# Post-mining land use selection: a framework for long-term value creation

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## Abstract

*The planning process for selecting post-mining land (PMLU) uses is driven by various factors such as stakeholder expectations, regulatory requirements, social and environmental impacts, cost and risks. With many elements that need to be carefully considered in selecting PMLUs, the identification and selection process may present significant challenges for mining companies. Existing guidelines and standards offer general guidance on repurposing mine sites. Due to their general nature, however, they often lack detailed guidance on actionable steps that could be undertaken. This paper aims to address some of these gaps through a literature review and also draws on our experiences on closure projects across Australia: first, by identifying key constraints and challenges associated with PMLU planning; and secondly, by developing a conceptual framework that aids in identifying and evaluating baseline and alternate PMLUs per mining domain. Determining the land capabilities, as well as the constraints and opportunities per domain, are key components of the proposed framework. The implementation of a strengths, weaknesses, opportunities and threats analysis per domain is proposed. This process enables more effective identification and mapping of potential PMLUs. A fatal flaw analysis is proposed through the development of a land suitability assessment, with the intent of shortlisting the possible PMLU options based on their technical feasibility. A multi-criteria analysis and financial modelling are proposed as the final steps in the framework for identifying preferred PMLUs per domain. A well-structured and robust PMLU planning framework provides transparency to stakeholders and greater certainty that potential opportunities for social and economic benefits will not be neglected.*

**Keywords:** *mine closure, post-mining land use, framework, repurposing, transition*

## 1    Introduction

Selection of post-mining land uses (PMLUs) is one of the most critical aspects of mine closure (Worden et al. 2024). It drives the design, scheduling and costs of the rehabilitation of the site (Worden et al. 2024). But, most importantly, it profoundly impacts the legacy of mining companies once they cease operations and exit the region. Legacies of unplanned closure have been devastating in certain instances. This can result in significant environmental risks, negative impacts on the remaining local communities (Amaro et al. 2022; Worden et al. 2024) and abandoned sites. Where there is a lack of clear closure objectives and lax regulations, companies may potentially walk away from a site. This practice was more prominent in previous years when strict environmental and closure planning regulations were widely absent. Werner et al. (2020) and Unger et al. (2015) claim that around 50,000 abandoned mines exist in Australia, while Yellishetty & Bach (2023) estimate that there are closer to 80,000. These outcomes highlight the importance of closure planning and identifying, selecting and implementing appropriate PMLUs for a site.

The planning process and selection of PMLUs are driven by various factors including stakeholder expectations, regulatory requirements, social and environmental impacts, cost and risks (i.e. threats and opportunities). With various elements that need to be carefully considered and their inherent

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multidisciplinary nature, the PMLU identification and selection process may present significant challenges for mining companies. Existing guidelines and international standards offer general guidance on mine site repurposing but fail to provide a systematic approach (Beer et al. 2021). Due to their general nature, they often lack detailed guidelines outlining actionable steps that should be undertaken. For example, the *Mine Closure Government Checklist* (APEC 2018) provides guidance to governments regarding regulatory requirements for PMLUs. These include a high-level checklist of principles. The list encourages rehabilitation and repurposing but lacks guidance on methodologies and PMLU selection processes.

The *Integrated Mine Closure: Good Practice Guide* 3rd edition (International Council on Mining and Metals [ICMM] 2025) provides valuable guidance regarding elements that must be considered in PMLU selection, such as evaluating PMLUs early on in the process, using a knowledge base to inform options, involving stakeholders and considering land capabilities. Additionally, it provides guidance on key knowledge base elements required to inform the PMLU planning process as well as positive case studies of mine site repurposing. However, it fails to provide a standardised method or framework for PMLU selection. No standard or internationally accepted framework exists to guide PMLU identification and selection processes.

To address this gap, this paper seeks to explore the various frameworks, tools and methods currently used for PMLU selection in the literature. Further, it seeks to combine these with experience in delivering closure projects across Australia in order to develop a robust and standardised framework for PMLU selection.

## 2    Post-mining land use selection

### 2.1    Mine site repurposing versus rehabilitation

It is critical that PMLU outcomes are consistent with common closure drivers to achieve a "safe (for humans and fauna), stable (erosionally and geotechnically), and non-polluting (geochemically)" site (Simpson et al. 2024). The transition process to achieve this goal will usually result in one of three key outcomes: A restored ecosystem (similar to pre-mining conditions), a rehabilitated landform (that has been altered or modified from the pre-mining state) or the repurposing of the site or assets. Restoring to pre-mining conditions is possible for some mines, depending on the type of mining operations and disturbance areas, but this is rare. Complete restoration of a site can be an unrealistic expectation for larger metalliferous mines, where the landscape has been highly altered through the creation of new landforms such as open pits, waste rock dumps and tailings storage facilities (Murphy et al. 2019). Thus a rehabilitated landform or repurposed site or set of assets is a more practicable outcome.

