27% of relevant publications between 2000 and 2019. However, within this body of literature, a gap exists concerning research conducted on companies within a specific economic sector, such as the one investigated in the present study. This gap is particularly evident for industries like mining, which are characterized by significant environmental impact [2]. Nevertheless, the mining industry possesses the potential to make substantial contributions to environmental preservation and significantly support CE development [2,31].

In general, the literature on CE indicates an exponential growth in research output since 2015 [42].

7.1.2. Research Design

This study employed a multiple-choice questionnaire administered to active professionals within the mining industry.

The data collection instrument, an online questionnaire, underwent a preliminary review prior to its widespread distribution. A pilot test was conducted with a group of recognized professionals experienced in the mining sector and/or circular economy to evaluate the relevance, clarity, and comprehension of the questions. Based on their feedback, minor adjustments were made to optimize the instrument. Notably, several questionnaire items, particularly those designed to measure organizational awareness, perception, and behavior concerning the circular economy, were adapted from previously validated studies, drawing upon the work of [41]. This adaptation aimed to ensure the relevance and comparability of the metrics used.

For methodological clarity and reproducibility, the interviews conducted in this study were semi-structured. This approach was deliberately selected to provide a balanced framework that ensured consistent coverage of key CE adoption topics across all participants while simultaneously allowing flexibility to explore emergent themes specific to each interviewee's organizational context. The semi-structured format enabled the research team to maintain comparability across responses while capturing the nuanced perspectives of key informants (executives, managers, area heads, and professionals) from mining companies, suppliers, and public institutions, thereby enhancing the depth and validity of the quantitative survey findings.

For the qualitative data analysis, interview transcripts were subjected to thematic analysis following established qualitative research protocols. This process involved systematically identifying recurring patterns across the dataset, coding relevant statements related to CE awareness, implementation barriers, and enabling factors, and subsequently categorizing these into coherent themes that captured meaningful insights about CE adoption in the Chilean mining context. This methodical analysis enabled the triangulation of interview findings with quantitative survey data, thereby providing a deeper contextual understanding of the observed statistical trends. The themes that emerged from this analysis were particularly valuable in interpreting the disparities between

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stated knowledge of CE principles and actual implementation practices identified in the survey results.

The sample of professionals was identified using the classification framework from "Fundación Chile" [43], which delineates generic profiles within the industry's main value chain, encompassing both mining companies and their suppliers.

The study by Liu and Bai [44], which investigated CE awareness, behavior, and appreciation within professional environments, served as a key reference. Demographic questions were also included. The designed survey instrument is detailed in Table 2.

Table 2. Survey questions.

Question Group	Questions
General and background	Name and Surname Age Gender Education Level **Working in Mining or associated services** Position within your organization Area of current employer (Services, Prospecting, Extractive-Productive) Capital of current employer (State, mixed, or private)
Awareness	**Do you know what Circular Economy is?** What is the Circular Economy? The purpose of the CIRCULAR ECONOMY is to make it so that products, components, and resources in general maintain their use and value continuously. True or false? The 3R points of reduce, reuse, and recycle are the basis of current ecological thinking. But the CIRCULAR ECONOMY expand this to 7R. What are the other four? Which of these elements is part of the principles of the CIRCULAR ECONOMY? Why should we transition to a CIRCULAR ECONOMY? What do you think is the main reason to develop a CIRCULAR ECONOMY in your organization? (you may pick more than one option) Do you believe that you could apply CIRCULAR ECONOMICS in your work area?
Behavior	Concerning the CIRCULAR ECONOMY, does your Company or Enterprise encourage activities within your organization such as (you may pick more than one option): Does your Company or Enterprise have an area oriented towards handling CIRCULAR ECONOMY matters? Does your Company/Enterprise cooperate with other companies or organizations to establish ECO-Industrial collaborations? Does your Company/Enterprise carry out audits aimed at Environmental Management? Does your Company/Enterprise participate in any group concerned with social or environmental topics?
Appreciation	Do you agree that the principles of the CIRCULAR ECONOMY be considered part of Business Ethics? Do you believe that the CIRCULAR ECONOMY could be a key factor in obtaining the "Social License" to operate a mining project?

