Research Directions: Mine Closure and Transitions

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How utility-scale solar energy generation on rehabilitated mine lands can contribute to decarbonising the resources sector

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Analysis

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Abstract

Many governments globally have climate change targets requiring rapid decarbonisation, calling for significant renewable energy generation. Utility-scale solar arrays will consume large swathes of land. Rehabilitated mine lands present a unique opportunity to host renewable utility-scale solar and reduce land use conflicts. There is however, to date, insufficient in-depth discussion of this opportunity and barriers to implementation in the academic literature. This paper describes challenges facing the resources industry, using Queensland's coal sector as a case study, then outlines some of the opportunities that accompany those challenges. Five reasons for reassessing the role of rehabilitated lands for utility-scale solar energy generation are presented – increasing demand for renewable energy, the global decarbonisation agenda, transformation in regional mining economies, as a progressive rehabilitation and post-mining land use, and a solution to reduce land use conflict. The barriers, perceived and actual, must be addressed and broken down to facilitate greater uptake of utility-scale solar onto rehabilitated mine lands. This can allow for a more orderly energy transition, and growth in renewable energy production that matches decarbonising and energy demand pathways, in the right locations and at the right time – with good planning and industry support.

Introduction

The Australian mining industry is a significant contributor to the national economy. According to Geoscience Australia, the resources industry (mining and petroleum) contributed $234B, around 60% of Australian export earnings in 2019 (Geoscience Australia, n.d.). In the decade to 2021, the Minerals Council of Australia (2022) stated that total export earnings for Australia was $2.1 trillion. As a major resources state, Queensland's resources industry is similarly a mainstay of its economy. According to the Queensland Resources Council (2022), the resource industry contributed $84.3B to the Queensland economy in fiscal year 2021, contributing $1 in every $5 of the economy and one in six jobs. At the height of the last mining "boom" up to 2011, Fleming and Measham (2014) estimated seven non-mining jobs were created for every mining job. Importantly, the resources industry provides economic opportunity in regional areas, as well as metropolitan support roles.

Queensland's metallurgical and thermal coal mining sector is the backbone of the mining industry's contribution to the state. Coal production tonnages derived from Queensland Department of Resources coal sales data in calendar year 2021 (~65% metallurgical coal used in steel making, ~35% thermal) was nearly 221 million tonnes. The industry is under pressure to decarbonise its operations, rehabilitate disturbed mining lands and participate in the long-term future of the regional economies in which it operates.

The Queensland and Australian governments have climate change targets that will require rapid decarbonisation. The Australian Government's *Climate Change (Consequential Amendments) Act 2022* commits Australia to greenhouse gas reduction targets of 43% by 2030 and net zero emissions by 2050. Queensland released its public commitment to 80% renewable energy by 2035 (Queensland Government, 2022) on 28 September 2022.

Rehabilitated mine lands present a unique opportunity to host renewable energy generation and reduce land use conflicts. Decarbonising the resources industry is an imperative for all forms of mining, and the introduction of utility-scale solar projects into the mine rehabilitation equation has merit for all mine types. However, particular challenges face the fossil fuel-based resources sectors – thermal and metallurgical coal, and petroleum. The coal industry provides a case study to explore the merits of renewables as part of the solution to the challenges facing this sector as it transitions to a less carbon-intensive world.

This paper briefly describes the global challenges facing the metallurgical and thermal coal industry and an important opportunity that accompanies those challenges. This paper focuses on utility-scale solar projects acknowledging that other renewable energy opportunities as well as storage options exist. The paper presents five reasons why renewable energy generation and in particular solar, should be a key element of mine rehabilitation and closure planning.

ESG challenges

Global investor pressure and government policy are driving ESG-focused changes apace (Delevinge et al., 2020). Companies in the thermal and metallurgical coal sectors are responding. Anglo American Services (UK) Ltd (Anglo American, 2021) has outlined its commitments as follows:

> "At Anglo American we are committed to playing our part. ... But we also recognise that we must do what we can to minimise the emissions related to the supply of those products as quickly as we can. We also accept the role we must play in supporting the decarbonisation of our value chains."

BHP Ltd (BHP, 2021, p. 8) has articulated goals to reduce scope 1 and 2 emissions by 30% by 2030 and net zero operational emissions by 2050.

Fossil fuel-based commodities are a central target of global decarbonisation agendas. Investment fund managers are shifting capital to so-called "ethical targets" at an increasing rate (e.g. Eccles & Klimenko, 2019; Gluyas, 2021; PWC, 2022). Gluyas (2021) writing in the Australian Financial Review cited a 30% increase in 2020, with 40% of managed funds now directed to ethical investments. The results reflected a global investment trend, seeing 36% of managed funds ($48 trillion) shifting into the responsible investment market. The article cites the Responsible Investment Association Australasia defining those investments as a

> "holistic approach to investing, where social, environmental, corporate governance and ethical issues are considered alongside financial performance when making an investment."

Such trends place pressure on resource companies, especially those extracting fossil fuel-based resources including thermal and metallurgical coal, oil and gas.

The world's largest asset manager, Blackrock, with US$10 trillion under management, reflects this shift. In his 2022 letter to CEO's, Blackrock's Larry Fink (Blackrock, 2022) outlines the trend;

> "... we have seen a tectonic shift of capital ... Actions and ambitions towards decarbonization have also increased. This is just the beginning – the tectonic shift towards sustainable investing is still accelerating. Whether it is capital being deployed into new ventures focused on energy innovation, or capital transferring from traditional indexes into more customized portfolios and products, we will see more money in motion."

