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Balancing competing uses for post-mining landscapes with the Post-Mining Land Use Options Assessment Tool

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Abstract

As societal demands continue to expand – ranging from biodiversity preservation and natural capital maintenance to renewable energy generation and raw material extraction – the competition for land is intensifying. Meeting these diverse needs requires innovative approaches to land management and regional planning, particularly in the context of post-mining landscapes. Land and assets previously utilised for mining present opportunities to address these competing stakeholder demands when current mineral extraction has been exhausted. Although post-mining land may be unsuitable for restoring premium natural assets, it can be strategically repurposed to reduce the burden on existing ecologically valuable sites. Effective land use planning must consider the diverse interests and needs of stakeholders, whose values frequently compete and are difficult to quantify.

Historically, there has been a notable gap in the availability of robust quantitative tools to support holistic decision-making and adequately evaluate options across multiple value drivers. This paper discusses the Post-Mining Land Use (PMLU) Options Assessment Tool (the Tool), collaboratively developed by CRC TiME and enviroMETS, as an objective framework for evaluating alternative PMLUs through consideration of value drivers across 4 domains: enterprise, environmental, community/regional and cultural/heritage. With user input as a modifying factor, the Tool highlights the relative benefits of each option and ensures stakeholder perspectives are incorporated into the evaluation process. Critically, the Tool can be used to provide scoring-based comparisons as well as more complex analyses that provide comparative economic assessments. Ultimately, the Tool provides decision-makers with a structured approach with which to compare land use alternatives, promoting informed, balanced and sustainable outcomes for post-mining landscapes.

Keywords: *post-mining land use, regional planning, stakeholder interests, quantitative evaluation, intangible value drivers, sustainable outcomes*

1 Introduction

Globally, mining regions are experiencing an accelerating wave of mine closures as mature assets reach the end of their productive lives (Boggs et al. 2025). This is the case in Australia, with 240 mines forecast to close by 2040 (CSIRO 2023). At the same time, lessons from projects moving through closure execution and the evolution of community expectations regarding post-mining futures are contributing to an escalation in closure liabilities. Reviews by Moody's Investors Service (2024) of 24 of the largest global mining companies estimated that in 2024, asset retirement obligations reached USD 78 billion while BNP Paribas, through its asset management arm (BNPP AM), has identified mine closure and decommissioning as a multitrillion-dollar

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risk; estimating that decommissioning liabilities across energy and mining sectors could reach USD 8 trillion in the coming decades (Halfon et al. 2023).

Historically, mine closure planning has been framed as a technical and regulatory exercise aimed at achieving physically stable, environmentally safe landforms capable of tenure relinquishment (Hamblin et al. 2022). While these objectives remain essential, research increasingly demonstrates that compliance-oriented closure rarely addresses broader socio-economic transition needs, particularly where mining has been a dominant regional employer (Simpson et al. 2025). Coupled with an increasing number of stakeholders having a heightened interest in how a post-mining land use (PMLU) can contribute to their wellbeing (Foran et al. 2022), closure strategies that default to return to pre-existing land uses often fail to recognise broader changes caused by the mining operation over time and fail to account for regional development priorities, Indigenous aspirations or emerging land use opportunities such as renewable energy, tourism, or circular economy activities (Pagouni et al. 2024).

Responding to these challenges, enviroMETS and CRC TiME developed the PMLU Options Assessment Tool (the Tool) to support earlier, structured consideration of alternative PMLUs (Morton & Merz 2024). The Tool seeks to bridge the gap between closure planning for regulatory purposes and longer-term regional transformation (Figure 1) by enabling stakeholders to systematically identify, evaluate and refine PMLU options using a range of value drivers in a transparent framework. As illustrated in Figure 1, the Tool sits at the midpoint between compliance-driven mine closure and value-based transitions as it facilitates early identification and prioritisation of higher-value PMLU options.