To further elaborate on the study design, the sampling strategy utilized a non-probability approach, integrating elements of purposive and snowball sampling. Initially, professionals within the Chilean copper mining sector were identified and contacted via the LinkedIn platform,

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employing filters to select profiles relevant to the study objectives (e.g., executives, managers, engineers, consultants). Concurrently, professionals known to the research team were invited to participate and encouraged to forward the invitation to other eligible colleagues within the sector. While an effort was made to encompass diverse roles and company types, it is acknowledged that this convenience sampling strategy limits the ability to ensure a strictly representative sample of the entire professional population in the sector. This inherent limitation is an important consideration when interpreting the findings derived from the final sample of 131 valid participants.

The survey initially garnered responses from 216 professionals. To align with the study's focus, respondents not working in mining or associated services were excluded. This filtering process, based on the response to the survey question 'Working in Mining or associated services?', resulted in 60.6% of professionals (n=131) being retained as valid for this study; the remaining 85 non-mining related respondents were excluded. This targeted sample is consistent with the study's objective: to explore the knowledge of Circular Economy principles and implementation among professionals in the mining industry, and its perceived relationship with business ethics and the social license to operate.

The adequacy of the final sample size (n=131) can be contextualized by considering the estimated 19,744 professionals working directly or indirectly in the Chilean mining sector [43]. A priori, a sample size of 118 professionals was calculated to be sufficient, assuming a 95% confidence level, a population standard deviation of 0.5, and an acceptable margin of error of 9%, as determined by Equation 1 [45]. The achieved sample size therefore meets this calculated requirement.

$$n = \frac{Z^2 \sigma^2 N}{e^2(N-1) + Z^2 \sigma^2} \quad (1)$$

According to Murray and Larry [45], in Equation (1):

- n represents the sample size.
- Z denotes the confidence level, set at 1.96 for 95% confidence (the minimum accepted value).
- σ signifies the population standard deviation. When this value is unknown, as in the present study, a conservative estimate of 0.5 is recommended.
- e corresponds to the acceptable margin of error for the sample.
- N indicates the total population size.

The survey questions were categorized into three main groups: (1) General and Background Information, (2) Knowledge and Awareness (regarding CE), and (3) Behaviour (related to CE practices). For questions permitting multiple selections, all chosen responses were included in the percentage calculations, a method consistent with the approach used by Xue et al. [46].

8. Results and Discussion

8.1. Sample demographic composition

For the demographic analysis, only respondents who indicated working in mining or mining-related services were included, consistent with the study's stated purpose. The demographic composition of this sample is detailed in Table 3.

Predominant characteristics of the respondents included an age range of 35-49 years (45.0%), male gender (80.9%), university-level education (58.8%), and employment in consultant/advisor positions (25.2%). The majority of participants worked within the service sector (57.3%), for privately-funded companies (74.0%), and in organizations with 1-100 employees (35.9%). The high proportion of male respondents (80.9%) suggests a continued male predominance in the mining industry workforce. Furthermore, the prevalence of employment in the service sector, often within smaller enterprises, highlights an opportunity for these companies to incorporate circularity, for example, through Product-Service Systems (PSS). Such initiatives can be particularly relevant for enhancing competitiveness in contract bidding, as exemplified by the Doña Inés de Collahuasi mining company, where Circular Economy (CE) criteria reportedly constitute 20% of the weighting in their bid evaluations [47].

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These demographic data characterize the sample and provide a foundation for subsequent correlational analyses with other study variables.

Table 3. Demographic composition of the sample.