The need to demonstrate environmental social and governance (ESG) credibility also spills over into jurisdictions seeking to be an investment destination of choice. In 2021, the Queensland Government produced its first Sustainability Report (Queensland Government, 2021). The report outlines seven key focus areas, including "*environmental protection and natural resource management*" (p.4). Amongst other priorities, this focus area gives emphasis to new economy minerals, waste management and resource recovery, and mine site rehabilitation. Anecdotal feedback from Queensland Treasury officials indicated the first and most consistent area of interest to investor audiences was the Sustainability Report.

Mining companies are also at risk from parties accusing them of "greenwashing" the decarbonisation agenda (Environmental Defenders Office, 2022). The continued extraction of carbon-based commodities such as thermal and metallurgical coal will continue to sit uncomfortably against stated commitments towards decarbonisation. A real opportunity exists for mining companies to look for carbon reductions as part of their commitments to rehabilitate mine lands to a post-mining land use.

Post-mining land use

Currently in Queensland, as for many jurisdictions, mining companies are required to rehabilitate land disturbed by mining to a safe, stable, non-polluting condition, able to sustain a post-mining land use, and to undertake this rehabilitation progressively, through the life of mine.

In Queensland, Chapter 5 of the *Environmental Protection Act 1994* (EP Act) describes the requirements for Environmental Authorities (EAs), Progressive Rehabilitation and Closure Plans and Environmentally Relevant Activities. The Environmental Protection Regulation 2019 requires that:

> "Rehabilitation of land to a stable condition will be achieved progressively during the life of the mine." (Schedule 8A, Part 3 Table 2).

Section 176A(3)(c)(i) requires that Progressive Rehabilitation and Closure Plans must outline a schedule of works that culminate in mined land being returned to a "stable" condition. Section 111A of the EP Act provides a definition of "stable condition" -

> "Land is in a stable condition if—
>
> (a) the land is safe and structurally stable; and
>
> (b) there is no environmental harm being caused by anything on or in the land; and
>
> (c) the land can sustain a post-mining land use."

Thus, environmental protection legislation in Queensland makes it clear that land must be progressively rehabilitated and that rehabilitation must be sufficient to meet the definition of "stable" and sustain a post-mining land use at the end of mine life.

Grazing and ecosystem rehabilitation are two of the most common post-mining land uses committed to by mining companies (Worden et al., 2021). Areas that are planned for rehabilitation to a grazing outcome (i.e. mostly grass pasturelands) lend themselves to the opportunity to play a significant role in meeting growing demand for renewables, decarbonisation of mine operations and a co-production model reducing land use conflicts and supporting new industries in regional economies.

Examples are emerging of mining companies either incorporating renewables into their operations or using former mine sites to host renewable energy projects. The Kidston gold mine ceased operations in 2001. The site is now host to a 50MW solar array constructed on the tailings storage facility (Figure 1). Construction is underway for a 250MW pumped hydro project, with an additional 270MW solar project planned (Genex Power Ltd, 2018). The Queensland Coordinator-General approved the project on 5 April 2019 (The Department of State Development, Manufacturing, Infrastructure and Planning, 2019). Rio Tinto has announced plans to invest $600M in renewable energy projects in its remote Western Australian iron ore projects in two 100MW solar projects and battery storage by 2026 (Rio Tinto Australia, n.d.). Canadian mines have pursued pumped hydro storage projects on abandoned mines (Saffron, 2022).

Appalachian coal counties have embraced the transition to utility-scale solar energy projects. The US EPA states around 500 former Superfund sites (both industrial and mine sites) have incorporated renewable energy onto the sites (e.g. Buckley, 2022). While the number is presented as a modest volume given the 130,000 sites considered, it reflects the potential for these sites to

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Figure 1. Genex Power's Kidston Hub showing solar array in background and planned pumped hydro in former open cut pits in foreground (reproduced with permission of Genex Power).

host renewables. In Queensland, the trend has been for miners to access renewable energy via power purchase agreements, rather than have renewables installed on their mines.

Renewable energy zones

The projected growth in demand under a range of scenarios is presented in Figure 3. In response to these scenarios, the Australian Energy Market Operator (AEMO) identified 43 potential "renewable energy zones" (REZ) across the National Electricity Market (NEM), nine of which are in Queensland (Australian Energy Market Operator, 2023). The NEM is one the of largest electricity networks in the world, extending across New South Wales, Queensland, South Australia, Tasmania and Victoria.

Queensland has identified its own draft REZ network. The Queensland Renewable Energy Roadmap (The State of Queensland (Department of Energy and & Climate), 2024) has initially identified 12 potential locations to develop a coordinated network to connect growing renewable energy generation. The REZ concept is in its nascent stages and locations are generic in nature. However, several locations are close to existing mining areas such as the Callide, Collinsville, Darling Downs, Tarong and Western Downs REZ (Figure 2).

REZs have been identified as the best locations to develop renewable energy projects to take advantage of the renewable energy resource, existing grid infrastructure, and to minimise costs incurred in development including transmission, stability and system strength. AEMO (2022) also identifies the importance of diversity of source and location and strong interconnection to balance variable energy generation from renewables.

Five reasons why utility-scale solar projects are an effective post-mining land use

The task of progressive rehabilitation and eventual closure of mines, if viewed through the lens of optimising positive post-mining outcomes, can be an opportunity for resource communities. Five reasons that utility-scale solar projects should be considered as part of post-mining land use are described in the following sections. They are;

- Demand growth for renewable energy
- The decarbonisation agenda
- Supporting regional mining economies in transition
- Progressive rehabilitation and sustainable post-mining land use, and
- Reducing land use conflict.

Demand growth

AEMO's 2021 Inputs, Assumptions and Scenarios Report (2021) informs its biennial Integrated System Plan (Australian Energy Market Operator, 2022). The reports use various scenarios (in the 2022 ISP – slow change, progressive change, step change and hydrogen superpower) to forecast potential growth and changes to the NEM's energy mix. The (then) Queensland Department of Energy and Public Works has also included a "strong electrification" scenario in its demand outlook forecast (Figure 3).

