Bridging Innovation and Policy: Tailings Recovery Technologies in Australia's Mining Sector

ENS5010

AT3: White Paper using Evidence-based Decision Making

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1. Introduction

1.1. Scope and Purpose

The circular economy is a development model that aims to minimise waste and optimise resource use by maintaining materials in circulation for as long as possible, rather than following the traditional linear "take–make–dispose" model (UNEP, 2019; Ellen MacArthur Foundation, 2013). With a circularity rate of only 4.6%, significantly below the global average of 7.2%, Australia aims to double its national circularity rate by 2035 and achieve 80% resource recovery across priority sectors, including mining (DCCEEW, 2024). However, as discussed in Part A, there is still insufficient evidence to justify this target, particularly because recovery performance depends heavily on technological effectiveness and practical implementation. Therefore, strengthening this evidence is important for supporting evidence-informed policy development and improving policy transparency and reliability.

Given the limited timeframe, a rapid review was used to synthesise existing evidence within rapidly evolving policy and technological contexts (Tricco et al., 2017). The research question was developed using the PICO framework (Bottrill et al., 2014) (Table 1).

How effective are tailings recovery technologies **(I)** in improving resource recovery and supporting circular economy targets **(O)** compared with conventional tailings management practices **(C)** in Australia's mining sector **(P)**?

1.2. Background

The mining sector contributes approximately 14% of Australia's GDP and accounts for 86% of material extraction activities. However, it also generates mining waste volumes more than four times greater than the combined waste produced by all other industries (Productivity Commission, 2025). Low-grade ores and large-scale tailings deposits from decades of mining have increased environmental pressures and waste management challenges, making mining waste an important policy issue within Australia's transition toward a circular economy (Geoscience Australia, 2024). Mining waste includes overburden, waste rock and tailings, which are fine-grained slurry remaining after mineral processing (DCCEEW, 2024). Most tailings are currently stored in tailings storage facilities (TSFs). The Cadia Gold Mine tailings dam incident in New South Wales in 2018 raised major concerns regarding TSF stability and environmental risks (Mining Technology, 2019). In this context, tailings recovery technologies are viewed as a promising approach for transforming tailings from environmental burdens into secondary resources. Previous studies suggest that these technologies can achieve recovery rates of 30–90% (Edraki et al., 2014). However, existing evidence remains fragmented and focused on individual technologies or specific sites, limiting assessment of effectiveness, scalability and suitability within the Australian context.

Therefore, evaluating the effectiveness of tailings recovery technologies is important for both academic and policy purposes. This study directly supports Australia's Circular Economy Framework, particularly the 80% resource recovery target (DCCEEW, 2024). As identified in Part A, strengthening evidence on technological effectiveness is necessary to support evidence-based policy and help policymakers, mining companies and sustainability practitioners develop reliable and feasible recovery strategies aligned with Australia's circular economy goals.

2. Review Protocol

2.1. Overview of the Review Process

According to Light and Pillemer (1984), establishing a review protocol from the beginning improves transparency and systematic structure. The review process was based on the PRISMA framework during the stages of study identification, screening, eligibility assessment and final selection (Page et al., 2021). Rapid review shortcuts included limiting databases, English-language sources and single-reviewer screening.

The rapid review process consisted of four stages:

(1). Developing the research question using the PICO framework;

(2). Identifying keywords and selecting databases;

(3). Screening studies using predetermined inclusion and exclusion criteria;

(4). Extracting evidence on technological effectiveness and implementation challenges.

2.2. Literature Types and Database Selection

The study used both peer-reviewed literature and grey literature to provide a broader understanding of tailings recovery technologies and applications in the mining sector (Tricco et al., 2017; Garritty et al., 2021).

No publication date restrictions were applied to capture the long-term development of tailings recovery technologies. For example, flotation technology has been used since the early twentieth century in mineral processing and remains one of the most widely applied methods in tailings reprocessing (Wills & Finch, 2016).

Scopus, ScienceDirect and Google Scholar were selected for their strong coverage of mining, sustainability and technical studies. ResearchGate was used as a supplementary source to access full-text articles when database access was limited. Grey literature was collected from organisations such as CSIRO, Geoscience Australia and DCCEEW because many pilot projects, industry reports and policy documents related to tailings recovery technologies are not yet fully represented in peer-reviewed literature (Adams et al., 2017).