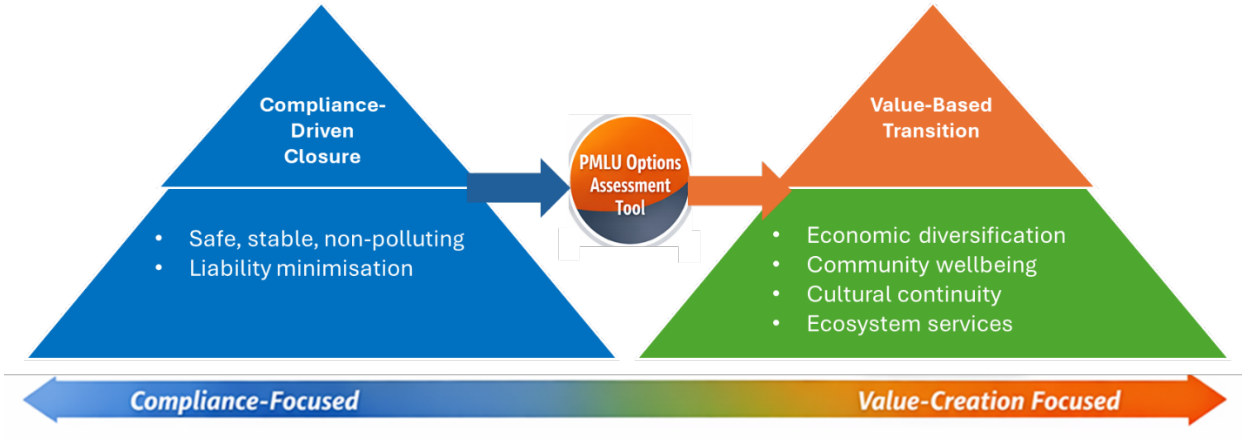

Figure 1 Conceptual continuum illustrating the shift in mine closure planning from a compliance-driven focus towards a value-based post-mining transition

1.1 Limitations of conventional closure planning

Traditional mine closure frameworks largely prioritise the minimisation of residual environmental risk and financial liability (Eshun et al. 2018). While these frameworks improve the technical robustness of proposed alternatives, they often fail to adequately capture non-financial values and defer stakeholder engagement until later in the mining life cycle, when design flexibility is constrained and the cost of change is significantly higher; thus limiting the ability to deliver enduring regional and community value. As illustrated in Figure 2, the PMLU Options Assessment Tool operates upstream of detailed feasibility studies and closure execution in the mining life cycle, enabling early identification and prioritisation of higher-value PMLU alternatives.

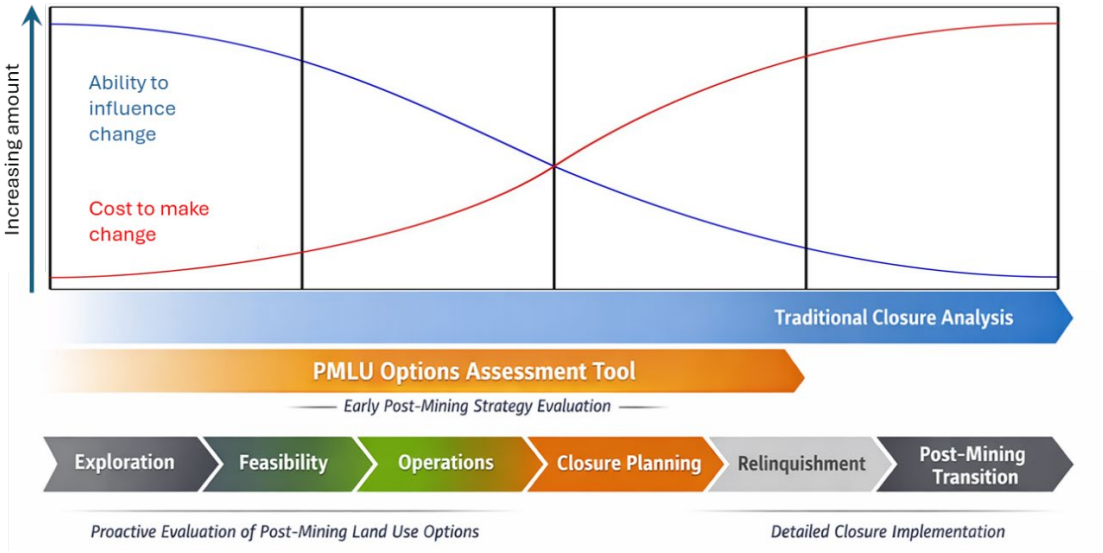

Figure 2 Position of the Post-Mining Land Use (PMLU) Options Assessment Tool within the mining life cycle

Empirical studies show that this sequencing constrains the implementation of potentially feasible innovative PMLUs and can create adversarial relationships between mine owners, communities, regulators and Indigenous groups (Hood et al. 2025). As a result, closure planning frequently produces outcomes that are socially contested, economically weak or misaligned with regional development strategies and do not lead to relinquishment. These are often reflected in poorly framed or misaligned completion criteria, lack of understanding or acceptance of residual risk transitions by rights or stakeholders and inappropriate tenure models for post-mining transitions.