AEMO (2021, p. 4) continually refines its scenarios acknowledging the pace of change in

> "economy-wide decarbonisation, the ongoing consumer investment in distributed energy resources, and the growth of transport and industry electrification."

According to AEMO (2021 Figure 2, p. 6), across the NEM, the hydrogen superpower scenario sees growth in energy consumption (demand) to 614 TWh over the slow change scenario (184 TWh) by 2040. Figure 3 shows the Queensland component of these scenarios.

In June 2023, Queensland had ~17,000 MW or 17 GW (Queensland Government, 2023) of utility-scale generation out of the total NEM's ~55 GW (approximate) installed capacity (Australian Energy Regulator, 2024). All scenarios except for

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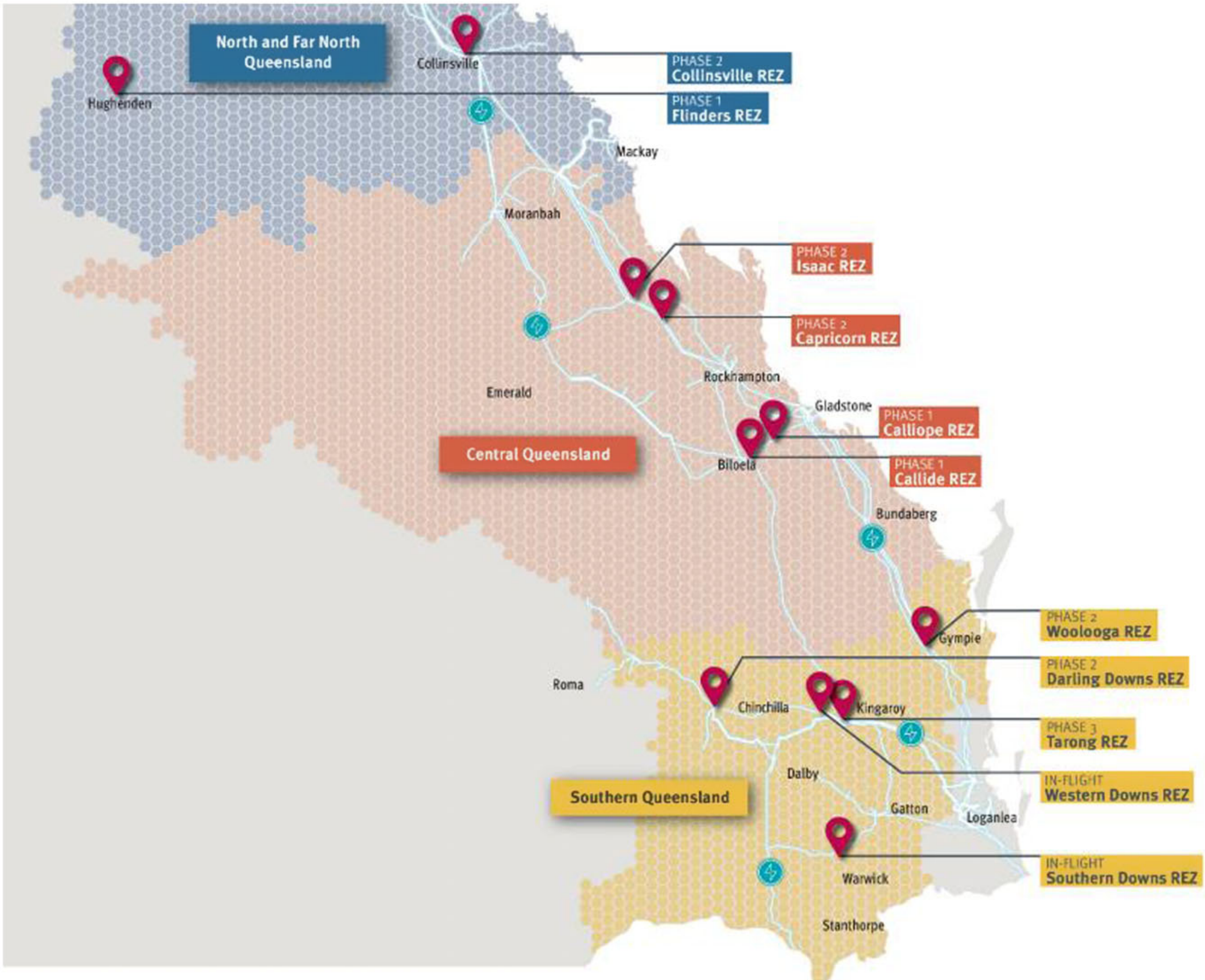

Figure 2. Queensland renewable energy zones (Powerlink, n.d.).