Generally, mining companies tend to pursue closure measures that aim to relinquish the land, and thus most commonly select PMLUs that focus on the rehabilitation of the land rather than repurposing. Their goal is to relinquish all residual liabilities by satisfying environmental requirements in their permits (Pagouni et al. 2024). Thus opportunities to develop PMLUs that provide higher social and/or economic benefits through repurposing are often overlooked. Examples of successful repurposing using commercial approaches to mine closure exist globally. Murphy et al. (2019) and Beer et al. (2021) provide examples of various repurposed mines worldwide. The book *102 Things to Do With a Hole in the Ground* (Whitbread-Abrutat & Lowe 2024) is a good reference source for identifying novel and successful case studies for repurposing mine sites. However, in many innovative repurposing cases, these are primarily driven by mining companies implementing environment, social and government strategies or by governments trying to manage abandoned mines that have fallen under their management and jurisdiction (Pagouni et al. 2024). In Australia, repurposing opportunities have only begun to be encouraged in the last five years, through research and government publications and research centres (Cote et al. 2023; Department of Regional NSW 2023; Beer et al. 2021; Dunlop et al. 2024). However, legislative frameworks have yet to evolve in order to effectively support repurposing opportunities. Unfortunately, this results in neglected opportunities to harness socio-economic benefits, not only for future land users but also for mining companies. In certain instances, the repurposing of a site can result in financial savings (Mborah et al. 2016) and reduced liabilities. Repurposing mining infrastructure, such as ore processing plants, water reservoirs, stockyards, workshops,

buildings and roads, can reduce demolition costs (Pagouni et al. 2024). Furthermore, when the site is constrained by technical aspects (for example, lack of growth media to support vegetation growth), repurposing provides opportunities to support future land uses where completion criteria maybe more achievable.

The cost of establishing solar and wind generation PMLUs, in the Pilbara region in Western Australia, with provisioning for land clearing and supporting infrastructure in place, is close to AUD 200–300 million to develop 100 MW generation capacity (Murphy et al. 2019). To provide context, closure and rehabilitation of the Ranger uranium mine (currently in closure execution) in the Northern Territory, Australia, is estimated to be between AUD 1.6 billion and 2.2 billion (ABC 2022). While repurposing will not be possible for every site, it is important to identify these opportunities. Thus a change in paradigm is required in the industry so that the potential of repurposing is valued more (Murphy et al. 2019). Mines are important regional assets and significant drivers of economic growth (Beer et al. 2021), and therefore their power as drivers of change must not be underestimated.

## 2.2    The importance of having a robust framework for planning

Lack of a proper PMLU planning process will most likely lead to unacceptable and/or unfeasible closure outcomes (Soltanmohammadi et al. 2010; Narrei & Osanloo 2011). For example, the Berkeley Pit in Montana, USA, a former open pit copper mine, was abandoned and allowed to transition into a pit lake but did not have appropriate closure planning or PMLU selection processes in place to support this outcome. Rainfall and groundwater inflows into the pit resulted in a toxic lake with dangerously high concentrations of heavy metals including arsenic, cadmium and sulphuric acid (University of Michigan 2025). Thousands of migratory bird deaths have been recorded due to contact with the highly acidic and metal-laden waters. The waters have also inhibited the growth of natural flora and fauna from thriving. Furthermore, the health effects on residents surrounding the pit are of high concern. In another example, the Blayney copper mine in Australia was going to be transferred to residential land use, given its proximity to the town of Blayney. However, a different land use eventually had to be adopted as the level of investigations and remediation required to achieve residential standards was constrained due to extensive costs (Soltanmohammadi et al. 2010). These cases serve as good examples and cautionary reminders of what can happen in the absence of unplanned closure. Having a robust PMLU selection process will aid in addressing and managing post-closure risk and liabilities with greater confidence.

Establishing a robust framework for PMLU selection is fundamental for a number of reasons, which include:

- determination of the technical feasibility of a PMLU in relation to post-closure land capabilities

- addressing the potential impacts of closure on local and regional economies through the selection of PMLUs that will provide greater environmental and socio-economic benefits

- enabling the participation of relevant stakeholders in the process (e.g. mining companies, government agencies, local communities, Indigenous groups) and reducing uncertainty, especially in the presence of conflicting stakeholder expectations for PMLUs

- providing transparency to stakeholders (e.g. communities, Traditional Owners and regulators) on a mining company's decision mechanisms to pursue a PMLU.

## 2.3    Challenges in identifying and selecting post-mining land uses

Various challenges and limitations exist for successfully identifying and selecting PMLUs for a site. The overarching challenge is that closure planning is a multidisciplinary and multidimensional endeavour that requires integrating social, economic, environmental, technical and legal aspects.

It is common for a site to have multiple stakeholder groups (e.g. regulators, local communities, Indigenous groups, environmental groups) impacted by the closure of mines. On certain occasions, the various

stakeholder groups can have conflicting expectations as sometimes the expectations of regulators may not always align with community needs.

Mining companies often hesitate to repurpose sites due to uncertainty around costs and liabilities, and a lack of precedent. Repurposing is commonly perceived as a deviation from core business objectives that can delay or prevent site relinquishment. Furthermore, mechanisms for liability transfer to future land users are unclear and while commercial agreements may manage this, they require further testing (Murphy et al. 2019). As a result, mining companies rarely pursue repurposing opportunities. PMLU planning is typically local in scope, missing broader regional development opportunities. There is growing global pressure to adopt approaches that consider regional planning drivers such as water, food, ecology, energy, settlements and socio-economic factors (Hattingh et al. 2019; Worden et al. 2024).