2.3. Search Keywords

Initial keywords such as “tailings recovery”, “mining waste recycling” and “resource recovery” produced many irrelevant results. Therefore, the search terms were refined and combined with Boolean operators (AND, OR) to improve search relevance (Table 2).

2.4. Screening and Data Extraction Procedures

The screening process followed rapid review methodology and the PRISMA framework (Figure 1) to ensure transparency and reproducibility (Tricco et al., 2017; Page et al., 2021). Inclusion, exclusion and data extraction criteria are presented in Table 3.

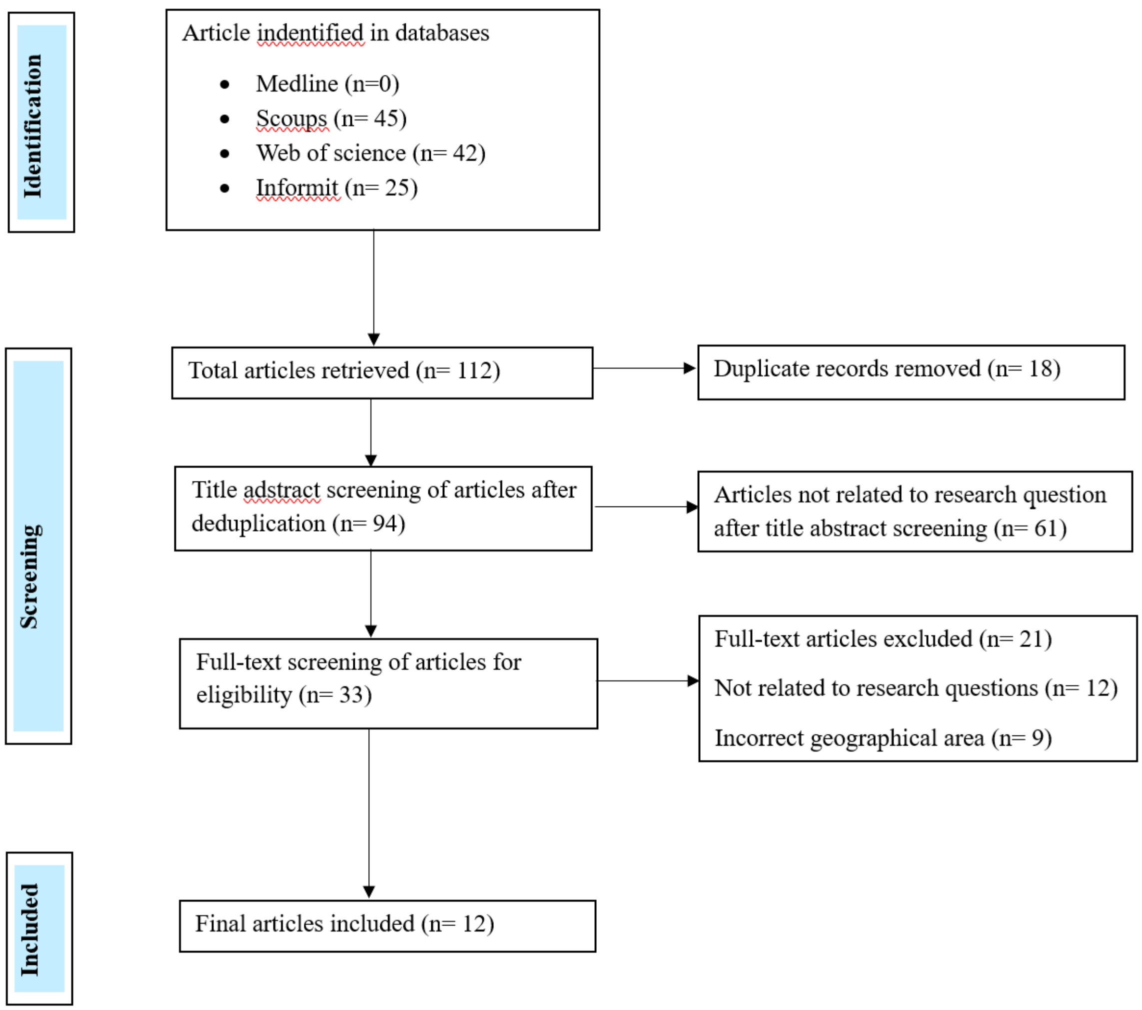

Figure 1. PRISMA flow chart showing the number of articles included or excluded in the rapid literature review stages.

