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# Evaluating the environmental and economic impacts of mine void infilling: a case study

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## Abstract

*This paper presents a study on the environmental and economic impacts of mine void infilling, focusing on a case study of an operating coal mine in Australia referred to as 'Mine Site A'. The study was initiated to understand the carbon cost of mine void infilling and its implications for enabling high-value post-mining land use (PMLU) initiatives.*

*The potential for some innovative PMLUs that could provide significant sustainable social, economic and environmental value for mining-impacted regional communities is often limited by the infilling of mining voids. Additionally, the act of void infilling incurs financial costs and contributes to greenhouse gas (GHG) emissions from diesel combustion. Alternative and innovative approaches to PMLUs may create the opportunity to redeploy a significant portion of rehabilitation costs towards investment in alternate repurposing and remining PMLUs while contributing to decarbonisation.*

*The study estimates that the GHG emissions from mine pit infilling at Mine Site A amount to 0.9 kg CO2e per tonne of spoil moved, resulting in approximately 121,000 t of CO2e per year. This is equivalent to the emissions generated by 26,000 passenger vehicles driven for a year. The annual diesel consumption for this specific mine site scenario is estimated to be AUD 83 million.*

*These emissions represent only scope 1 emissions from diesel usage for pit infilling activities and do not consider (a) associated scope 2 and scope 3 emissions of mine pit infilling and (b) GHG emissions associated with implementing an alternate PMLU in place of pit infilling. The study emphasises the need for a pilot site-specific trial study to improve the accuracy of these estimates and to account for variable factors such as spoil data, haul distances and onsite diesel usage.*

*Overall, this paper provides valuable insights into the carbon emissions and financial costs of mine void infilling and its impact on innovative PMLU options. It emphasises the need for a broader research perspective to inform sustainable mine closure and rehabilitation practices.*

**Keywords:** *post-mine land use, mine regeneration, greenhouse gas emissions, mine pit infilling, diesel costs*

## 1 Introduction

Closure and rehabilitation are important processes in transitioning land following its temporary use for mining operations to a post-mine landform that supports a post-mining land use (PMLU). In Australia the complete rehabilitation of mined land to pre-mining conditions and relinquishment to Traditional Owners has not been a widespread practice.

In Queensland alone there are approximately 120 complex abandoned mine sites. These abandoned mine pits have left behind several environmental and human safety risks. This has resulted in a growing need for effective closure and remediation solutions (Tiemann et al. 2022; Queensland Government 2024).

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Current regulations in Queensland stipulate that rehabilitation of mined land is to be carried out in a manner that facilitates a final landform that is 'safe', 'stable' and 'non-polluting' in accordance with the *Environmental Protection Act of 1994* (Queensland Resources Council 2024). For open cut mines, regulations in place typically encourage (a) the infilling of mine voids and (b) mined land being progressively rehabilitated into a landform that reflects pre-mining conditions.

## 1.1 Mine void infilling as a closure strategy

Mine void infilling may be a necessary rehabilitation strategy for pit stabilisation or water quality requirements. A study carried out by Mudd (2016) presents the environmental case for backfilling of the McArthur River mine. This is an example where backfilling is a recommended strategy to minimise the environmental risks of acid mine drainage from waste rock dumps as well as improve social outcomes for the Traditional Owners.

For surface operations, retaining mine voids can lead to poorer (saline) water quality, where residual mine void waters have the potential to contaminate groundwater from seepage and surface water. This may pose severe environmental risks, and further dewatering and water management strategies may be required (Queensland Government 2023).

The social impacts of residual mine voids include human safety risks and the voids being highly visible within the landscape. Leaving behind residual mine voids means that waste rock dumps with potentially acid forming materials are left on the surface of the mine. These present a commercial and legal liability as strategies to mitigate environmental and health risks from pollution are required (Energy Resources Law 2023).

In Queensland, current regulation inhibits the implementation of alternative PMLUs that may have provided value elsewhere to achieve the required rehabilitation objectives of 'safe, stable and non-polluting' rehabilitation. However, the act of void infilling itself can cause conflict with these espoused requirements in several ways.

Although not the focus of this paper, void infilling via progressive rehabilitation can pose safety and stability risks due to rehabilitation being carried out prematurely at steeper batter slopes (Purtill & Littleboy 2023).