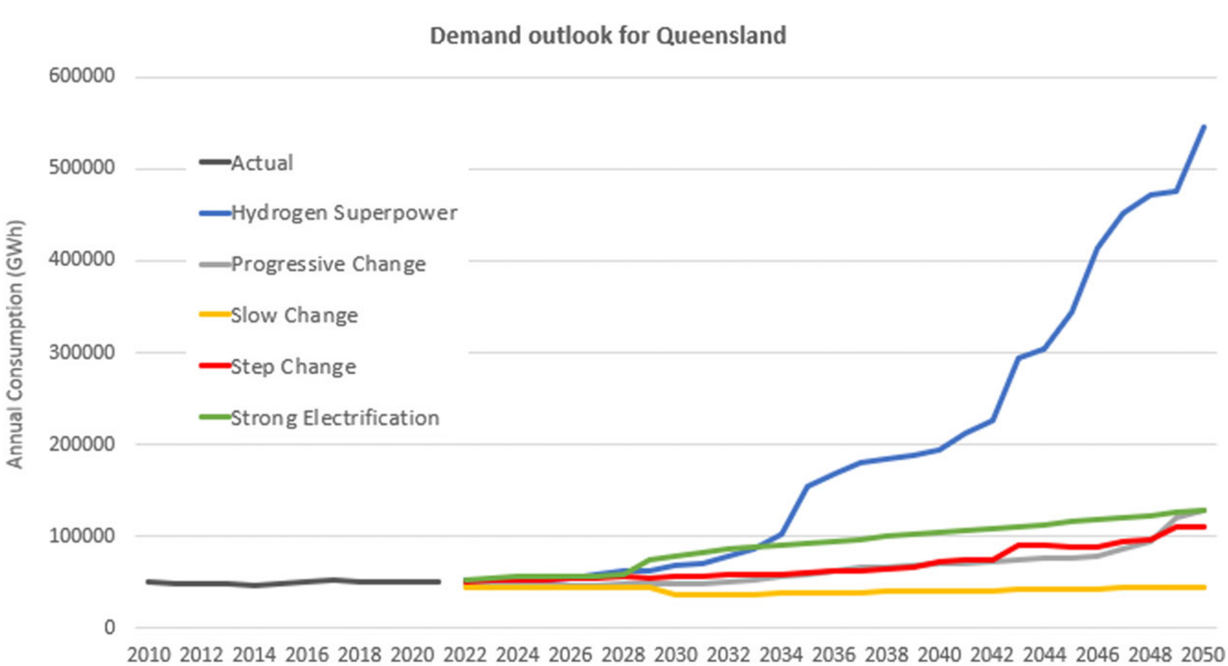

Figure 3. Demand scenarios for Queensland (after Australian Energy Market Operator, 2021).

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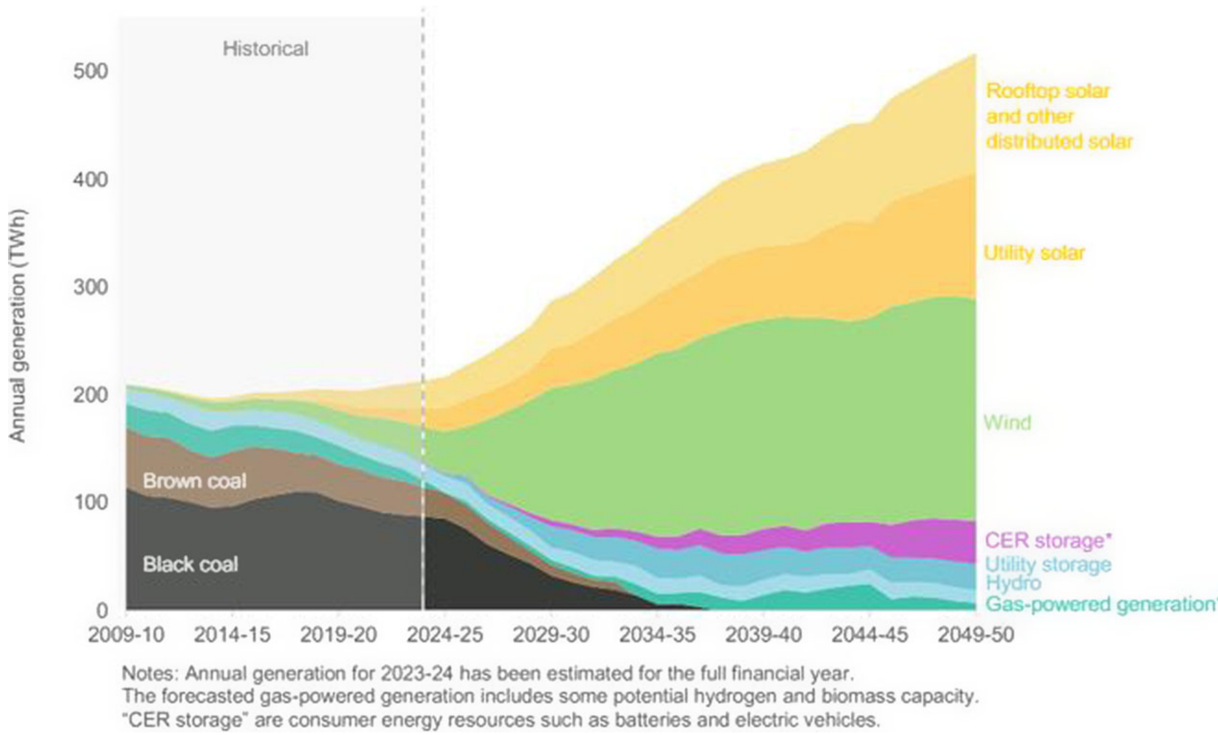

Figure 4. Forecast National Electricity Market generation to 2050; step change scenario (Australian Energy Market Operator, 2024 Figure 9, p. 30).

"slow change" see a minimum doubling of the consumption experienced across the period 2010 to 2020 by 2050.

AEMO (2022, p. 39) outlines the build task for variable renewable energy (VRE) under its most likely (step change) scenario.

> "...the ISP forecasts the need for over 125 GW of additional VRE by 2050, to meet demand as coal-fired generation withdraws. This means maintaining the current record rate of VRE development every year for the decade to nearly treble the existing 16 GW of VRE by 2030 – and then doubling that capacity by 2040, and again by 2050."

Figure 4 shows the AEMO (Australian Energy Market Operator, 2024) generation contributions required to 2050, under the Step Change scenario. The Step Change scenario has been chosen as it reflects strong action on climate change leading to a step change reduction of greenhouse gas emissions. Given recent commitments at the state and federal level (see section 1) this scenario is currently a plausible outcome. By 2050, utility-scale solar needs to provide around 22% (~110 terawatt hours of ~500 TWh) of total generation and will require nearly 300 GW of installed capacity (Australian Energy Market Operator, 2024, Figure 14, p. 45).