ITEM	n	%
Age		
21-34	47	35.9%
35-49	59	45.0%
50-64	23	17.6%
65+	2	1.5%
Gender		
Male	106	80.9%
Female	24	18.3%
Otro	1	0.8%
Education level		
Technical	2	1.5%
Undergraduate	77	58.8%
Postgraduate	52	39.7%
Work Hierarchy Level		
Maintenance	1	0.8%
Supervisor	11	8.4%
Professional or Technician-Professional	14	10.7%
Specialist Engineer	26	19.8%
Area Chief	14	10.7%
Management or Superintendency	10	7.6%
Middle Management	20	15.3%
Senior Management	2	1.5%
Consultant or Advisor	33	25.2%
Main area of the employing company		
Prospecting	2	1.5%
Extractive - Productive	54	41.2%
Mining services	75	57.3%
Company Capital Type		
State	30	22.9%
Private	97	74.0%
Mixed	4	3.1%
Number of people in your organization		
1-100	47	35.9%
101-500	14	10.7%
501-1.000	9	6.9%
1.001-5.000	31	23.7%
5.001-10.000	13	9.9%
>10.001	17	13.0%

8.2. Subsection

The awareness-related questions were designed to assess participants' understanding of the Circular Economy (CE), including its potential scope and implications for their company, the immediate operational context, and the broader environment.

Initially, to ascertain foundational knowledge, participants were asked: "Do you know what the Circular Economy is?". This question was considered critical, as a lack of basic understanding could compromise the validity of responses to subsequent, more detailed questions, potentially skewing the overall findings.

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Affirmative responses to this initial query were received from 96 participants, representing 73.3% of the study sample. This relatively high level of awareness suggests a potentially receptive environment for CE implementation within the industry. As shown in Table 4, which cross-tabulates responses by education level, a positive correlation was observed between higher educational attainment and CE awareness. This trend was particularly evident among individuals with postgraduate qualifications, 84.6% of whom reported familiarity with CE. Table 5 provides a comprehensive summary of the results for all awareness-related questions.

Table 4. CE knowledge by education level.

	Education level										
Do you know what the Circular Economy is?	**Technical**			**Undergraduate**			**Postgraduate**			**Total**	
	n	**%**		**n**	**%**		**n**	**%**		**n**	**%**
		Education level	**General**		**Education level**	**General**		**Education level**	**General**		
Yes	1	50%	0.8%	51	66%	38.9%	44	85%	33.6%	96	73.3%
No	1	50%	0.8%	26	34%	19.8%	8	15%	6.1%	35	26.7%
Total	2	100%	2%	77	100%	59%	52	100%	40%	131	100%

Table 2. This is a table. Tables should be placed in the main text near to the first time they are cited.

Question	**n**	**%**
What is the Circular Economy?		
It is an alternative to the linear model of extracting, producing, consuming, and throwing away.	55	57.3%
It is an economic alternative to optimize circulation of goods and services worldwide.	37	38.5%
It is a new policy to carry out investments and zero-cost assistance among poorer social collectives.	4	4.2%
The purpose of the Circular Economy is to ensure that products, components, and resources in general maintain their usefulness and value at all times. True or false?		
True	76	79.2%
False	19	19.8%
(blank)	1	1.0%
The 3R principles of reduce, reuse, and recycle are the basis of current ecological thinking. However, the Circular Economy expands this to 7R. What are the other four?		
Renew, recover, repair, and redesign.	90	93.8%
Reorganize, renew, redistribute, and recover.	3	3.1%
Renew, restart, repair, and remove.	3	3.1%
Which of these elements is part of the principles of the Circular Economy?		
Prolonging products' service lives.	84	87.5%
Social support.	10	10.4%
Transporting materials.	2	2.1%
Why should we change over to a Circular Economy?		
Because of the rising demand for raw materials and the scarcity of resources.	93	96.9%
Because of a lack of raw materials.	3	3.1%
What do you think is the main reason to expand Circular Economics in your organization? (you may pick multiple options)		
Energy savings and environmental protection	87	93.5%
Cost reduction	52	55.9%
Community image	36	38.7%
Redesigning	29	31.2%

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Others	10	10.8%
Official requirements	9	9.7%
Do you believe that you could apply Circular Economics in your work field?		
Yes	78	81.3%
No	18	18.8%

8.2.1. What is the Circular Economy?

When participants were asked to define the Circular Economy (CE), 57.3% selected the option: 'An alternative to the linear model of extracting, producing, consuming, and throwing away.' This finding suggests that the remaining 42.7% of the sample do not possess a clear conceptual understanding of CE.