Following screening, full-text studies were reviewed and synthesised using narrative synthesis to identify technological trends, trade-offs and policy implications related to tailings recovery systems.

3. Results

3.1. Summary of Findings

The synthesis of 12 selected studies (Table 4) indicates that tailings recovery technologies are increasingly improving resource recovery within the mining sector, particularly through flotation reprocessing, hydrometallurgy, bioleaching and integrated recovery systems (Abbadi & Mucsi, 2024; Edraki et al., 2014; Kinnunen et al., 2022).

Kinnunen et al. (2022) found that flotation reprocessing combined with fine grinding in Chile and Australia improved copper recovery efficiency by approximately 10–15% for fine particles remaining in tailings. Shi et al. (2023) reported recovery rates of approximately 70–90% for rare earth elements in China using acid leaching and solvent extraction. In African mining contexts, Kasongo and Mwanat (2021) reported cobalt recovery rates exceeding 90% under optimised reductive leaching conditions

A key trend identified in the literature is the shift from waste disposal toward integrated recovery and reuse systems that improve resource efficiency and support circular economy objectives. Canada and several European countries have applied geopolymer technologies to reuse tailings in construction materials such as bricks, cement substitutes and aggregates (Zhang et al., 2011).

Australia has adopted advanced technologies and was the first country to develop advanced flotation technologies (CSIRO & Australian Critical Minerals R&D Hub, 2024; Discovery Alert, 2026). However, most applications remain at the pilot or demonstration stage rather than commercial-scale implementation (CSIRO & Australian Critical Minerals R&D Hub, 2024)

However, these technologies involve major trade-offs between recovery efficiency, environmental sustainability and economic feasibility. Flotation reprocessing and fine grinding require high energy consumption and water demand, while hydrometallurgy may generate secondary waste streams and chemical contamination if not properly managed (Edraki et al., 2014).

3.2. Research Gaps and Evaluation

The rapid review indicates that most studies focus on recovery efficiency under laboratory or pilot-scale conditions, while evidence on industrial-scale implementation remains limited (CSIRO & Australian Critical Minerals R&D Hub, 2024; Kinnunen et al., 2022). This is evident in bioleaching and hydrometallurgy studies, where high recovery rates are reported without sufficient evaluation of long-term operational costs, infrastructure requirements and lifecycle environmental impacts (Brierley & Brierley, 2013).

A significant gap also exists between Australia and leading international practices in integrating tailings recovery technologies across the mining value chain. While Canada and several European countries have combined geopolymer technologies and reuse systems to maximise resource efficiency, Australia still mainly relies on isolated technologies or pilot projects.

Australian studies also show that electricity demand, water use and infrastructure requirements significantly increase operational costs (Adiansyah et al., 2017). In addition, current literature lacks long-term lifecycle assessments and comparative analyses needed to identify suitable technologies for different tailings types and geographical conditions across Australia (Carneiro, 2019; Beylot et al., 2022).

4. Limitations and Recommendations

During the rapid review process, the study encountered several limitations affecting the reliability of findings. Key limitations included limited research time, fragmented datasets and the lack of commercial-scale and long-term lifecycle studies in Australia. In addition, many studies focused on pilot-scale projects or laboratory conditions, limiting the evaluation of scalability, economic feasibility and environmental trade-offs in practice.

Future studies should prioritise long-term comparative studies, lifecycle assessments and integrated recovery systems to improve evidence-based decision-making and support circular economy outcomes. In addition, a unified national dataset on mine tailings, reuse potential and cross-sector applications should be developed to support evidence-based policymaking (Table 5).