A key challenge in selecting PMLUs is often the lack of comprehensive environmental knowledge and understanding of site-specific risks. Inaccurate data can lead to poor outcomes, as seen in the Berkeley Pit lake case. A strong technical and environmental knowledge base is essential, as factors like landform stability, geochemistry and contamination can limit land use options (e.g. agriculture). In cases where contamination is present, planning should focus on minimising exposure and dispersion (Pagouni et al. 2024). Fundamental knowledge base elements and disciplines that should be assessed are discussed in Section 2.4.3.1.

There is limited global government guidance on PMLU planning, with regulations often focused on rehabilitation and harm minimisation rather than repurposing. In jurisdictions such as Brazil and Queensland, Australia, the limited diversity of repurposing opportunities in closure planning can be attributed to overly complex approval processes or non-conducive regulatory frameworks, which collectively discourage mining companies from exploring a broader range of land use outcomes (Mborah et al. 2016; Sales Rosa et al. 2018; Worden et al. 2024). Furthermore, the lack of clear guidance on rehabilitation targets and completion criteria to support land repurposing further undermines efforts to implement more varied and sustainable PMLUs (Sales Rosa et al. 2018). For example, the Queensland Government has released a number of technical papers offering guidance on rehabilitation and completion criteria for native ecosystems (Spain et al. 2025) and grazing-focused PMLUs (Clay et al. 2024). However, comparable guidance specifically addressing completion criteria that enables tenure relinquishment and addresses future productive land uses is rare and an important regulatory gap (Murphy et al. 2019). There are also limited forums for stakeholder engagement, which hinders innovation in PMLU repurposing opportunities (Murphy et al. 2019).

While international guides exist (e.g. ICMM), local regulations play a key role and often act as barriers to repurposing. For example, Western Australia prioritises restoring original ecosystems, limiting alternative uses in their mine closure planning requirements (Murphy et al. 2019). In New South Wales (NSW), complex and fragmented regulations discourage investment in repurposing (NSW Minerals Council 2024; Parliament of NSW 2025). Regulatory inertia and legal limitations discourage mining companies and regulators from challenging "approved" land uses (Murphy et al. 2019; Parliament of NSW 2025). However, certain government agencies in Australia have begun to acknowledge these limitations and are taking steps toward establishing regulatory frameworks designed to guide and promote the adoption of PMLUs that deliver beneficial outcomes (Parliament of NSW 2025).

To address this, frameworks should:

- provide guidance on completion criteria to support repurposing

- streamline approval processes

- enable stakeholder forums for regional planning to bridge regional socio-economic needs, government priorities and business opportunities for mining companies and land developers

- offer clearer guidance on PMLU selection and repurposing mechanisms.

## 2.4 Literature review

Several frameworks in the literature have been reviewed to assist in the complex process of selecting appropriate PMLUs. The review identified the most common approaches, methods, and tools employed to select PMLUs and understand what classification systems were used to define land uses.

It is important to separate a land use classification system from a framework for selecting PMLUs. The former relates to the system used to identify and categorise the different land use categories (e.g. agriculture, rehabilitation, residential, etc.), while the latter refers to the method used to identify and select PMLUs for a site.

The outcomes of the literature are further discussed in the sections below.

### 2.4.1 Land use classification systems

Various global land use classification systems exist, each with different levels of detail and applicability to mining projects:

- The National Land Cover Database (USGS 2025) offers 20 broad classes but lacks granularity, limiting its use in mining contexts.

- The Corine Land Cover (Copernicus 2025) provides 44 detailed classes, making it more comprehensive and suitable for mining projects.

- The Land Cover Classification System (FAO 2025) is a flexible framework for determining land uses based on site-specific features, though it lacks predefined land use classification categories.

- The Australian Land Use and Management Classification System (ABARES 2016) is designed to align with Australian national planning standards and has been used in mine closure planning in Western Australia.

Pagouni et al. (2024) compiled the most detailed global land use list, with 12 general classes, 38 sub-classes and 119 alternatives, making it highly applicable to mining projects.

### 2.4.2 Summary of frameworks used for decision-making

Several frameworks have been developed to assist in the complex process of selecting appropriate PMLUs. The outcomes of this review are provided in Figure 1. Overall, the frameworks reviewed employed different approaches, generally tailored to site-specific requirements or objectives of the study. Some frameworks reviewed were highly mathematical and quantitative in their approach, others semi-quantitative and others of a qualitative nature. Generally, when the list of alternatives and criteria to be evaluated was extensive, mathematical models were employed to assist with the process. Most frameworks reviewed are strictly focused on employing tools to facilitate the decision-making process but fail to provide an overarching framework that can support mining companies with overall PMLU planning.