The estimate for utility-scale solar will require substantial land areas. Estimates on generation from utility-scale solar vary. Ergon Energy, Queensland's regional retail and network service provider advises 1 ha per 1-1.5 MW; other estimates range to 2-3 ha per MW (Squadron Energy, 2022). AEMO's projections will require large tracts of land regardless – ~65,000 to 200,000 ha for the NEM.

The potential for renewable energy in Australia to be converted into a non-polluting export fuel has been widely forecast (e.g. COAG Energy Council, 2019). Scenarios including strong growth in hydrogen production push demand growth exponentially (Australian Energy Market Operator, 2021). Projections for growth in hydrogen production reflect the wider growth in renewable electricity demand. AEMO (2022, p. 39) describes the "Hydrogen Superpower" build task as "monumental." Any renewable demand growth arising from the conversion of the Queensland aluminium industry to renewable energy, would create additional demand.

In September 2022, the Queensland Government released its Energy and Jobs Plan (Queensland Government, 2022). The implications for the stationary energy mix and mine rehabilitation are discussed in more detail below. Figure 5 shows the change in energy mix and the projected generation growth to 2040.

It becomes apparent that more renewables are required to simply meet the existing commitments in Queensland (50% of electricity generation from renewables by 2030, 70% by 2032, 80% by 2035) and the 2022 emissions reduction targets introduced by the federal government. Plausible scenarios should Australia seize the opportunities afforded by the global decarbonisation agenda, such as green metals and hydrogen, see net growth in total energy demand, to be delivered by renewable energy sources.

Rehabilitated mine lands occupy tens of thousands of hectares. While the Queensland REZ locations continue to evolve, there are already areas that coincide with mining areas. The disturbed (and subsequently rehabilitated) areas have been retired from agricultural production for many years, in many cases decades. They lend themselves as highly suitable locations to meet even the most modest of energy demand growth scenarios.

The Decarbonisation agenda

A large proportion of global resources companies, including those active in Queensland, have signed up to carbon emissions reductions, including net zero emissions by 2050 such as BHP Ltd (BHP, 2021), Glencore PLC (2021) and Peabody Energy Inc. (Peabody Energy Inc., 2023). The Queensland Resources Industry

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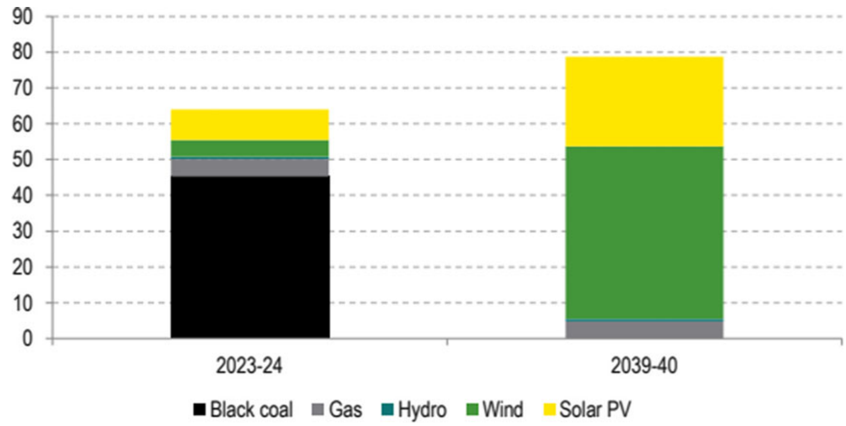

Figure 5. Forecast annual mix of NEM-connected large-scale generation in Queensland in the Plan Scenario (after Queensland Department of Energy and Public Works, 2022, p. 5). Y-axis is TWh.

Development Plan (Department of Resources, 2022, p. 21) has included a proposal to develop a decarbonisation policy with industry to be prepared for mining operations in the State, aiming to achieve

> "…. substantial and consistent reductions in Scope 1 and 2 emissions."

The Australian Government's Resources 2030 Taskforce (2018, p. 40) noted

> "… the Australian resources sector needs to continue to identify, develop and adopt new measures and technologies to reduce carbon emissions from its operations."

Net zero by 2050 is a bold, ambitious but necessary aspiration for all organisations, especially those energy-intensive operations, or those producing emissions-intensive products, or both. To achieve net zero 2050, companies are looking for the immediate next steps they can take on that path. The mining industry's direct greenhouse contribution is attributed 4-7% of total global emissions (Delevinge et al., 2020). Of these, Scope 1 (emissions generated by the activity itself) and Scope 2 (emissions generated by the goods and services provided to the operation, including energy) emissions account for 1%.

The Scope 3 emissions from the use of mining products including the combustion of coal are attributed 28% of global emissions (Delevinge et al., 2020). While addressing Scope 3 emissions may remain elusive in the short-term, real action can be taken in the short to medium term to address Scope 1 and Scope 2 emissions from Queensland mines. They present an opportunity for mining companies to begin their decarbonisation journey with real, practical emissions reductions.

Reducing the carbon intensity of operations is of primary importance to those companies committing to net zero by 2050 and staged interim reductions (such as BHP's 30% reduction in operational levels by 2030). BHP has identified the introduction of renewable energy sources into its first 40% of reductions. From 1 January 2021, BHP entered into a power purchase agreement with the state's newest generator, CleanCo Queensland, to provide renewable energy from the Western Downs Clean Power Hub and Karara windfarm. BHP states the deal will reduce their operational emissions in Queensland by 50% by 2025. BHP (n.d.) has also committed to behind-the-meter renewables where grid connectivity is limited.