The act of void infilling requires the movement of an extensive quantity of earthworks. This incurs financial costs because of diesel usage and is also a source of greenhouse gases (GHG) from diesel combustion. Based on a desktop review, the economic and environmental costs of such infilling have not been widely reported and there is limited public data on GHG emissions from pit infilling as part of closure. A study by Mudd (2016) indicates high-level estimates of pit infilling to be AUD 800 million for 800 Mt of overburden material moved, based on diesel cost alone (not including labour expenses).

Pit infilling to grazing or pre-existing land prevents alternative and innovative PMLUs that utilise mine voids and that may provide social, economic and environmental value. Additionally, future mine closures present a threat to regional towns and communities that may face decline due to a dwindling local economy previously reliant on mining.

## 1.2 Alternative post-mine land uses

There are several examples of successful PMLUs that use residual mine pits. One is the Woodlawn Eco Precinct in New South Wales, Australia, which has repurposed a derelict open cut copper, lead and zinc mine into a centre for several sustainable ventures including a bioreactor landfill, a fish farm using regenerated waste heat, and a mechanical and biological treatment facility for waste (Veolia 2024).

In addition, the Kidston Pumped Storage Hydro Project (the third largest electricity storage device in Australia) utilises the head differential from residual mine pits from an abandoned gold mine for pumped storage hydropower, with the potential to generate a peaking 250 MW over an eight-hour period. The project has delivered 900 direct jobs within the region and has an estimated total construction cost of AUD 777 million.

Repurposing the existing mine pits for reservoirs and existing mine infrastructure has also allowed for a lower capex than an alternative greenfield site (Australian Renewable Energy Agency 2024; Genex 2024).

Potential PMLUs aren't just limited to energy initiatives as residual mine pits can also be utilised for recreational and tourism purposes. The Eden Project in Cornwall, England, is an eco-facility consisting of several greenhouse gardens within the pit of a former clay mine which now attracts over half a million visitors per year (Eden Project 2023).

It is evident that there are numerous creative and innovative ways in which residual mine voids can be used to leave behind a positive legacy that contributes to economic, social, environmental, stakeholder and community objectives. This paper considers an alternative perspective toward PMLU strategies by looking at mine voids in open cut mines as the base case to allow PMLU activities. This paper looks at GHG emissions released from mining operations during pit rehabilitation processes as an indication that economic and environmental value may be achieved by keeping the mine void. The further environmental implications of these emissions are also investigated using carbon emissions equivalencies.

# 2 Emissions from pit infilling: a case study example

This study determined scope 1 emissions from void infilling activities based on volumetric parameters from an operating coal mine in Australia referred to as Mine Site A. This case study represents a possible mine closure and rehabilitation scenario involving pit infilling at the end of the mine's life.

To simplify this calculation it has been assumed that the mine consists of a single pit and strip-mining operations would not be concurrent. GHG emissions were determined from existing operational diesel usage data. These results represent a high-level estimate of GHG emissions from mine pit infilling and do not consider emissions associated with a proposed PMLU as these emissions figures are highly dependent on what the intended PMLU is.

This case study example considered only scope 1 emissions arising from diesel emissions from mining vehicles. Scope 1 emissions are defined as 'Direct GHG emissions [that] occur from sources that are owned or controlled by the company: for example, emissions from combustion … owned vehicles etc.' by the World Resources Institute and World Business Council for Sustainable Development (2004).

Scope 1 emissions from diesel usage from the following operational mining activities were considered:

1. hauling of spoil from the stockpile to the pit using haul trucks
2. loading of material from the stockpile to haul trucks
3. movement of material in the pit using dozers.

The emissions for scopes 2 and 3 were not included in this study and are considered 'indirect' emissions from electricity and other sources not owned or controlled by the company, respectively (World Resources Institute and World Business Council for Sustainable Development 2004). This study also did not consider emissions from any PMLU activities; only activities involved in pit infilling, i.e. moving the backfill from overburden stockpiles to the mine pit, and not including the extraction of backfill as part of mining operations.

Diesel usage data from the assumed mine vehicles were used to determine annual emissions based on the potential earthworks movement intensity on site. This estimate considered the earthworks involved in moving 140 Mt of overburden per year, using existing online data from Mine Site A for strip ratios and average material mined with an assumed 40-year mine life and 10-year closure period for pit infilling. In total, 1,400 Mt of overburden was moved to infill the mine voids.