Simpson et al. (2024) provide an overarching framework that mining companies can use to guide the PMLU planning and selection process in relation to sustainable development goals. This paper further builds on that framework and seeks to explore the process in greater depth. It also recommends specific tools and methods that can be employed to support decision-making.
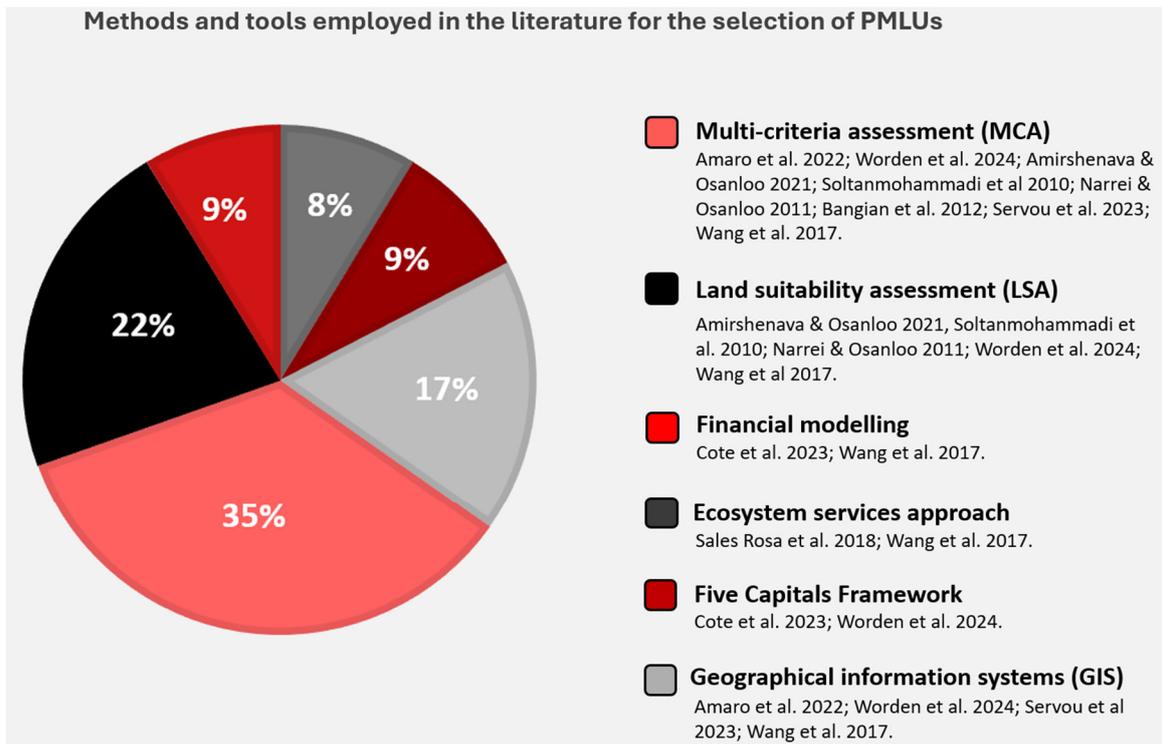
**Figure 1    Methods and tools employed in the literature for post-mining land use selection**

### 2.4.2.1    Ecosystem services approach

The ecosystem services (ES) approach has been widely used in international policies (e.g. The Economics of Ecosystems and Biodiversity, the European Union's Biodiversity Strategy and the European Union's Common Agriculture Policy) to support ecological, social and economic outcomes (Wang et al. 2017). For PMLU planning, it helps identify land uses that benefit both ecosystems and local communities. Studies by Wang et al. (2017) and Sales Rosa et al. (2018) applied ES-based methods in PMLU planning to identify relevant services (e.g. water conservation, agricultural production, carbon sequestration and cultural significance) that could be supported through rehabilitation and that would enhance social and ecological benefits. Incorporating an ES approach is especially important where communities rely on natural resources, as poor rehabilitation can negatively impact their livelihoods.

### 2.4.2.2    Five capitals framework

The Five Capitals Framework – social, natural, financial, human and manufactured – is widely used to assess complex and multidimensional experiences (Worden et al. 2024). The framework is widely recognised and is generally used to characterise the goods and services needed to maintain the property and quality of life of communities or residents of a region (Cote et al. 2023). Worden et al. used it to reflect community aspirations, while Cote et al. applied it to rank PMLU options. Incorporating this framework supports sustainable, resilient PMLU planning with long-term benefits.

### 2.4.2.3    Geographical information systems

Pagouni et al. (2024) identified geographical information systems (GISs) as a key tool in PMLU selection due to their ability to integrate spatial data (e.g. slope, elevation, distance) with land constraints. They are widely used for land suitability assessments (LSAs), often combined with multi-criteria analysis (MCA) (Wang et al. 2017; Servou et al. 2023). The land suitability models that emphasise spatial allocation in GISs are simple (binary), fuzzy and weighted, each with different interpretations and scale references (Servou et al. 2023). Amaro et al. (2022) used GIS modelling in the final step of the PMLU selection process as a tool to enable stakeholder participation in the final ranking of the PMLUs. Servou et al. developed a GIS-based model using fuzzy logic to

evaluate land suitability for four land uses across six physical criteria, producing comprehensive suitability maps. Overall, integrating GISs and LSAs can be a highly effective and successful approach to selecting PMLUs as it provides a robust assessment of the technical capabilities of the land to support a PMLU. A key limitation to this approach is that it requires access to specific software and technical capabilities to employ mathematical approaches, which may not always be available during the PMLU selection processes.