A survey of mine managers at 162 mine sites globally was conducted in early 2022 (GlobalData, n.d.). On-site renewable energy options were preferred by 38% of respondents and more than 20% citing purchased renewable energy. And it is that global preference for on-site renewable power that presents a win-win opportunity for miners to reduce their emissions-intensity while developing a sustainable post-mining land use.

The $62B Queensland Government Energy and Jobs Plan (2022) seeks to rapidly decarbonise the stationary energy economy and take Queensland beyond its stated 2030 target of 50% renewables in the stationary energy sector. Figure 5 shows the proposed growth in demand and the change in generation sources proposed in the Plan (Queensland Department of Energy and Public Works, 2022). The Plan transitions Queensland from coal-fired generation by 2040.

An initial focus on reducing the carbon intensity of mining operations, using behind-the-meter renewable energy generation on site, would be a proactive, if modest step towards mining companies' decarbonisation strategies. Growth in renewables on-site can be matched to the rehabilitation task, occur over the operating period of the mine and provide renewable energy as a complement to traditional energy sources.

Supporting regional mining economies in transition

The Cooperative Research Centre for Transformations in Mining Economies (CRC TiME) is a collaboration of over 70 institutions committed to responsible mine rehabilitation, closure and sustainable post-mining economies. The formation of the CRC TiME reflects the importance of planned transformations, particularly for fossil fuel-based commodities. The challenges outlined previously suggest that, over time, these commodities face diminishing market demand, especially for energy production. CRC TiME has commenced a project *Identifying future economic development pathways for mining regions and increasing transition capacity* (Poruschi et al., n.d.). Bainton and Holcombe (2018) identified potential economic linkages to mine closure. Ensuring a sustainable post-mining land use and opportunities for resources communities is an important aspect of mine closure planning.

Integrating renewables into the mine rehabilitation landscape will bring new, "green" energy opportunities. In turn, industries attracted to REZs will contribute to the long-term sustainability of regional economies hosting renewables.

In the Queensland context, the thermal and metallurgical coal open cut mines located close to announced REZs are prime candidates. Metalliferous mines will also "transform" regional

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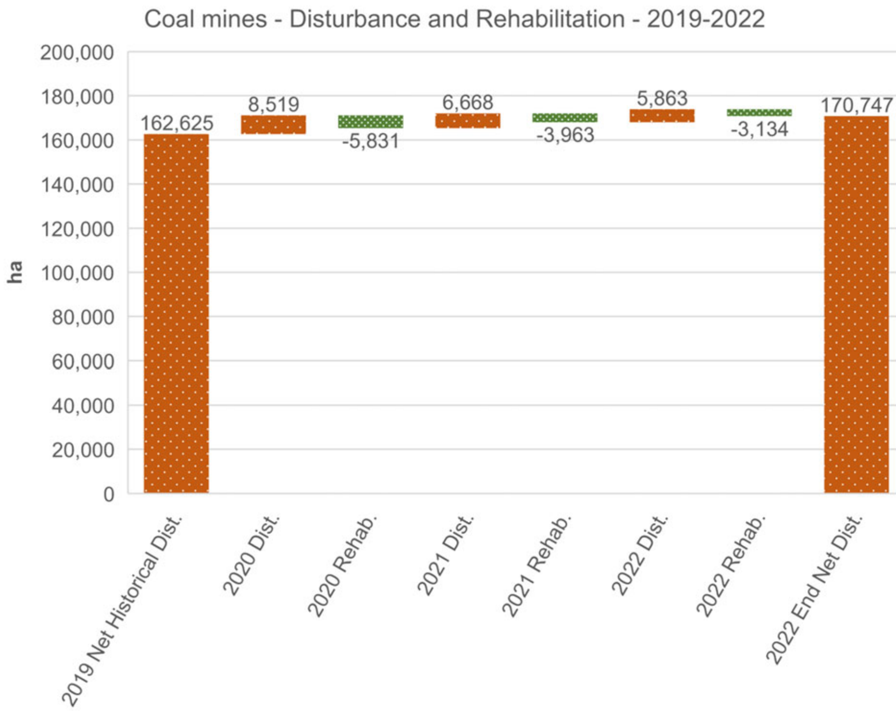

Figure 6. Progressive rehabilitation, including disturbance (Dist.) remaining after rehabilitation (Rehab.) for metallurgical and thermal coal mines in Queensland (Queensland Mine Rehabilitation Commissioner, 2023, p. 19).

economies. Demand for new economy minerals will lead to lower grades becoming commercial, more waste being removed to access these resources, tailings and other "wastes" being remined, and new mines opening, all with demands for energy.

Many mines in southern and central Queensland are located on freehold land, often owned by the companies themselves. These types of tenure arrangements make introduction of renewable energy during the operational life of the mines smoother as the subsequent landholder post-mining is the company itself (or often a subsidiary pastoral entity, ultimately owned by the mine operator).

The resources industry is and will continue to be a major contributor to the Queensland economy. Planned, orderly integration of new technological and economic development opportunities can provide transformation over time that supports regional economic development and sustainability.

Progressive rehabilitation and sustainable post-mining land use

Many jurisdictions around the world require progressive rehabilitation of mined lands, integration of rehabilitation into operations and mine planning, consideration of social aspects of rehabilitation and requirements that land be rehabilitated such that the land can sustain a post-mining land use (e.g. Kabir et al., 2015; Kung et al., 2020; Manero et al., 2021). Progressive rehabilitation is particularly applicable to strip mining operations, such as open cut coal, shallow bauxite, phosphate and other bulk commodities, and mineral sands operations. As the working face of the mine progresses across the landscape, disturbed lands trailing that open face can be progressively rehabilitated during mine life.