## 2.1 Assumptions and considerations

This study presents a high-level estimate of GHG emissions released from diesel consumption by mine vehicles. Where possible, site-specific data was obtained from desktop study research and several assumptions were made to facilitate this calculation.

The following assumptions and considerations were involved in the completion of this estimate:

1. Earthworks moving operations in mine closure vary depending on factors such as mine layout, mining methods and commodity type. In this scenario, pit infilling has been assumed to be through truck and shovel operations and with non-autonomous mine vehicles.
2. The inclusion of scope 2 and 3 emissions, and considering PMLU emissions and land use change emissions, are likely to alter GHG emissions associated with mine closure and rehabilitation involving pit infilling.
3. These results were based on non-site data, and assumptions for haul distances, vehicle operating hours and onsite vehicles were made based on engineering judgements. These assumptions are outlined fully in Table 1.
4. A diesel unit rate of AUD 1.90/l was used based on the average diesel retail price for the June quarter 2023 from the Australian Competition and Consumer Commission (2023). This is subject to changes over time.
5. These estimations assume that the total mine overburden produced during the operation will be infilled in the pits as part of non-progressive rehabilitation. In practice, open pit mines may be progressively rehabilitated as part of ongoing mining operations.
6. No bulking factors were taken into account for the pit infilling scenario as it was assumed that the volume of overburden was sufficient to infill the pit completely.

## 2.2 Methodology

The following parameters have been used to estimate annual GHG emissions for infilling the mine voids at Mine Site A. These parameters were sourced from supplier sources as well as operating data. It should be noted that:

1. An average haul distance of 2,000 m (one way) from waste rock dumps to the mine pit has been assumed. Haul trucks would be loaded and travelling into the mine pit for 46% of the distance covered.
2. For the haul trucks there would be no loss in payload of mined material as the trucks travel from the waste rock dump to the mine pit.

Table 1 outlines the parameters used in determining diesel usage for pit infilling activities at Mine Site A. Greenhouse gas emissions factors from the Department of Climate Change, Energy, the Environment and Water (2023) were then used to determine emissions from mine vehicle diesel burn.

**Table 1 Operating parameters for diesel usage during pit infilling for Mine Site A**

| Vehicle | Parameter | Value |
|---|---|---|
| Haul truck — CAT 777 (hauls 85% of material) | Equipment units | 40 |
| | Engine hours/unit/year | 5,500 hours per year |
| | Fuel burn rate | 76 l/hr |
| | Operating efficiency | 62% |
| | Average haul distance (one way) | 2,000 m |
| Haul truck — CAT 772 (hauls 15% of material) | Equipment units | 14 |
| | Engine hours/unit/year | 5,500 hours per year |
| | Fuel burn rate | 40 l/hr |
| | Operating efficiency | 62% |
| | Average haul distance (one way) | 2,000 m |
| Loader — CAT 6030 | Equipment units | 14 |
| | Loading cycle (to fill one Cat 777) | 2.3 mins |
| | Engine hours/unit/year | 5,500 hours per year |
| | Fuel burn rate | 218 l/hr |
| | Operating efficiency | 66% |
| Dozer — CAT D11 | Assumed weighted average movement of material | 500 m of material moved per dozer |
| | Equipment units | 18 |
| | Fuel burn rate | 109 l/hr |
| | Engine hours/unit/year | 4,000 hours per year |

## 2.3 Results

Scope 1 emissions were estimated based on diesel emissions from mine vehicles during infill of the open mine pits. Scope 1 emissions from pit infilling were determined to be 121,000 t CO2e/annum, this equates to approximately 17% of Mine Site A's annual scope 1 emissions. Mine Site A's annual scope 1 emissions were determined using published online data.

Using an assumed diesel cost of AUD 1.90/l, this equates to an approximate cost of AUD 83 million for diesel per annum for haulage, dozing and loading of spoil material into mine pits. Over a 10-year closure period with 140 Mt of material moved per annum, this would equate to AUD 830 million.

A comparison of annual scope 1 emissions from pit infilling at Mine Site A to equivalent emissions from alternative sources was carried out to set these emissions in context.