5. Conclusion

This rapid review demonstrates that tailings recovery technologies can improve resource recovery and support circular economy objectives within Australia's mining sector. However, the findings suggest that Australia is unlikely to achieve the 80% resource recovery target in the short term because most technologies remain at the pilot-scale stage and continue to face barriers related to scalability, infrastructure costs and environmental trade-offs.

Analysis of the technological gap indicates that if Australia expands commercial-scale implementation and integrates multiple technologies, achieving the 80% resource recovery target may become more feasible in the long term. The findings emphasise the importance of evidence-based policy development, long-term lifecycle assessments and integrated recovery systems in supporting Australia's transition toward a more sustainable and circular mining industry.

Word count: 1487 words.

Table 1:

Structure of the research question (PICO framework)

Population	Intervention	Comparation	Outcome
Tailings waste generated in Australia's mining sector, particularly low-grade tailings and legacy mine waste, within the context of circular economy and resource recovery policies.	Tailings recovery and reprocessing technologies such as flotation reprocessing, hydrometallurgy, bioleaching and integrated recovery systems. These technologies aim to improve resource recovery, recover critical minerals, reduce mining waste and support circular economy objectives through reuse and recycling practices.	Conventional tailings management practices based primarily on long-term storage in TSFs and linear waste management approaches, with limited recovery and reuse of residual materials.	Improved resource recovery and contribution to Australia's circular economy targets through reduced mining waste, increased critical mineral recovery and more sustainable mining practices. Outcomes also include reduced environmental risks and improved resource efficiency within the mining sector.

Table 2:

List of Search Keywords

Key concept	Key words
Mine tailings in Australia	("mine tailings" OR "tailings waste" OR "Australian mining waste" OR "legacy mine waste Australia" OR "tailings management Australia")
Material recovery	("tailings recovery" OR "tailings reprocessing" OR "resource recovery" OR "secondary resource recovery" OR "metal recovery rate" OR "resource recovery from tailings") AND

	("mining waste" OR tailings)
Tailings reprocessing technologies	("flotation tailings recovery" OR bioleaching OR hydrometallurgy OR "acid leaching" OR "solvent extraction" OR "gravity separation" OR "integrated recovery systems") AND (tailings OR "low-grade ores")
Technology effectiveness and scalability	("recovery efficiency" OR "technology effectiveness" OR scalability OR "commercial-scale implementation" OR "pilot-scale projects" OR "industrial-scale recovery") AND (tailings OR mining)
Comparison with conventional management	("tailings storage facilities" OR TSFs OR "conventional tailings management" OR "mine waste disposal" OR "tailings storage")
Economic feasibility	("economic feasibility" OR profitability OR "techno-economic analysis" OR "cost-benefit analysis" OR "life cycle cost") AND ("tailings reprocessing" OR "critical minerals recovery")
Circular economy and reuse	("circular economy mining" OR "resource efficiency mining" OR "waste-to-resource mining" OR "mine waste reuse" OR "tailings reuse" OR geopolymer OR "secondary materials")
Environmental impacts and risks	("tailings environmental impact" OR "mine tailings risk assessment" OR "heavy metal contamination" OR "water pollution mining waste" OR "environmental externalities mining") AND (tailings OR mining)
Australia mining context	("Australia mining tailings" OR "CSIRO tailings research" OR "Australian mining sector" OR "critical minerals Australia")

Table 3:

Screening and Data Extraction Criteria

Eligibility Criteria	**Included**	**Excluded**
Topic	Studies related to tailings recovery, mining waste recycling, circular economy in mining, resource recovery and sustainable tailings	Studies unrelated to mining waste, tailings recovery or circular economy in mining, including studies focused only on primary mineral extraction

	management.	or unrelated environmental sectors.
Intervention	Studies examining tailings recovery and reprocessing technologies such as flotation, hydrometallurgy, bioleaching, geopolymer reuse and paste backfill systems.	Studies not evaluating tailings recovery technologies or recovery-related outcomes.
Outcome	Studies reporting recovery efficiency, environmental impacts, economic feasibility, scalability, sustainability or circular economy outcomes.	Studies without measurable recovery, environmental or economic outcomes.
Study Design	Peer-reviewed articles, government reports, industry reports and technical studies published in English.	Opinion pieces, editorials, conference abstracts without full text and studies lacking clear methodology.
Language	English-language studies.	Non-English publications.
Geographic Context	Australian studies and relevant international best-practice case studies.	Studies unrelated to mining or tailings recovery contexts.
Data Extraction	Data on technology type, recovery efficiency, environmental impacts, scalability, implementation barriers and case-study context were extracted.	Studies with insufficient methodological detail or missing key information.
Synthesis Approach	Studies were synthesised using descriptive and narrative analysis to identify technological trends, benefits, limitations and trade-offs.	Studies that could not contribute to thematic synthesis or evaluation of the research question.