The surface area of disturbed mined land in Queensland presents a considerable opportunity for the development of renewables. The mined land disturbance footprint in Queensland is dominated by the coal sector (80%), and therefore data from this sector was selected to evaluate this opportunity. To do so, disturbance and rehabilitation data for 88 mines (around 50 operating mines and a variety of proposed mines, mines in care and maintenance and related infrastructure authorities) with environmental authorities (i.e. environmental licences) for extracting metallurgical and thermal coal in Queensland is presented here (Queensland Mine Rehabilitation Commissioner, 2023). Figure 6 shows the cumulative disturbance and rehabilitation data provided by companies in their annual returns to the end of calendar year 2022. Both open cut and underground operations are included, as some mines have a combination of methods operating simultaneously.

Figure 6 shows that net disturbance (Dist.) remaining after rehabilitation (Rehab.) between 2019[1] and 2022 has increased by 8,122 ha to 170,747 ha. "Rehabilitation" is measured as the sum of certified rehabilitation and rehabilitation identified by companies as "completed" but not certified in the annual returns to the regulator. Total rehabilitation (historically to end of 2022) is 52,175 ha and total disturbance for the same period is 222,922 ha.

With over 50,000 ha already rehabilitated to some extent and more to come, the opportunity for these lands to play an important role in hosting renewable energy generation becomes apparent. In strip mines, as land is rehabilitated to a safe, geotechnically stable landform, renewable energy infrastructure can be incrementally introduced. In Queensland, the most prevalent nominated post-mining land use is "grazing." The rehabilitation to a stable, grassed landform lends itself to installation of utility-scale solar. With forward planning, the landform shaping programme can also maximise the solar budget by aligning aspect and slope to optimise future solar energy generation.

Many Queensland coal mines use electric draglines for removal of overburden. As such, significant investment in electricity transmission infrastructure is in place, serviced by grid-connected supply. With modification, intermittent renewable supply

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"behind-the-meter" can be introduced incrementally. At the conclusion of mining operations, those "green" electrons can then be directed into the wider grid.

A more common practice at present is for mining companies to simply enter into a power purchase agreement with a generator and purchase renewable energy. This reduces the burden of coordinating a new activity onto operational sites and allows miners to stick to their core business. However, the generator in turn must source and locate renewable projects, often into agricultural lands, or lands requiring the clearing of remnant vegetation. If barriers to on-site renewables as part of progressive rehabilitation can be reduced, renewables as part of progressive rehabilitation can greatly assist in decarbonisation of operations and provide an ongoing economic life after mining ceases.

Reducing land use conflict

As at 31 December 2022, the Queensland coal industry reported a total area of disturbed land of over 170,000 hectares (see Figure 6), and the entire mining industry (exclusive of petroleum tenements) around 213,000 ha (Queensland Mine Rehabilitation Commissioner, 2023). The total area of mining leases is larger again, as not all land on any lease is necessarily disturbed by mining. Although relatively small in footprint compared to agriculture, the use of mine sites for renewables during progressive rehabilitation and at end of mine life, potentially avoids a raft of land use conflicts that have already arisen with the current growth in the renewable energy sector and agricultural interests globally (e.g Akita et al., 2020; Ketzer, 2020; McBain et al., 2021). Using rehabilitated mine lands also avoids further clearing of remnant vegetation, another source of community conflict historically (England, 2018). This is especially attractive where mining companies own the underlying freehold title.

Queensland's resources industry presents strategic opportunities to host renewable energy infrastructure. At least two of the four mine mouth power stations are well suited to renewables being a large part of the post-mining land use, where progressive rehabilitation of the adjacent thermal coal mines could leverage the substantial transmission infrastructure at the power stations and skills base of the local workforce. Energy generators are already committed to installing network-scale batteries at a number of these sites to provide not only energy to the grid but also system stability services, reinforcing their utility as enduring "energy precincts" long after coal ceases to be the primary fuel source.

In a study commissioned by the Queensland Resources Council (Worden et al., 2021), both the Bowen and Surat/Moreton basins were identified as suitable for solar projects. The study identified 9,000 ha of mine lands within 1 kilometre of high-voltage transmission lines and 50,000 ha within 2 kms (pp. 66, 71).

If the projected demand for renewable energy forecast from industrial load growth and the onset of the hydrogen industry are to come to fruition, available land and its optimal use will become limiting factors. An integrated approach from all levels of government that facilitates the use of land impacted by mining can be a significant contributor to the overall growth of the sector while sustaining its licence to operate in regional communities.

Queensland legislation, similar to many jurisdictions in OECD and other countries, requires mined land to be rehabilitated to a stable level, suitable to sustain a post-mining land use. In Queensland, "stable" means safe, structurally stable and non-polluting. These are the necessary pre-conditions to then consider the land's post-mining use. Grazing land outcomes that meet all regulatory requirements for relinquishment, are then suitable for hosting renewables, either as standalone facilities or under co-production models with small livestock. Integrated mine planning can maximise aspect and rehabilitate lands to be amenable to renewables. Of course, there are mined areas that through their remote location and topography, will not be suitable.

Barriers

Incorporating renewables into progressive mine rehabilitation is not without challenges. Physical restrictions may arise from system protection from intermittent renewable generation into the mine, spoil types, final landform topography and maintenance of covers over wastes. Operational challenges may arise from mining safety regulations, interactions with mining operations such as dust generation, reworking of areas and transmission infrastructure being continually shifted as the working face in strip mining moves.

There are regulatory and "cultural" barriers to non-mining activities being progressively introduced onto operational mine sites. In Queensland, industrial manslaughter laws have been extended to the mining industry, long exempted from these statutes (*Mineral and Energy Resources and Other Legislation Amendment Act 2020 (Qld)).* While carve-outs and exemptions can be negotiated such that the safety locus of control can be re-allocated from the site senior executive to the safety lead on the carved-out project, the reputational risk of third parties conducting activities not within the locus of control of the site senior executive make the prospect understandably unappealing.