Contemporary mine closure planning increasingly emphasises post-mining transitions, recognising closure as a process that spans the entire mining life cycle that intersects with economic diversification, workforce transition and land use planning (Boggs et al. 2025). This shift is reflected in international guidance such as the International Council on Mining and Metals (ICMM) Integrated Mine Closure Good Practice Guide, which advocates for integration of social and economic considerations early in closure planning (ICMM 2025).

In parallel, the need for tools capable of accommodating diverse stakeholder perspectives, non-market values and long-term uncertainties, which are key characteristics of post-mining landscapes, has also been identified (Pagouni et al. 2024; Svobodova et al. 2025). However, many existing frameworks tend to assume a predefined set of options or rely on data-intensive cost-benefit analyses not suited to planning in the early stages of a mine when scoping level data is available.

2 Foundations for the Tool

2.1 Multicriteria decision analysis for post-mining land uses

Deciding on an appropriate PMLU involves a complex system of decisions and trade-offs that must weigh the benefits and risks to be faced by a range of stakeholders. These decisions involve balancing environmental, economic, social and cultural factors to determine the most appropriate and sustainable use of post-mining lands. Decision-making tools and techniques play a critical role in guiding the interactions among these often competing factors to facilitate the identification (and potential selection) of outcomes that are sustainable and beneficial to all stakeholders, with several tools and techniques having been applied to solve this problem (Manero et al. 2020). They often combine qualitative and quantitative analysis techniques, and include:

- cost-benefit analysis (CBA), which involves quantification of the costs and benefits associated with the various alternatives to determine that with the greatest net benefit to society

- environmental impact assessment, which evaluates the potential environmental consequences of various PMLU options
- geographic information systems, which are tools that provide spatial analysis and visualisation functionality that can map and support analysis of various environmental and socio-economic data layers to support informed decision-making
- multicriteria decision analysis (MCDA), which is a method that involves the evaluation of multiple criteria that are often in competition. MCDA allows decision-makers to prioritise the factors so that choices can be made that reflect the values and goals of multiple stakeholders
- scenario analysis, which examines different possible future scenarios to explore the impacts of each PMLU option
- stakeholder engagement and participatory decision-making, which include techniques such as public consultations, workshops and surveys that are used to gather input and ensure that the decisions made reflect the needs and aspirations of all affected parties
- sustainability frameworks, which evaluate the environmental, social and economic impacts of PMLU decisions.

Mardani et al. (2015) note that multicriteria decision-making is a 'complex decision-making tool' used for quantitative and qualitative criteria and variables. As a result, MCDA has been widely applied in many sectors, including:

- environmental management, to assess and prioritise environmental projects such as land rehabilitation, resource allocation and pollution control
- urban planning to evaluate development projects, infrastructure investments and zoning regulations
- healthcare to support clinical decision-making, resource allocation and health policy development
- business strategy to inform strategic planning, investment decisions and performance evaluation.

As a result of its broad application and framework that facilitates the engagement of multiple perspectives into the decision-making process, MCDA is identified as being applicable for the PMLU decision. It is particularly useful in complex scenarios where decisions cannot be based on a single criterion, and where trade-offs between different factors need to be explicitly considered and managed. It has been designed to tackle 4 types of problems (Roy 1996; Sitorus et al. 2019):

1. the choice problem, where MCDA is used to select the best option from a set of alternatives
2. the sorting problem, where MCDA is used to assign a set of alternatives to predefined categories
3. the ranking problem, where MCDA is used to provide a ranking of alternatives
4. the description problem, where MCDA is used to elaborate on the alternatives.

There have been many additional applications of MCDA in the mining sector. Robertson & Shaw (1998, 2004) describe the use of a multiple accounts analysis (MMA) technique to evaluate mine development and reclamation alternatives by systematically comparing economic, environmental, technical and socio-economic impacts. This application is a form of MCDA that uses a hierarchical system of accounts, sub-accounts and indicators, combined with ranking, scaling and weighting functions, to rank the indicators across alternatives. Further, Samanta et al. (2002) applied the formalised use of MCDA techniques for the selection of mining equipment in a surface mining operation.

When applied to PMLU decisions, MCDA is often used to evaluate and prioritise land use options based on diverse environmental, economic and social criteria, with the typical process illustrated in Figure 3.