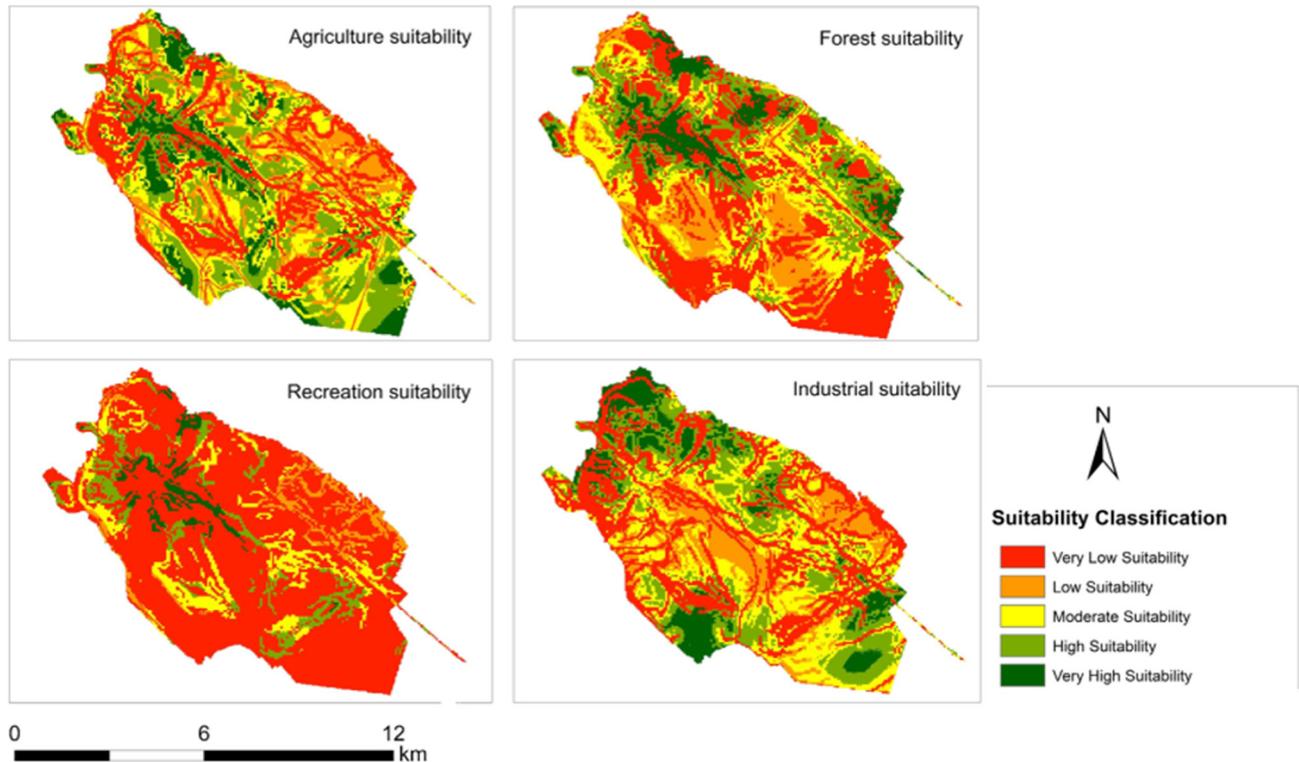Examples of suitability maps that can be created using GISs are provided in Figure 2.



**Figure 2    Examples of final land use suitability map outputs (Servou et al. 2023)**

### 2.4.2.4    *Multi-criteria analysis*

Due to the multidimensional nature of PMLU planning and selection, most frameworks reviewed in the literature employed a type of MCA method to select PMLUs. These methods can be either qualitative, semi-quantitative or quantitative. MCAs help compare alternatives, even with conflicting goals, and are chosen based on problem complexity, data availability and decision context (Amaro et al. 2022).

Some of the most popular alternative ranking techniques employed in the literature are the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Soltanmohammadi et al. 2010; Narrei & Osanloo 2011; Amaro et al. 2022), Sequential Interactive Method for Urban Systems (SIMUS) (Amaro et al. 2022), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) (Amaro et al. 2022), Compromise programming (Pagouni et al. 2024; Narrei & Osanloo 2011; Servou et al. 2023) and the Likert scale (Worden et al. 2024). While these typically require technical expertise, they offer robust, defensible results. Simpler methods, like simple additive weighting (SAW), that employ semi-quantitative or qualitative methos are also widely used in industry for their ease of use and communication.

The process of assigning weights to the different criteria can be undertaken through qualitative methods such as expert judgement or through mathematical approaches such as the Analytic Hierarchy Process (AHP) (Soltanmohammadi et al. 2010) and linear programming techniques.

### 2.4.2.5    Financial modelling

Of all the frameworks reviewed, none, except for Cote et al. (2023), identified the use of cost modelling in their methodologies for selecting PMLUs. In a survey conducted by Young et al. (2019) in Western Australia, regarding the most common methods to determine PMLUs, both consultants and mining companies identified that the use of cost-benefit analysis was less than 5%. No other cost modelling methods were identified in the survey outcomes. These statistics are surprising, given the importance of cost in the identification and selection of a PMLU. Although economics is an essential aspect in PMLU planning, these findings may suggest a lack of guidance for mining companies on how to incorporate financial modelling into their PMLU selection process.

### 2.4.2.6    Land suitability assessments

An LSA aims to understand whether the land can sustain a specific PMLU. Various frameworks employed LSAs combined with MCA methods to rank PMLUs (Soltanmohammadi et al. 2010; Worden et al. 2024; Amirshenava & Osanloo 2021; Narrei & Osanloo 2011; Wang et al. 2017; Servou et al. 2023). The LSAs compare and score each PMLU against multiple attributes. Some studies considered natural, environmental and technical factors while others also incorporated social and economic factors into their assessment (Soltanmohammadi et al. 2010; Servou et al. 2023).