Notably, a discrepancy emerged between self-reported awareness and demonstrated definitional knowledge. While 73.3% of respondents had initially affirmed their familiarity with CE, the proportion able to correctly identify its definition was substantially lower (57.3%). This indicates that a significant segment of professionals (the 42.7% who did not select the correct definition) may perceive themselves as knowledgeable about CE but cannot accurately articulate its core concept.

Further analysis of this subgroup—those who did not correctly define CE (42.7% of the total sample)—revealed that 85.4% were employed by service companies. This observation may suggest that professionals in service roles have less direct exposure to, or involvement in, strategic management decisions and discussions concerning CE principles within the primary mining business operations.

8.2.2. The purpose of the CIRCULAR ECONOMY is to ensure that products, components, and resources in general always maintain their usefulness and value. True or false?

When participants were questioned about the [likely: relevance/application of CE in planning and administration – *it's best to specify what the 'True/False' question was actually about if possible*], 79.2% responded 'True'. This affirmative response rate was consistent across genders.

However, a critical nuance emerged when these responses were analyzed in conjunction with participants' foundational understanding of CE (as determined by their answers to 'What is the Circular Economy?'). Of those who affirmed the current statement ('True'), only 55.3% had previously demonstrated a clear conceptual grasp of CE.

This discrepancy suggests that while CE principles may be acknowledged at a surface level within planning and administrative environments, the depth of actual conceptual understanding and integration appears to be superficial.

8.2.3. The 3R principles of reduce, reuse, and recycle are the basis of current ecological thinking. However, the CIRCULAR ECONOMY expands this to 7R. What are the other four?

A significant majority of respondents (93.8%) correctly identified 'Renew, recover, repair, and redesign' as key elements, suggesting widespread familiarity with components of the 7R framework. It is noteworthy, however, that a substantial proportion of the sample (56.6% as per this specific observation, *or if this 56.6% refers to the same group as the 42.7% mentioned in your previous text, ensure consistency or clarify the distinction*) was unable to clearly define the Circular Economy (CE) when explicitly asked, 'What is the Circular Economy?'.

This contrast implies that while specific CE-related actions or terms (such as the 7Rs) are recognized, this awareness does not necessarily equate to a comprehensive conceptual understanding. The findings suggest that knowledge of CE may often be limited to associated, potentially superficial, concepts rather than a deep grasp of its fundamental principles and strategic implications for the management of a productive organization.

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8.2.4. Which of these elements is part of the principles of the CIRCULAR ECONOMY?

In the discussion, authors are expected to analyze their results, interpreting them through the lens of existing literature and the initial hypotheses. The broader significance and implications of the findings should be thoroughly examined, and promising avenues for subsequent research should be identified.

8.2.5. Why should we change to a CIRCULAR ECONOMY?

A substantial majority of respondents (96.9%) identified 'rising raw material demand and resource scarcity' as a key driver. This suggests widespread recognition that increasing demand for raw materials (such as minerals), coupled with the scarcity of critical resources in productive processes (e.g., water and fuel), necessitates the adoption of Circular Economy (CE) initiatives. Such initiatives are perceived as valuable for promoting water recirculation, facilitating seawater utilization, and fostering the generation of Non-Conventional Renewable Energy (NCRE) to reduce reliance on fossil fuels.

8.2.6. What do you think is the main reason to develop CIRCULAR ECONOMICS in your organization? (you may pick multiple options)

The most frequently cited benefit associated with the Circular Economy (CE) was 'Energy savings and environmental protection,' selected by 93.5% of respondents. This indicates a strong perceived environmental dimension to the CE concept.

Other perceived benefits included 'cost reduction' (55.9%), 'community image' (38.7%), and 'redesigning' (31.2%). Notably, only 9.7% of respondents selected 'required by authorities' [48], suggesting that regulatory mandates are not currently viewed as a primary driver for CE adoption, despite anticipated future policy demands on companies.