Using the CASP (Critical Appraisal Skills Programme) and Source Credibility Evaluation Framework, assess each article's quality.

1. Research Quality Assessment Framework

- **High quality** study shows a strong methodology, providing robust evidence such as rigorous data collection and analysis. It is well-designed and offers clear, valuable insights that directly align with your research objectives.
- **Medium quality** study offers useful insights but should be interpreted with caution due to methodological or analytical limitations and partial alignment between the research goals and findings.
- **Low quality** study lacks methodological rigour and credibility, making it unreliable for providing meaningful insights.

2. Relevance to Research Question

- **Highly relevant:** The study handles all major aspects of the research question directly.
- **Semi-Relevant:** The study focuses on some aspects of the research question, but not all or not in-depth.
- **Irrelevant:** Study does not address the research question.

Table 4:

Collation table

	Author, Year, Title	Study Overview	Key Results	Study Quality	Comments / Relevance to Research Question
1	Abbadi, A., & Mucsi, G. (2024). *A review on complex utilization of mine tailings: Recovery of rare earth elements and residue valorization*. (Primary literature)	Review study examining integrated recovery systems, residue valorisation and circular economy approaches for mine tailings.	Integrated recovery systems combine extraction, reuse and secondary resource recovery technologies to improve resource efficiency and reduce tailings disposal.	**High Quality** Peer-reviewed review article with strong technical analysis.	**Highly Relevant** Supports integrated recovery systems and circular economic approaches in tailings recovery.
2	Adiansyah, J. S., et al. (2017). *Sustainable mine tailings management approaches*.	Sustainability-focused study examining operational and environmental challenges in tailings management systems.	Electricity demand, water use and infrastructure requirements significantly increase operational costs of tailings recovery	**Medium Quality** Peer-reviewed study with practical focus but limited large-scale	**Highly Relevant** Supports analysis of economic feasibility and scalability barriers in Australia.

	(Primary literature)		systems.	comparative evidence.	
3	Beylot, A., et al. (2022). *Comparative environmental assessment of recovery systems*. (Primary literature)	Comparative analysis of environmental performance across recovery technologies.	Existing studies lack cross-site comparative analyses needed to identify suitable technologies across different mining contexts and geographical conditions.	**Medium Quality** Strong comparative methodology but limited industry-scale application evidence.	**Highly Relevant** Supports discussion of evidence gaps and comparative assessment limitations in Australia.
4	Brierley, J. A., & Brierley, C. L. (2013). *Progress in bioleaching: Fundamentals and mechanisms of bacterial metal sulfide oxidation*. (Primary literature)	Review of bacterial metal sulfide oxidation and global bioleaching applications.	Bioleaching technologies demonstrate strong recovery potential but lack sufficient evidence on long-term operational costs, scalability and lifecycle environmental impacts.	**High Quality** Peer-reviewed biotechnology review article with strong scientific methodology.	**Highly Relevant** Supports discussion of scalability limitations and lifecycle assessment gaps.
5	Carneiro, J. (2019). *Lifecycle assessment approaches for mining recovery systems*. (Primary literature)	Lifecycle assessment study evaluating environmental impacts of recovery technologies.	Current literature lacks sufficient long-term lifecycle assessments and comparative analyses across different tailings conditions.	**Medium Quality** Useful methodological contribution but limited comparative scope.	**Semi-Relevant** Supports identification of lifecycle assessment and comparative analysis gaps.
6	CSIRO & Australian Critical Minerals Research and Development Hub. (2024). *Critical minerals processing and innovation pathways*. (Grey literature)	Industry and policy-focused report examining Australia's critical minerals value chain and processing technologies.	Australia demonstrates strong innovation in critical mineral recovery technologies; however, most applications remain at pilot or demonstration stage rather than commercial-scale implementation.	**Medium Quality** Government-supported research and industry evidence.	**Highly Relevant** Supports discussion of innovation, scalability and commercialisation challenges in Australia.
7	Discovery Alert. (2026). *Advanced flotation technology revolutionises phosphate and potash*	Industry report examining advanced flotation and critical mineral recovery technologies in Australia.	Australia has demonstrated strong innovation in advanced flotation technologies, although most applications remain at pilot or demonstration stage.	**Medium Quality** Government-supported research and industry evidence.	**Highly Relevant** Supports discussion of Australian recovery technologies and scalability limitations.