Soltanmohammadi et al. (2010) used AHP-TOPSIS to weigh and rank 50 PMLU criteria across technical, economic, social, and mine-related factors. Amirshenava & Osanloo (2021) employed a semi-quantitative LSA that included a second score for potential corrective measures, enabling reconsideration of less viable options like pit lakes. Wang et al. (2017) integrated GIS with an ecosystem services approach,  AHP and grey relational analysis to map PMLU suitability into four classes, incorporating environmental and socio-economic criteria.

While LSAs assess the technical land suitability, few studies integrated them with spatial tools such as GISs (Wang et al. 2017; Worden et al. 2024). Incorporating a spatial dimension into the PMLU selection framework is critical in determining the viability and sustainability of a PMLU and identifying land constraints with greater certainty.

### 2.4.3    Proposed framework for post-mining land use selection

A framework has been developed to address some of the key constraints and challenges that mining companies experience when selecting PMLUs. The framework was developed based on the outcomes of the literature review and overall experience in projects across Australia. The aim is to empower mining companies to assess options for alternative land uses and shift from the tendency to focus purely on rehabilitation outcomes. Overall, we propose that the identification, mapping and selection of PMLUs be conducted on a domain-by-domain basis. The most important output from this framework is that PMLU selection is an iterative and adaptive process. As the knowledge base and stakeholder sentiments evolve throughout the process, so will the PMLUs (ICMM 2025). It is recommended that the process of mapping and selecting PMLUs is incorporated early on in the mining life cycle, as the PMLU will inherently drive the closure methods, activities, schedule and costs. Currently PMLU planning is undertaken close to the end of the mine life, once closure methods have already been established or sometimes executed, to address environmental impacts and threats. Thus at this stage, opportunities for PMLU selection become limited by what is technically possible.

The framework proposed is presented in Figure 3. Overall, it is important to highlight that the baseline PMLU (if there is one already agreed upon in an approvals pathway) needs to be incorporated into the assessment in order to understand its performance against other options and defend its appropriateness.
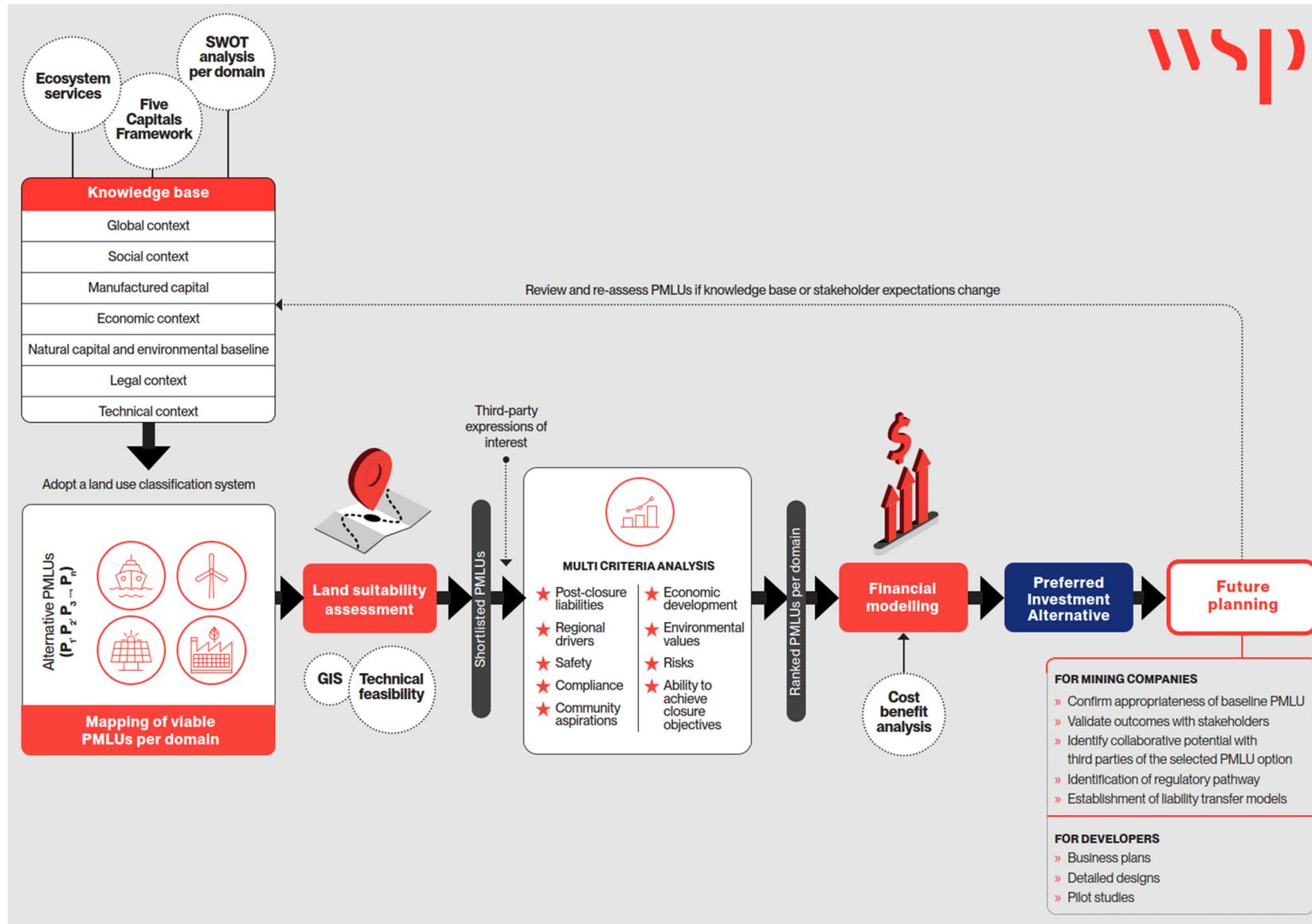
**Figure 3    Proposed framework for post-mining land use planning, identification and selection**