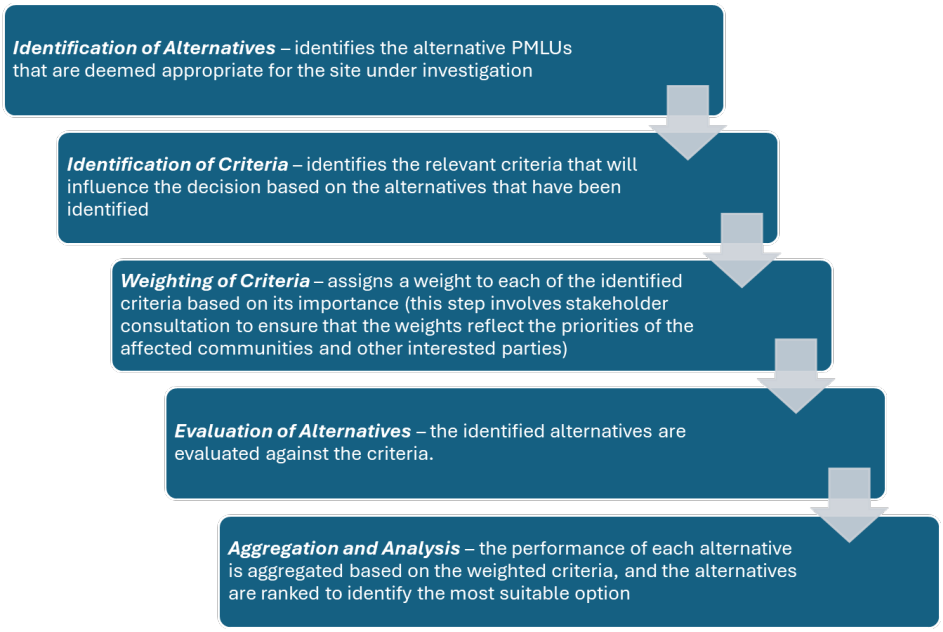

Figure 3 Illustration of a typical multicriteria decision analysis process applied to a post-mining land use (PMLU) decision

This process typically assesses choices between:

- reforestation and agricultural use of post-mining areas
- urban development and recreation in mining towns
- traditional agriculture and planting energy crops on post-mining land
- conservation, wetland creation and/or tourism development versus renewable energy projects
- industrial and agricultural land use.

It should be noted that while MCDA tools have seen broad application for assessing alternatives with a complex set of value drivers, they are a decision-support framework and not a substitute for detailed feasibility, technical, environmental and/or social impact studies that are required for ultimate implementation decisions. These requirements will continue to be used prior to final investment decisions. The opportunity for MCDA techniques is to help narrow the feasible set of alternatives to a manageable number to limit the expenditure required to identify the choice for final implementation.

2.2 Limitations of traditional multicriteria decision analysis and the objectives of the Post-Mining Land Use Options Assessment Tool

Reviewing the MCDA applications for PMLU decisions, four key gaps were identified that the PMLU Options Assessment Tool presented in this paper has been designed to address as follows:

1. Indigenous cultural and heritage considerations are not explicitly identified as factors and/or criteria against which alternative PMLUs are evaluated. Components are sometimes included within the social criteria, but for the Australian context this is an important consideration that has been included in the PMLU Tool.
2. In traditional MCDA, alternatives are often selected prior to identification of the factors/criteria against which they will be assessed. In such a process, the factors/criteria are then set for the alternatives, creating a structural decision bias that may discount some higher-value alternatives. In the PMLU Tool, discipline-specific factors that contribute to the value are determined prior to identifying alternatives for a specific site. This allows a broader scan for, and initial valuation of, potential land use alternatives.

3. In traditional MCDA, alternative scenarios that include multiple unique land uses are identified as mutually exclusive options prior to assessment, limiting the potential to assess multiple hybrid solutions after high-value individual land uses have been determined. In using the PMLU Tool, identification of the net best value scenario will require assessment of several alternatives that can be combined in varying proportions of the individual land uses to create scenarios for quantification. As such, it identifies the value for the individual land uses based on discipline-specific factors and not criteria developed with specific combinations in mind. This approach avoids elimination of potentially value-generating uses and thus keeps optionality open.
4. Traditional MCDA is undertaken to rank the alternatives so that the best can be chosen. This is normally done using a scoring system, which does not capture the quantum of the factors being evaluated beyond the chosen scoring system and can be difficult to communicate to different stakeholder groups that have different views on what value is, yielding different perspectives on the attractiveness of different options. A key driver for the PMLU Tool is to move beyond the scoring system by working with discipline experts to identify monetary values for the individual land use options to promote transparency and communication among stakeholders with often competing objectives. This valuation must include both tangible and intangible factors as well as an assessment of the risks that may impact the decision. Various evaluation techniques have been applied to areas of the mining industry, including techniques aimed at valuing intangibles (e.g., valuing natural capital assets based on the services provided [Maybee et al. 2023; O'Grady et al. 2023]), have been leveraged along with the discipline-specific expertise to progress the assessment of monetary values.