	recovery. (Grey literature)				
8	Edraki, M., Baumgartl, T., Manlapig, E., Bradshaw, D., Franks, D. M., & Moran, C. J. (2014). *Designing mine tailings for better environmental, social and economic outcomes*. (Primary literature)	Review study evaluating environmental, economic and social impacts of tailings management approaches.	Tailings recovery technologies improve resource recovery but involve trade-offs related to energy demand, water use, secondary waste streams and environmental risks.	**High Quality** Published in *Journal of Cleaner Production* with multidimensional sustainability analysis.	**Highly Relevant** Provides evidence on trade-offs between recovery efficiency, sustainability and economic feasibility.
9	Kasongo, K. B., & Mwanat, H.-M. (2021). *Application of Taguchi method and artificial neural network model for the prediction of reductive leaching of cobalt(III) from oxidised low-grade ores. South African Journal of Science*. (Primary literature)	Experimental study examining cobalt recovery from low-grade ores using reductive leaching and optimisation models.	Cobalt recovery exceeded 90% under optimised conditions, demonstrating the potential of bioleaching and hydrometallurgical approaches.	**High Quality** Peer-reviewed experimental study with quantitative modelling methods.	**Highly Relevant** Supports the effectiveness of alternative recovery technologies for improving cobalt recovery from mining waste and low-grade ores.
10	Kinnunen, P., Karhu, M., Yli-Rantala, E., Kivikytö-Reponen, P., & Mäkinen, J. (2022). *A review of circular economy strategies for mine tailings. Cleaner Engineering and Technology.*	Review on tailings recovery technologies and circular economy practices, with a global focus on flotation, hydrometallurgy and reuse systems.	Flotation reprocessing combined with fine grinding improved copper recovery efficiency by approximately 10–15% for fine particles in tailings. Tailings can also be reused as secondary resources within circular economy systems.	**High Quality** Peer-reviewed review article with comprehensive synthesis of recovery technologies and circular economy approaches.	**Highly Relevant** Directly supports recovery effectiveness, reuse systems and circular economy outcomes related to the research question.

	(Primary literature)				
11	Shi, S., et al. (2023). *Bioleaching of rare earth elements: Perspectives from primary and secondary resources*. (Primary literature)	Review study examining hydrometallurgy and bioleaching technologies for rare earth recovery in China.	Hydrometallurgical technologies achieved recovery rates of approximately 70–90% for rare earth elements through acid leaching and solvent extraction.	**High Quality** Peer-reviewed Minerals journal with strong technical evidence.	**Highly Relevant** Provides evidence on critical mineral recovery efficiency and advanced recovery technologies.
12	Zhang, L., Ahmari, S., & Zhang, J. (2011). *Synthesis and characterization of fly ash modified mine tailings-based geopolymers*. (Primary literature)	Experimental study investigating geopolymer technologies using mine tailings in construction materials.	Tailings can be reused in bricks, cement substitutes and aggregates, supporting circular economy objectives and waste minimisation.	**Medium Quality** Experimental study with applied industrial relevance but limited large-scale implementation evidence.	**Highly Relevant** Supports integrated recovery and reuse systems within circular economy frameworks.

Criteria for Assessing Impact Level

The impact level of each limitation was assessed based on its influence on evidence reliability, validity, comprehensiveness, scalability assessment and policy applicability, adapted from systematic review and rapid review appraisal frameworks, including CASP, PRISMA 2020 and rapid review methodological guidance (Tricco et al., 2017; Page et al., 2021).