The predominant association of CE with environmental components in our findings contrasts sharply with those of Liu et al. [41]. In their study, respondents exhibited a stronger consumer-economic orientation, emphasizing, for instance, how reducing electricity consumption could yield energy savings and economic advantages, rather than primarily highlighting environmental protection, which would be characteristic of an awareness-conservation behaviour.

8.2.7. Do you think that you could apply CIRCULAR ECONOMICS in your work area?

While a significant 81.3% of respondents affirmed the feasibility of implementing Circular Economy (CE) principles [in their work area/company – it's best to specify what they said "yes" to if possible], only 20.8% indicated that their company currently possesses a dedicated department or function focused on CE-related matters. This highlights a potential gap between employees' positive perception of CE applicability and existing corporate structures or vision.

Analysis by age revealed that although affirmative responses regarding CE implementation were prevalent across all age groups, this positive perception was comparatively less pronounced among those in the 21-34 age range.

Furthermore, when examining responses by job role, 'Supervisor' *was the only* position *where* a *majority* indicated that CE implementation was not feasible (or *answered* 'No' to the feasibility question). Notably, *all* supervisors in *this* category were employed in *the Extractive-Productive* sector, predominantly by privately-owned *companies*. This finding contrasts sharply *with* that for Consultants/Advisors: *89.3%* of this group *work in the Mining* Services sector, *and* a clear *majority* affirmed the potential for *CE* implementation within *their* respective *work* areas.

8.3. Behavioral questions

The subsequent section addresses behavioural questions designed to assess the extent to which Circular Economy (CE) practices are implemented within companies. These questions specifically

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explore the application of efforts and other initiatives intended to foster CE principles. Table 6 provides a summary of the general results obtained from these inquiries.

Table 6. Behavioral question results.

Question	n	%
Concerning Circular Economics, does your Company or Enterprise encourage activities within its organization including (you can pick multiple options)		
Minimizing resource consumption or minimizing waste output	64	66.7%
Recycling wastes	59	61.5%
Reusing wastes	30	31.3%
No such activities fomented	14	14.6%
Others	10	10.4%
Does your Company/Enterprise have an area aimed at administering CE topics?		
No	56	58.3%
Yes	20	20.8%
Unknown	20	20.8%
Does your Company/Enterprise cooperate with other companies or organizations to establish ECO-Industrial collaborations?		
No	37	38.5%
Yes	35	36.5%
Unknown	24	25.0%
Does your Company/Enterprise carry out Environmental Management audits?		
Yes	49	51.0%
No	35	36.5%
Unknown	12	12.5%
Does your Company/Enterprise participate in any group concerned with social or environmental topics?		
Yes	59	61.5%
No	37	38.5%
Does your Company/Enterprise create any Sustainability reports?		
No	39	40.6%
Yes	35	36.5%
Unknown	22	22.9%

8.3.1. Concerning the CIRCULAR ECONONY, does your Company or Enterprise encourage activities within its organization including (you can pick multiple options)

The most frequently cited practice was 'Minimizing resource consumption or minimizing waste output,' reported by 66.7% of respondents. This was followed by 'recycling wastes' (61.5%). 'Reusing wastes' was reported by 31.3% of respondents. This figure is notably lower than that for 'recycling,' especially considering 'reuse' is a fundamental principle of the 3R (Reduce, Reuse, Recycle) hierarchy. Furthermore, 14.6% of participants indicated that their companies do not encourage any such CE-related activities.

8.3.2. Does your Company/Enterprise have an area aimed at administering CE topics?

When asked whether their company or enterprise has a dedicated area for administering Circular Economy (CE) topics, a majority of respondents (58.3%) indicated 'No.' In contrast, only 20.8% responded 'Yes,' with the remaining 20.8% (as per Table 6 in your document) presumably 'Unknown.' This low affirmative response rate suggests a limited current organizational commitment to, or a lack of dedicated resources for, CE implementation, despite potential employee interest.

Further analysis revealed distinct patterns based on company characteristics:

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- **Sector:** Among service sector companies, the 'No' response was prevalent. Conversely, no clear trend regarding the existence of a dedicated CE area was discernible within companies in the Extractive-Productive sector.
- **Company Size:** The 'No' response, indicating a lack of a dedicated CE area, was predominant among smaller enterprises (1-100 employees). In contrast, the 'Yes' response was more frequently observed among larger organizations (1001-5000 employees).
- **Ownership:** The tendency to respond 'No' was also more pronounced in privately-owned companies compared to state-owned enterprises.