Equivalent GHG emissions were determined using the United States Environmental Protection Agency Greenhouse Gas Equivalencies Calculator (United States Environmental Protection Agency 2024). Annual scope 1 emissions of 121,000 t CO2e were found to be equivalent to GHG emissions released from 26,000 passenger vehicles, and the carbon sequestered by approximately 64,000 ha of US forest in one year. Refer to Table 2 for a summary of scope 1 emissions and associated diesel costs for Mine Site A.

**Table 2 Emissions and diesel cost data from Mine Site A pit infilling activities**

| Mine site A result | Value |
|---|---|
| Scope 1 GHG emissions per tonne of overburden (spoil) material moved | 0.9 kg CO2e/t of material moved |
| Scope 1 GHG emissions per annum | 121,000 t CO2e/annum |
| Passenger vehicle GHG emissions equivalent | 26,000 passenger vehicles |
| Diesel consumption per annum | 44,000,000 l/annum |
| Approximate cost of diesel for infilling operations | AUD 82,900,000/annum |
| Approximate cost of diesel per tonne of overburden (spoil) | AUD 0.60/t of material moved |

There are several variations in these associated costs that are due to factors such as mine operational planning, site layout and mine type. To account for these emissions and cost variabilities from pit infilling activities and to further enhance accuracy in estimates, a comprehensive study with site-specific data such as site diesel usage, electricity purchased and emissions from external sources should be carried out.

# 3 Conclusion

The increasing requirement from Australian state governments to commence early planning for post-mining rehabilitation indicates a need for companies to adopt more creative and innovative approaches which may deliver enhanced community and environmental benefits while assuring an enriched legacy. Pit infilling to pre-mined land conditions may be necessary for environmental, safety and slope stability purposes where retaining a mine void is not suitable. However, we know from existing case studies that rather than pit infilling to a past-use state and instead adopting innovative solutions which combine environmental knowledge and foresight with astute commercial decision-making will deliver longer-term benefits to our communities and our industry.

Successful PMLUs such as the Eden Project in Cornwall, England, and the Kidston Project in Queensland, Australia, demonstrate that there is value to be found from a hole in the ground and raise the question of whether mine regeneration by void infilling is the best way forward for all mines. The Kidston Project is an example of how economic benefits can be achieved in the form of reduced capex from utilising mined landforms for a specific purpose as well as downstream economic benefits.

This study estimated the total cost of mine infilling for Mine Site A as AUD 830 million for 1,400 Mt of total material infilled. This figure should not be taken as a standalone figure as the cost of mine infilling is highly variable. However, this is an indication of the significance of the financial cost of mine regeneration through mine infilling.

Retaining the mine void can offer tangible and realisable financial savings that could be invested elsewhere; for example, saving direct costs incurred from operations of moving extensive quantities of earthworks in order to infill mine voids . When compared to the construction costs of the Kidston pumped hydropower at AUD 777 million and the further forecasted economic benefits, it is evident that alternative PMLUs which utilise the mine void may provide a greater return on capital than the status quo approach of pit infilling.

This study also compared annual equivalent emissions from mine pit infilling of 140 Mt of material to 26,000 passenger vehicles, equating to 17% of Mine Site A's annual scope 1 operating emissions. This is not an insignificant figure. To put the potential environmental impact from emissions into context, if we consider the scale of mining operations Australia-wide, and the entirety of overburden material, the environmental consequences from cumulative GHG emissions alone are likely to be of a very significant magnitude.

The GHG emissions are just one indicator of environmental sustainability risks. The wider environmental consequences from mine infilling are worthy of more investigation and must factor into future mine project investment decision-making, especially when it comes to meeting global decarbonisation and other sustainability targets.

Retaining these voids presents an opportunity to aid in decarbonisation of the mining industry. Simultaneously, PMLUs that use the mined landform, e.g. renewable energy facilities, could be implemented as a strategy to provide further environmental value creation. It is important to investigate the potential of adopting these strategies as a decarbonisation measure, given the importance of reducing GHG emissions globally.

The estimated emissions figure in this study should not be taken as a standalone figure but should be looked at in a broader context and taken as an indication that it is worth investigating the significant environmental and economic costs attached to pit infilling. A comparative study that demonstrates a direct comparison between void infilling versus a PMLU that utilises the same void/s is one way in which we can further strengthen the argument of innovative and creative PMLU. Expanding the scope of mine regeneration can be facilitated through a combination of industry advocacy and leadership, community engagement and regulatory change. This will allow for the development of PMLU strategies that are fit for purpose and leave behind a positive legacy.

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