- **High**: Limitations that substantially affect the reliability, completeness or policy relevance of the findings and may significantly influence interpretation or decision-making.
- **Medium**: Limitations that moderately affect methodological consistency, comparability or evidence interpretation but do not critically undermine the overall conclusions.
- **Low**: Limitations with minimal influence on the overall validity, interpretation or applicability of the review findings.

Table 5:

Limitations and Recommendations

	Limitations	Potential Impacts	Impact level	Recommendations	Practical effectivenesses
1	Limited rapid review scope and databases may increase the risk of missing evidence	Important studies or industrial evidence may be overlooked,	**High**	Apply iterative search strategies and expand searches to industrial datasets, mining	Broader search strategies improve evidence coverage and reduce publication bias

	and publication bias (Garritty et al., 2021; Adams et al., 2017).	reducing the comprehensiveness and reliability of the review.		repositories and grey literature sources (Tricco et al., 2017).	in rapid reviews (Garritty et al., 2021).
2	Subjective bias in screening and evidence appraisal due to the interdisciplinary nature of mining sustainability studies (Page et al., 2021).	May reduce consistency and reliability during evidence selection and synthesis.	**Medium**	Use dual screening, peer review and reviewer calibration exercises to improve methodological consistency (CASP, 2018).	Peer-review and calibration approaches improve reliability and transparency in systematic evidence appraisal (Page et al., 2021).
3	Limited industrial-scale and long-term evidence, as most studies remain at laboratory or pilot scale (Edraki et al., 2014; Kinnunen et al., 2022).	Makes it difficult to evaluate scalability, operational feasibility and long-term performance under real mining conditions.	**High**	Increase stakeholder engagement and access to operational industry datasets and long-term monitoring systems (ICMM et al., 2020).	Industrial bioleaching projects in Chile and South Africa used continuous monitoring to evaluate long-term recovery performance (Brierley & Brierley, 2013).
4	Tailings recovery technologies are highly site-specific, limiting the generalisability of findings across mining sites (Lottermoser, 2011).	Results from one mining site may not be transferable to different geological or mineral conditions.	**High**	Apply cross-site techno-economic assessments and context-sensitive recovery approaches (Carneiro, 2019).	Comparative assessments improve technology selection and adaptation across mining regions (Edraki et al., 2014).
5	Limited evidence on economic feasibility and lifecycle trade-offs of recovery technologies (Kinnunen et al., 2022).	May result in incomplete evaluation of sustainability performance, implementation costs and environmental trade-offs.	**High**	Integrate techno-economic analysis, lifecycle assessment (LCA) and environmental trade-off analysis (Beylot et al., 2022).	Comparative LCA studies in Europe found that geopolymer technologies reduced GHG emissions and raw material consumption (Zhang et al., 2011).

6	Grey literature and industry reports often lack peer review and methodological transparency (Adams et al., 2017).	Increases the risk of reporting bias and limited evidence regarding operational failures or environmental impacts.	**Medium**	Improve reporting transparency, evidence traceability and disclosure standards (ICMM et al., 2020).	The Global Industry Standard on Tailings Management (GISTM) improves transparency and environmental monitoring in tailings management systems (ICMM et al., 2020).
7	Limited standardised terminology and integrated datasets across studies and countries (Geoscience Australia, 2023).	Creates difficulties in searching, comparing and integrating evidence across studies and mining contexts.	**Medium**	Develop national datasets and standardised reporting frameworks for mine waste and recovery systems (Geoscience Australia, 2023).	The Atlas of Australian Mine Waste supports evidence integration and policy evaluation for circular mining systems (Geoscience Australia, 2023).
8	Limited stakeholder perspectives and policy integration evidence in current studies (Tricco et al., 2017).	Restricts evaluation of social feasibility, governance barriers and policy implementation challenges.	**Medium**	Increase collaboration between mining companies, regulators, policymakers and researchers (ICMM et al., 2020).	Greater stakeholder collaboration improves policy relevance, implementation pathways and access to operational evidence (ICMM et al., 2020).

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