3 Post-Mining Land Use Options Assessment Tool architecture

The PMLU Tool[†] is grounded in MCDA as it is a methodology that has been widely applied to complex environmental and resource management decisions involving multiple objectives and stakeholders (Amaro et al. 2022; Singh et al. 2024). It is particularly well suited to post-mining contexts where trade-offs between economic viability, environmental outcomes and social acceptability cannot be reduced to a single metric. MCDA approaches have been applied to mine closure planning across a range of jurisdictions, demonstrating their ability to structure deliberation, enhance transparency and make value judgements explicit (Eshun et al. 2018). However, many applications remain project specific and lack scalability or adaptability to differing regional contexts.

The key enhancements to MCDA that are made through the PMLU Tool focus on the way that Indigenous cultural and heritage factors are recognised, how those criteria are linked to the options under assessment and how the quantum of value is communicated, as discussed in Section 2.2. Where traditional MCDA starts with the identification of alternatives followed by identification of the criteria for assessment based on those alternatives, this Tool identified the value drivers (criteria) independent of the alternatives to be assessed and the stakeholders making the assessment. As such, alternatives with different value-generating and detracting properties are then compared across the entire set of value drivers, including Indigenous cultural and heritage drivers as a unique set, promoting identification of a broad range of alternatives for assessment.

Identifying the value drivers independent of the alternatives being assessed also facilitates the identification of the quantum of value for each, which contributes to an assessment of feasibility and sustainability for each alternative. It also promotes the ability to combine unique land use options that may not be mutually exclusive into scenarios for assessment and identification of higher-value outcomes.

[†] For more detail on the structure and use of the PMLU Options Assessment Tool, please see the full development report (Browning et al. 2026) and the tool itself with user guides explaining its application at https://crctime.com.au/project/projet-lhp2-lighthouse-project-two/.

3.1 Structure

The Tool has been designed in alignment with contemporary mine closure guidance where stakeholder engagement is treated as foundational rather than supplementary (ICMM 2025; Hood et al. 2025). As a result, the Tool organises value into 4 core discipline-specific domains, as illustrated in Figure 4, following consultation with discipline-specific experts and practitioners engaged to identify the key drivers of value in their discipline areas. These drivers of value are then used to score the identified options in a consultative process that can take several forms (e.g. interdisciplinary workshops, interviews, surveys, etc.).

Figure 4 Structure of the Tool with descriptions of the discipline-specific value driver domains

It should be noted that the value driver sets are not specific to a stakeholder group but rather drivers of value that impact all stakeholders. As a result, each alternative is scored against each value driver and value driver set irrespective of the stakeholder, removing personal bias from the process. This structure mirrors best practice decision analysis guidance, which emphasises problem definition and option generation prior to detailed quantification (Stevens et al. 2021) as a means of ensuring that higher-value options are not discarded prematurely. Using a hub and spoke design model, the Tool can also be embedded within any PMLU planning process as a framework that both facilitates the inclusion of diverse stakeholders and suggests the data required to quantify the comparative value of available options.

This typology reflects empirical findings from closure research indicating that durable post-mining outcomes require balanced consideration of economic, environmental and socio-cultural dimensions (Simpson et al. 2025; Svobodova et al. 2025). As such, the Tool explicitly recognises the importance of mine owners, regulators, local governments, traditional owners, community representatives, environmental advocates and investors in the decision-making process, as research shows that early, deliberate engagement with these groups improves legitimacy, reduces conflict, and enhances alignment between closure outcomes and local aspirations (Svobodova et al. 2025).

The review of assessment techniques applied to PMLU decision-making showed that there is a need for tools that can value PMLU options in dollar terms with confidence. This valuation is important as it identifies the quantum of value, which is important for identifying the feasibility and sustainability of alternatives, and provides a common unit upon which the value of different alternatives can be communicated to multiple groups with different value propositions. As discussed, the input of experts and practitioners from each of the 4 disciplines was used to identify and quantify the specific value drivers that are modelled in the Tool.

This modelling was done through facilitated workshops to support shared understanding and negotiated scoring of a range of options, with the list of primary drivers displayed in Figure 5.