### 2.4.3.1    Knowledge base

The first key step in the framework is the development of a comprehensive knowledge base. This knowledge base is necessary to inform the PMLU planning process and ensure that the selected option is sustainable and appropriate to the local and regional context. The knowledge base should enable identification of opportunities that exist for repurposing of the land or assets, and whether there are market opportunities for these (e.g. capacity of workforce, local demands for specific goods and services, existing infrastructure). Findings from the literature and the Five Capitals Framework and ES approach were used to develop key knowledge base requirements to inform the PMLU planning process (Refer to Table 1 for a summary of key knowledge base requirements).

To gather the technical context data, it is recommended that a strengths, weaknesses, opportunities and threats (SWOT) assessment be completed with key site subject matter experts. This will enable an understanding of the land capabilities to commence mapping of potential PMLUs.

**Table 1    Key knowledge base requirements to support post-mining land use planning**

| Knowledge base element | Aspects to consider |
|---|---|
| Global context | Climate change, biodiversity loss, decarbonisation and geopolitics, international standards/agreements |
| Social context | Demographics, social and human capital – livelihood quality, cultural and social identity, community cohesion, skills and knowledge of local population, health, innovation potential, social impacts of closure |
| Manufactured capital | Local industries, transportation systems, infrastructure technologies and processes that present market opportunities for repurposing PMLUs |
| Economic context | For mining companies: economic feasibility. Cost for mining companies – capital operational, monitoring costs, opportunities for cost reduction and funding, circular economy |
| | For communities: income for local community and government, economic assets, employment. Understanding the socio-economic impacts of closure of the mine, regional plans and post-mining economies, beneficial land uses and opportunities |
| Natural capital and environmental baseline | Site characteristics and natural capital – soil properties, climate, topography, biodiversity, aesthetics, geology, relief, hydrology and drainage, hydrogeology, environmental values, key ecosystems services |
| Legal context | Land ownership (is the land being leased and who will be the future user?) Regulatory obligations and commitments |
| Technical context | Domains, facilities and assets, risks, soil and water quality, presence and distribution of contaminants, geotechnical and geochemical stability, final landform, surface and groundwater flows and interactions, pit geometry, accessibility, proximity to population centres |

### 2.4.3.2    Land classification system and post-mining land use mapping

The second step involves mapping viable PMLUs, considering the reviewed knowledge base. At this point, opportunities for repurposing and beneficial uses should be considered and identified. A land use classification system should be adopted. From the classification systems reviewed, the one collated by Pagouni et al. (2024) seems to be the most comprehensive and applicable to mining, and is thus recommended as an appropriate classification system.

### 2.4.3.3    Land suitability assessment

The third step in the framework involves conducting an LSA. The aim of this step is to understand the technical feasibility of each PMLU per domain. Any PMLUs identified as not feasible or having a low suitability will be removed. The PMLUs that are identified as being "highly suitable" or "suitable" per domain will be shortlisted and then progressed to the next step (MCA).

LSAs can be undertaken qualitatively using high-level spatial analysis or a Likert scale incorporating expert judgement, or it can be combined with MCA-driven mathematical approaches. The latter can provide more robust and defendable outcomes. However, it can be more difficult to undertake as it requires certain capabilities (application of mathematical models) and tools (software) to undertake the assessment, which not all mining companies or consultants may possess. However, pairing with GIS and spatial analysis tools is recommended to improve the accuracy of the results.

In the proposed framework it is recommended that assessing the PMLUs against social and economic criteria should be excluded from this step as the LSA should focus on the technical feasibility of the land and domains to support a specific PMLU. Social and economic factors are assessed separately in the next steps.

Upon completion of the LSA, if opportunities for repurposing and redevelopment are identified, it is at this stage that mining companies should seek to release expressions of interest from third parties. Potential partnerships can be explored with real estate development companies.

Some examples of land suitability criteria for common PMLUs identified in the literature and from our projects across Australia have been collated and provided in Table 2.

**Table 2    Examples of land suitability assessment criteria for common post-mining land (PMLU) uses**

| Potential PMLU | Example criteria to consider (not complete) | Framing author |
|---|---|---|
| Native ecosystems | Proximity of mine lease to areas with remnant ecosystems or high ecological values | Worden et al. (2024) |
| Grazing | Precipitation regime, sensitivity to climate change (e.g. flooding, temperature and rainfall increase), soil suitability, growth media suitability to support pastures, proximity to transport infrastructure | Cote et al. (2023) Worden et al. (2024) |
| Cropping/ agriculture | Slopes (ideal is 0–2°) Distance from rivers (ideal is 1,000–1,500 m) Distance from roads (ideal is 400–900 m) Distance to towns (ideal 0–1,650 m) Distance from transmission lines (1,873–2,635 m) | Wang et al. (2017) Servou et al. (2023) |
| Solar energy | Solar radiation (ideal is > 20 MJ/m$^2$ in winter and summer) Slopes (ideal slope < 5°) Proximity to transmission network (ideally within 2 km) Open land and sparse cover Low rainfall and cloud coverage Proximity to roads | Cote et al. (2023) Murphy et al. (2019) |
| Wind energy | Proximity to transmission network (ideally within 5 km) Wind speeds (6.0 m/s or greater at 100 m) | Cote et al. (2023) |