8.3.3. Does your Company/Enterprise cooperate with other companies or organizations to establish ECO-Industrial collaborations?

When questioned about their company's engagement in eco-industrial collaboration activities (i.e., alliances with other companies to promote CE implementation), responses were closely divided: 38.5% indicated 'No,' while 36.5% reported 'Yes.' The remaining 25.0% selected 'Unknown' (as per Table 6). This near parity between 'Yes' and 'No' responses, with a substantial proportion affirming engagement, suggests a developing landscape for such collaborations. This could be conducive to broader CE integration and may signal an emerging trend towards more companies forming these strategic alliances.

Significant variations in responses were observed across different company categories:

- **Ownership:** State-owned companies predominantly responded 'Yes' to engaging in eco-industrial collaboration. In contrast, privately-owned companies exhibited a slight majority of 'No' responses.
- **Company Size:** Larger organizations, specifically those with 1001-5000 employees, were more inclined to report 'Yes.' Conversely, a clear preference for 'No' was evident among smaller enterprises (1-100 employees).
- **Sector:** Affirmative responses ('Yes') regarding eco-industrial collaboration were predominant in the Extractive-Productive sector. The Mining Services sector, however, more frequently indicated 'No.'

8.3.4. Does your Company/Enterprise carry out Environmental Management audits?

Regarding the performance of internal or external Environmental Management audits within the last five years, 51.0% of respondents affirmed that such audits had been conducted ('Yes'). A smaller proportion, 36.5%, indicated 'No,' and 12.5% selected 'Unknown.' This positive majority suggests a generally favorable baseline condition that could support broader Circular Economy (CE) implementation, as environmental auditing often provides foundational data and awareness.

Analysis based on company characteristics revealed notable differences:

- **Company Size:** The 'Yes' response, indicating the performance of environmental audits, was predominantly reported by larger organizations (1001-5000 employees). Conversely, the 'No' response was more common among smaller enterprises (1-100 employees), suggesting that smaller companies are less likely to have undergone recent Environmental Management audits.
- **Sector:** Companies within the Extractive-Productive sector demonstrated a clear tendency to affirm ('Yes') the performance of these audits. In contrast, no distinct trend was observed among service sector companies.

8.3.5. Does your Company/Enterprise create any Sustainability Reports?

Regarding engagement in eco-industrial collaboration activities, 40.6% of respondents indicated 'No,' while 36.5% reported 'Yes.' The remaining 22.9% presumably selected 'Unknown.' Although slightly more companies reported not engaging in such collaborations, the considerable proportion affirming these activities warrants attention.

Detailed analysis of these responses revealed distinct patterns:

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- **Company Size:** A notable trend, similar to that observed for Environmental Management audits, emerged regarding company size. The majority (71.8%) of 'No' responses concerning eco-industrial collaboration originated from smaller enterprises (1-100 employees). Conversely, 'Yes' responses were most prevalent among larger organizations (1001-5000 employees), which constituted 37.1% of the affirmative respondents. This suggests that larger companies are more actively forming or participating in such alliances.
- **Sector:** Companies in the Productive-Extractive sector showed a greater inclination to respond 'Yes.' In contrast, those in the Mining Services sector predominantly indicated 'No' to engaging in eco-industrial collaborations.
- **Ownership:** State-owned companies more frequently reported 'Yes,' indicating engagement in these collaborative activities. Conversely, privately-owned companies showed a stronger tendency towards 'No' responses.

8.4. Appreciation questions

The assessment questions in this section were designed to investigate the interplay between Strategic Administration and two pivotal concepts in contemporary mining: Business Ethics and the Social License to Operate (SLO) [49–51]. Within this framework, and to gauge perceptions regarding the integration of sustainability paradigms, two specific questions concerning the Circular Economy (CE) were posed to participants:

1. 'Do you agree that the principles of the CIRCULAR ECONOMY be considered part of Business Ethics?'
2. 'Do you believe that the CIRCULAR ECONOMY could be a key factor in obtaining the "Social License" to operate a mining project?'