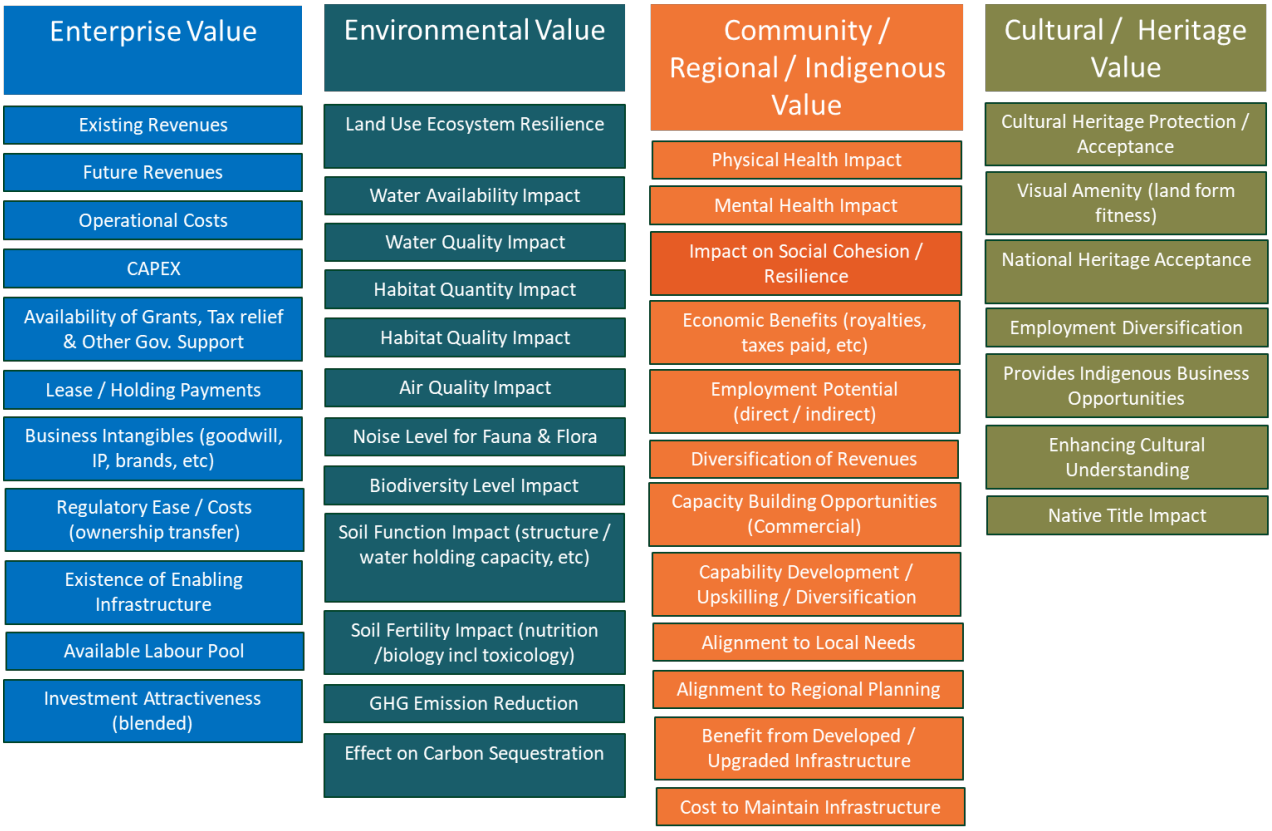

Figure 5 Primary drivers of value for each discipline area in the Post-Mining Land Use Options Assessment Tool

3.2 Scored options and quantified value versions of the Tool

The PMLU Tool is deployed as two versions, Scored Options (SO) and Quantified Value (QV), using the same value drivers (Figure 5). For the purposes of illustration in this paper, a set of alternative PMLUs has been assumed to facilitate discussion of the application of the SO and QV versions and illustrate their outputs. These alternatives are:

- mining of waste – going into waste dumps to extract remnant mineralisation
- natural environment – restoring the native vegetation and environment
- geotourism – establishing a tourism business venture on the site that focuses on its unique characteristics and mine infrastructure
- soft adventure – establishment of a business focused on outdoor activities like mountain biking
- light manufacturing or services – development of a manufacturing or services precinct.

The SO version of the PMLU Tool applies a structured qualitative MCDA approach to compare unique, mutually exclusive PMLU alternatives against a defined base case. In this version of the model, alternatives are scored on a 5-point scale ranging from -2 (major negative) to +2 (major positive) across the value drivers within each of the core domains (Figure 5), consistent with the use of MCDA in mine closure planning (Amaro et al. 2022).

The qualitative nature of this stage is critical. Early-stage closure decisions are characterised by uncertainty and incomplete data where premature monetisation can obscure important qualitative differences and bias decisions towards easily quantifiable outcomes (Eshun et al. 2018). By assessing the wide range of

alternatives, initially through this process, those that have the highest utility to users present as attractive. This is illustrated in Figure 6, where each of the 4 discipline-specific driver sets (enterprise, environmental, community/regional, cultural/heritage) are given equal weighting.