| Potential PMLU | Example criteria to consider (not complete) | Framing author |
|---|---|---|
| Pumped hydro energy storage | Head availability (elevation difference available to drive flow between highest and lowest storage) | Cote et al. (2023) Murphy et al. (2019) |
| | Water volumes (requires a minimum of 1 GL) | |
| | Distance between upper and lower reservoirs to minimise cost of infrastructure | |
| Aquaculture | Water quality suitability for selected species | |
| | Assessment of contaminant uptake by fish | Cote et al. (2023) |
| | Additional investment in terms of food sources | |
| | Scale of production | |
| | Existing infrastructure | |
| Tourism/recreational pit lakes | Water quality to comply with local guidelines | |
| | Slope stability | Cote et al. (2023) |
| | Proximity to towns and hubs | |
| | Presence of infrastructure (buildings, power, water, sewage) | |
| | Accessibility – presence of road networks | |

### 2.4.3.4    Multi-criteria analysis

The fourth step in the framework is the MCA. The aim of this step is to score, weight and rank the shortlisted alternative PMLUs to identify the preferred option per domain. Since the technical feasibility of the PMLU has already been assessed in the previous step (LSA), the aim of the MCA is to evaluate how each alternative performs against key criteria that will drive the PMLU selection. These key criteria should focus on the PMLU's ability to: reduce legal liabilities and risks; enhance regional drivers; ensure public safety; support the community, environmental values and closure objectives; ensure compliance with agreements; and provide opportunities for economic growth. The MCA should, however, exclude costs to prevent this from driving the outcomes. It is recommended that cost modelling be undertaken subsequently.

There are quantitative (TOPSIS, AHP, SIMUS, PROMETHEE), semi-quantitative (SAW) and qualitative procedures (Likert scale), as well as GIS-based tools, that exist for the MCA process. Semi-quantiative and qualitative methods should be pursued during the early stages of planning, when participatory decision-making requires inputs from various stakeholders, and when there is a high level of data uncertainty. Overall this approach is quicker and may ease communication with stakeholders. Quantitative methods are the preferred approach when dealing with complex decision problems with multiple attributes and criteria, and/or conflicting stakeholder expectations, and when a detailed project evaluation is required. While these methods may require certain resources (e.g. software) and a level of expertise which may not always be readily available, they can provide more robust and defendable outcomes.

### 2.4.3.5    Financial modelling

This step involves high-level cost modelling to compare the cost-effectiveness of the baseline and top-ranked PMLUs, not to estimate detailed implementation costs. Initially, due to the level of uncertainty, it can be assumed third parties will cover future development costs, with the mining company responsible only for land preparation. Costs will vary by PMLU type and land preparation requirements (for example flattening of slopes, retaining usable buildings, enabling utilities like water, power and sewage). For instance, a pit domain with an aquatic ecosystem or recreational pit lake PMLU may require water treatment, with costs varying based on geochemical conditions. In contrast, a pumped hydro storage PMLU may not need water treatment but will have other requirements such as slope modification and enabling physical stability. Detailed

implementation costs can be assessed at a later stage when third party interests and transfer of liabilities are further defined. Although this paper focuses on PMLU selection and repurposing from a relinquishment perspective, mining companies could also look into repurposing opportunities for sites that will be managed in perpetuity, with the aim of gaining financial benefits and offsetting closure costs.

### 2.4.3.6    Future planning

Upon completion of the cost modelling a preferred investment alternative will be identified, which will also assist with validation of the baseline PMLU. Mining companies are then encouraged to continue planning to implement the preferred PMLU for closure. Suppose repurposing was part of the selected option. In that case, additional planning will involve the identification of an approvals pathway, potential partnerships and collaborators, liability transfer models, assessment of its commercial viability and technical implementation, and validation with stakeholders, as well as progressing the design and required completion criteria. For standard rehabilitation PMLU options, outcomes will need to be validated with stakeholders, and additional planning should focus on the design of the PMLU and completion criteria to be achieved.

## 3    Conclusion

No standardised or systematic approaches exist within the international guidelines to guide mining companies on PMLU planning and selection. Paired with many challenges and limitations related to social, economic, environmental/technical and legal factors, mining companies have generally pursued rehabilitation outcomes (through an approved pathway), often overlooking repurposing opportunities that can drive social and economic benefits for a region. Furthermore, a lack of robust PMLU planning has led to inappropriate post-mining outcomes, affecting mining companies' legacies and resulting in negative impacts on communities and the environment.

To address some of these gaps and challenges, a framework has been proposed to provide a robust, transparent and stepped approach for PMLU identification and selection, derived from findings from the literature review and our experience in closure projects across Australia. We highlight the importance of an adaptive PMLU planning process, as evolving knowledge base elements and stakeholder sentiments will require re-evaluation and assessment of the preferred PMLUs. Early planning and engagement with stakeholders are key factors as they will enable more opportunities to be explored and developed. The framework seeks to support a positive long-term legacy for mining companies post-closure, and enhanced social, economic and environmental benefits.

## Acknowledgement

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