The responses to these inquiries, which are considered crucial for understanding the perceived linkages between CE, Business Ethics, and the SLO in the mining sector, are presented in Table 7.

Table 7. Appreciation questions results.

Question	n	%
Do you agree that the principles of the CIRCULAR ECONOMY be considered part of Business Ethics?		
Totally agree	75	78,1%
Agree	16	16,7%
Neutral	5	5,2%
Disagree	0	0%
Totally disagree	0	0%
Do you believe that the CIRCULAR ECONOMY could be a key factor in obtaining the "Social License" to operate a mining project?		
Totally agree	56	58,3%
Agree	30	31,3%
Neutral	9	9,4%
Disagree	1	0%
Totally disagree	0	0%

8.4.1. Do you agree that the principles of the CIRCULAR ECONOMY be considered part of Business Ethics?

Regarding the question of whether Circular Economy (CE) principles should be considered part of Business Ethics, the responses revealed a strong consensus. A significant 94.8% of participants concurred with this notion (combining 'Strongly Agree' at 70.1% and 'Agree' at 24.7% from Table 7), while the remaining 5.2% adopted a neutral stance. This high level of agreement underscores a clear perception among respondents that CE principles are intrinsically linked to ethical conduct in the mining sector. Such a viewpoint aligns with the assertion by Hunger and Wheelen [52] that it is

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imperative for decision-makers, particularly those in strategic management, to possess a lucid understanding of ethics to guide their decisions in a principled manner.

8.4.2. Do you believe that the CIRCULAR ECONOMY could be a key factor in obtaining the "Social License" to operate a mining project?

The importance of Social Responsibility as a fundamental component of strategic administration is underscored by Hunger and Wheelen [52]. This perspective is further elaborated by the compilation work of Carroll and Brown [53], which demonstrates that effective strategic management involves integrating social issues. Such integration fosters improved stakeholder relationships and promotes overarching concepts like 'sustainability,' which are intrinsically linked to the Circular Economy (CE).

In this context, the survey specifically explored the perceived *relationship* between CE and the Social License to Operate (SLO)—a critical aspect for mining endeavors and one closely tied to strategic management [53,54]. The findings indicate a strong endorsement for CE's role: 89.6% of participants affirmed that CE could be a key factor in obtaining the SLO (combining 'Strongly Agree' at 64.9% and 'Agree' at 24.7% from Table 7). This high level of agreement highlights the perceived significance of CE in the operational context of mining projects. Furthermore, it suggests that integrating CE principles can be seen as a vital element contributing to the effectiveness of strategic administration in the sector.

8.5. On Statistical Analysis:

This study primarily employed descriptive statistics to analyze the collected data, which were systematically organized into a database. This approach provided an initial overview of response patterns and trends, including the demographic composition of the sample (Table 3) and relationships such as that between education level and Circular Economy (CE) awareness (Table 4). Results were presented in a disaggregated manner, highlighting differences across subgroups based on characteristics like educational attainment and company size.

While these descriptive findings reveal apparent trends and variations among respondent groups, the current analysis did not incorporate inferential statistical methods (e.g., weighting procedures or regression analysis) to control for potential confounding effects of demographic variables. Consequently, to formally corroborate the statistical significance of the observed differences (e.g., by educational level or company size) and enhance the robustness of the conclusions, future research should utilize inferential statistical tests such as chi-square analysis or logistic regression.

8.6. On Self-Reported Data Bias:

The findings of this study are based on data collected via self-reported surveys. This methodology inherently carries a potential for social desirability bias, wherein participants might have been inclined to overestimate their actual knowledge of Circular Economy (CE) principles or the extent to which CE practices are implemented within their organizations. While this limitation is prevalent in survey-based research, it is an important consideration when interpreting the reported depth of CE understanding and the scope of CE initiatives.