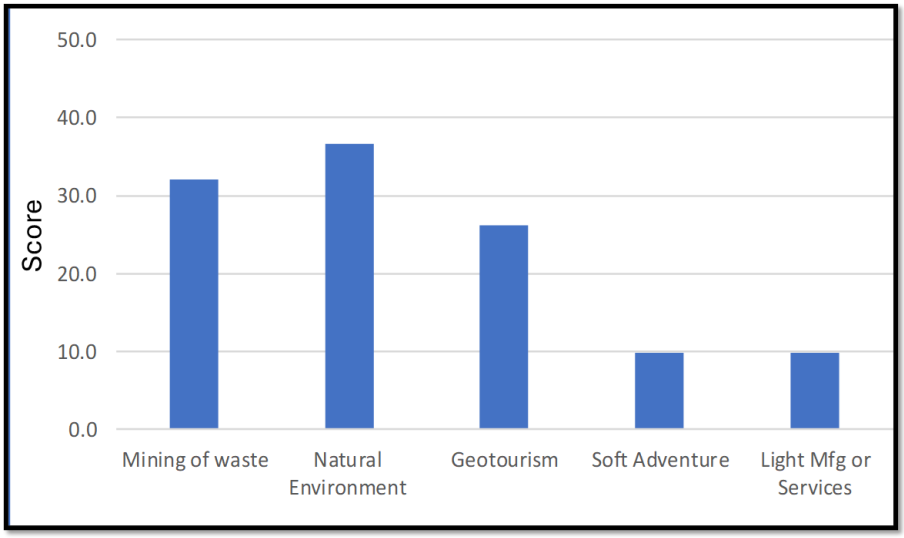

Figure 6 Comparison of 5 post-mining land use (PMLU) options using the Scored Options version of the PMLU Options Assessment Tool for the situation where the 4 discipline-specific driver sets are given equal weighting

At this stage, users can also introduce a perspective of value by placing a higher weighting on one or more of the discipline-specific driver sets. This does not alter the scoring of each individual value driver but rather alters the method by which they are combined into a total, representative of a user's value proposition. In Figure 7, the comparison results are presented for the situation where a preference (value proposition) is for values that contribute more towards the community/regional and cultural/heritage driver sets, which are given a weighting that is 3 times greater than the enterprise and environmental driver sets. Here it can be seen that the relative attractiveness of the options may change, suggesting the importance of having the correct people included early in the scoring process so that valuable alternatives are not discarded prematurely, as can occur if the individual criteria are altered to satisfy a personal bias. Also, as PMLU is not an all-or-nothing decision, those alternatives that rise to the top can also be combined in different proportions (should they not conflict) to create scenarios that can be taken through the quantification approach with the QV version of the Tool.

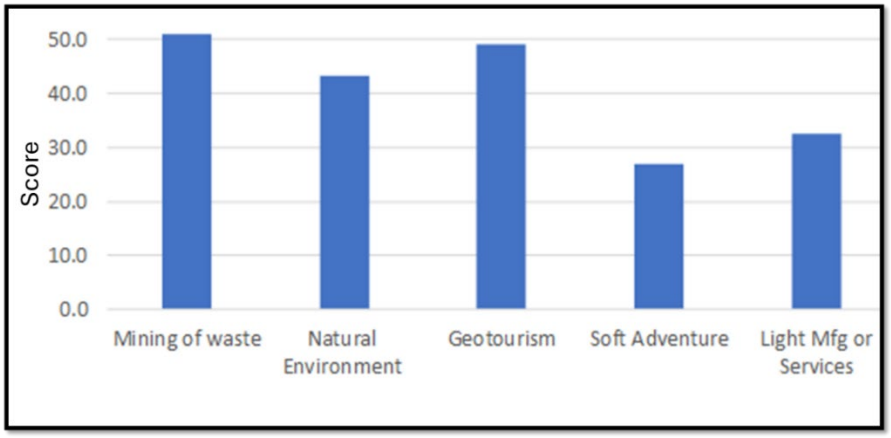

Figure 7 Comparison of 5 post-mining land use (PMLU) options using the Scored Options version of the PMLU Options Assessment Tool for the situation where community/regional and cultural/heritage drivers are weighted at 3 times the importance of the enterprise and environmental drivers

The QV version of the PMLU Tool takes the shortlisted alternatives and/or scenarios (mining of waste, natural environment and geotourism) as input and calculates a comparative monetary value for each based on the drivers of value that were identified as important to the decision-making process. Importantly, the Tool does not seek to generate absolute valuations but rather to support a relative comparison between alternatives, consistent with guidance from environmental economics and social CBA (Fregonara & Ferrando 2023). As with the identification and classification of the value drivers, their quantification in monetary terms has also been developed in consultation with experts and practitioners in each of the discipline areas.

A key difference between the 2 versions is that while the SO version presents higher-value alternatives it does not recognise the quantum of the different value drivers, which is done using the QV version. This demonstrates the feasibility and sustainability of an alternative. The following figures illustrate the comparative values found with the QV version of the PMLU Tool for the 3 most attractive alternatives from those compared using the SO version for the situation where the discipline-specific driver sets are given an equal weighting (Figure 8) and when the weighting is more heavily focused on the community/regional and cultural/heritage drivers (Figure 9).

Calculated Net Value	Tab #	Perspective	Natural Environment	Geotourism	Mining of Waste
Total Enterprise Value Uplift	*X.1*	***1***	*-$63,365,000*	*-$52,290,000*	*$44,974,000*
Total Environmental Value Uplift	*X.2*	***1***	*$22,513,000*	*$13,971,000*	*$19,330,000*
Total Community/ Regional Value Uplift	*X.3*	***1***	*$20,000*	*$9,556,000*	*$18,627,000*
Total Cultural/Heritage Value Uplift	*X.4*	***1***	*$115,000*	*$74,127,000*	*$1,657,000*
Cumulative Value			***-$40,717,000***	***$45,364,000***	***$84,588,000***

Figure 8 Comparative values from the Quantified Value version of the Post-Mining Land Use Options Assessment Tool for the situation where the discipline-specific drivers are given an equal weighting

Calculated Net Value	Tab #	Perspective	Natural Environment	Geotourism	Mining of Waste
Total Enterprise Value Uplift	*X.1*	***0.5***	*-$63,365,000*	*-$52,290,000*	*$44,974,000*
Total Environmental Value Uplift	*X.2*	***0.5***	*$22,513,000*	*$13,971,000*	*$19,330,000*
Total Community/ Regional Value Uplift	*X.3*	***1.5***	*$20,000*	*$9,556,000*	*$18,627,000*
Total Cultural/Heritage Value Uplift	*X.4*	***1.5***	*$115,000*	*$74,127,000*	*$1,657,000*
Cumulative Value			***-$20,223,500***	***$106,365,000***	***$62,578,000***

Figure 9 Comparative values from the Quantified Value version of the Post-Mining Land Use Options Assessment Tool for the situation where the discipline-specific drivers associated with community/regional and cultural/heritage are given preferential weighting

As was seen with the results of the SO version of the Tool, the comparative results for the QV version of the Tool can also change in relative attractiveness for the different alternatives, depending upon the importance of the different driver sets. It can also be seen that while all of these alternatives were seen as ‘valuable’ when compared using the SO version of the Tool, they may not contribute to increased value as expected when quantified using dollar figures. This supports the importance of making sure that the quantum of value is also assessed before decisions are made to reject some of the alternatives.

4 Conclusion

The Post-Mining Land Use (PMLU) Options Assessment Tool (the Tool) demonstrates how multicriteria, stakeholder-centred frameworks can reframe closure as a platform for value creation rather than compliance and liability minimisation. It tackles challenges faced by traditional multicriteria decision analysis (MCDA) applications by decoupling the assessment criteria (value drivers) from the alternatives to be assessed and the stakeholders making the assessment. This creates a more robust process that is replicable across a broad range of alternatives and situations. It also meets the need for monetary quantification of alternatives to assess the feasibility and sustainability of alternatives at an early stage while facilitating the assessment of combined PMLU scenarios.

The Tool provides users with a framework that embeds economic, environmental, community/regional and cultural/heritage considerations within a transparent comparative evaluation that advances the assessment of Indigenous cultural and heritage considerations, suggests the data that is required to make an assessment between alternatives and facilitates objective conversations around typically subjective viewpoints.

The Tool contributes to mine closure practice by providing a replicable, stakeholder-centred method for early-stage PMLU evaluation. By integrating qualitative MCDA with comparative financial assessment, the Tool aligns with emerging calls for decision frameworks capable of recognising multiple values, navigating uncertainty and meeting regional transition objectives (Boggs et al. 2025; Pagouni et al. 2024).

While the Tool does not replace detailed feasibility studies, it improves decision quality by ensuring that such studies are focused on options demonstrated to offer multidimensional value and the potential for enabling enduring, sustainable value from mined land.

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