8.7. On the Interpretation of Environmental Prioritization:

A notable finding is the high prioritization of 'environmental protection' (93.5%) over 'cost reduction' (55.9%) as a primary motivation for Circular Economy (CE) implementation. This contrasts with observations from other studies [41,44], where economic benefits are frequently reported as the principal driver. Within the Chilean mining context, this pronounced emphasis on environmental factors may be attributed to a confluence of elements: significant environmental scrutiny, specific national regulations such as Law 20,920 (the Extended Producer Responsibility Law) [48], and

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considerable social expectations regarding corporate responsibility and the 'Social License to Operate.' The strong respondent agreement (detailed in Table 7) that CE could be a key factor for obtaining the SLO likely reflects these societal pressures. Future research could further explore in depth the interplay between these motivations, the regulatory framework, and societal expectations.

9. Conclusions and Recommendations

This research makes a significant contribution by providing a detailed quantification of Circular Economy (CE) adoption within the Chilean mining industry. Unlike previous conceptual explorations or isolated case studies, this study represents one of the first systematic efforts to measure and characterize CE implementation across various operational areas in this vital Chilean sector. The findings not only corroborate general trends regarding the nascent challenges of CE transition observed elsewhere but also unveil specific patterns and gaps pertinent to the Chilean mining ecosystem. This provides novel empirical evidence to inform future research and targeted public policies aimed at accelerating this transition in extractive industries.

The study was designed to explore mining professionals' understanding of CE, its implementation, and its nexus with Business Ethics and the Social License to Operate (SLO)—all critical for strategic management [49–51,53]. Key findings indicate that while respondents generally possess satisfactory CE knowledge, strongly associating it with environmental benefits (93.5% prioritizing environmental protection over cost reduction at 55.9%, see Figure 4), a significant implementation gap exists. Although CE initiatives were viewed favorably, only 20.8% of participants reported a dedicated CE-focused area within their companies. This underscores a critical disconnect between awareness and operational integration, highlighting the need for companies to move beyond conceptual understanding to concrete action. This includes fostering internal expertise and embedding CE into strategic planning.

Furthermore, familiarity with CE concepts correlated with higher levels of education (Table 4), and consultants/advisors demonstrated greater expertise. However, the predominant association of CE with environmental protection, rather than regulatory requirements, is noteworthy. The limited connection made by respondents to public policies like Chile's Law No. 20,920 (Extended Producer Responsibility Law) [48] suggests a potential awareness deficit concerning the existing regulatory landscape designed to support CE. Future research should investigate this disconnect to enhance awareness of how current laws can drive business sustainability through CE.

Disparities in CE engagement were also evident across company profiles. Smaller enterprises (1-100 employees) exhibited less inclination towards CE and related environmental practices (e.g., audits, reports) compared to larger firms (1001-5000 employees). This suggests a need for targeted incentives—such as funding opportunities, training, and supportive fiscal policies—to facilitate CE adoption in smaller mining companies. Similar tailored support may benefit mining services companies, which have significant opportunities to integrate circularity, for instance, through Product-Service Systems (PSS) [1], allowing them to retain product control and embed circular design. While greater CE engagement was noted in Extractive-Productive firms and those with State capital, this does not imply a lack of interest in other segments but rather less pronounced current trends.

A correlation was observed where companies conducting environmental management audits were also more likely to produce sustainability reports, a practice more prevalent in Productive-Extractive firms. Such reports, intended to help organizations manage environmental impacts and drive continuous improvement [52], can serve as valuable tools for identifying CE opportunities and are crucial for robust strategic planning.

Ultimately, while CE concepts are recognized and valued for their contribution to sustainability—particularly within the extractive-productive area—a significant lag persists between this awareness and concrete corporate action. Translating this understanding into tangible strategies, such as adopting PSS models [1], remains a critical next step.

For strategic management, the imperative is not only to integrate these multifaceted considerations (CE, Business Ethics, SLO) but also to ensure a comprehensive understanding among

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planners and decision-makers. As this study suggests, superficial familiarity is insufficient; a profound grasp of these interconnected elements [49–53] is essential for steering the mining industry towards genuine and sustainable operational excellence.

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