On face value, acquiring renewable energy via a simple power purchase agreement with an energy generator is a more straightforward decarbonisation strategy, but as discussed above, does not provide the full range of benefits to resources communities or companies. This approach may be a more commercially straightforward way to reduce Scope 1 and 2 emissions than introducing the complexity of a utility-scale solar project onto the mine. This barrier needs to be overcome. Power purchase agreements typically involve renewable projects distal to the affected community, may involve land use conflicts with agricultural or environmental interests (e.g. *Mirani Solar Farm Pty Ltd v Mackay Regional Council and Anor* [2018] QPEC 38) and miss the opportunity for enduring value post-mining that renewable energy production on site can bring.

Regulatory definitions of "mining" and the ability to amend approvals to allow non-mining activities also present challenges. Section 6A of the Mineral Resources Act 1989, defines a mine and identifies activities ancillary to the winning of mineral resources. Other uses on a mining tenure may be deemed incompatible with the form of mining tenure approved. Western Australia, for example, is introducing a new "diversification lease" to facilitate renewable energy projects on crown land leased historically for other uses, including mining (Department of Planning, Lands and Heritage, 2022). Major amendments to environmental authorities can open up those approvals to wider third-party appeals. Given the growing antipathy to fossil fuel-based mining, this can pose a risk to existing operations.

Conclusions

Rehabilitated mine lands offer many opportunities for regional communities. Five reasons for reassessing the role of rehabilitated lands for renewables have been presented – increasing demand for renewable energy, the global decarbonisation agenda, supporting regional mining economies in transition, as an important post-mining land use and the potential to reduce land use conflict. This can happen over a long period of time, allowing for a more orderly transition, and growth in renewable energy production that matches decarbonising and energy demand pathways, in the right locations and at the right time – with good planning and industry support.

As the construction of renewable energy projects grows to meet the escalating demand of the global decarbonisation agenda, more land is being consumed, leading to land use conflicts between the agricultural and conservation sectors and the renewable energy industry. Simultaneously, tens of thousands of hectares of mined land require progressive rehabilitation. Currently the commercial and regulatory settings managing mine rehabilitation and expansion of renewable energy projects are not aligned.

The use of utility-scale solar generation in Queensland thermal and metallurgical coal sectors has been used as the case in this paper. However, rehabilitated mine lands represent a universal opportunity to play a role in the decarbonisation agenda post-mining. Consideration of a new paradigm where rehabilitated mine lands in proximity to electrical transmission infrastructure are re-imagined as ideal settings for renewables growth, can substantially contribute to a sustainable transition to a less carbon-intensive world.

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Note

1 2019 figures reflect entire net disturbance up to 31 December 2019. Each subsequent year's values reflect disturbance and rehabilitation for that calendar year.

Connections references

Perlatti F and Gagen EJ (2024). What emerging technologies and innovations present opportunities for economic repurposing of mined land, assets, and waste materials? *Research Directions: Mine Closure and Transitions*. 1, e1, 1–2. https://doi.org/10.1017/mcl.2023.4

References

Akita N, Ohe Y, Araki S, Yokohari M, Terada T and Bolthouse J (2020) Managing conflicts with local communities over the introduction of renewable energy: The solar-rush experience in japan. *Land* **9**, 290.

Anglo American (2021) *Climate Change Report 2021*. Anglo American. Available at ~https://www.angloamerican.com/~/media/Files/A/Anglo-American-Group-v5/PLC/investors/annual-reporting/2022/climate-change-report-2021.pdf.

Australian Energy Market Operator (2021) *2021 Inputs, Assumptions and Scenarios Report*. **Australian Energy Market Operator**. Available at https://aemo.com.au/-/media/files/major-publications/isp/2021/2021-inputs-assumptions-and-scenarios-report.pdf?la=en.

Australian Energy Market Operator (2022) *2022 Integrated System Plan*. **Australian Energy Market Operator**. Available at https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en.

Australian Energy Market Operator (2023) *Appendix to the draft 2024 Integrated System Plan for the National Electirity Market (Appendix3)*. AEMO. Available at https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2023/draft-2024-isp-consultation/appendices/a3-renewable-energy-zones.pdf?la=en.

Australian Energy Market Operator (2024) *Draft Integrated System Plan 2024*. Available at https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2023/draft-2024-isp-consultation/draft-2024-isp.pdf.

Australian Energy Regulator (2024) Annual Generation Capacity and Peak Demand - NEM. Available at https://www.aer.gov.au/industry/registers/charts/annual-generation-capacity-and-peak-demand-nem.

Australian Government (2018) *Resources 2030 Taskforce: Australian Resources – Providing Prosperity for Future Generations*. Australian Government. Available at https://www.industry.gov.au/sites/default/files/September%202018/document/pdf/resources-2030-taskforce-report.pdf.

Bainton NA and Holcombe S (2018) *The Social Aspects of Mine Closure: A Global Literature Review*. Centre for Social Responsibility in Mining (CSRM), Sustainable Minerals Institute (SMI), The University of Queensland.

BHP (n.d.) *Our GHG emission reduction targets and goals*. Climate Change. Available at https://www.bhp.com/sustainability/climate-change (accessed 19 March 2024).

BHP (2021) *Climate Transition Action Plan 2021*. BHP. Available at https://www.bhp.com/-/media/documents/investors/annual-reports/2021/210914_bhpclimatetransitionactionplan2021.

Blackrock (2022) *Larry Fink's 2022 letter to CEO's: The Power of Capitalism*. Available at https://www.blackrock.com/corporate/investor-relations/larry-fink-ceo-letter.

Buckley C (2022) *Coming Soon to This Coal County: Solar, in a Big Way*. New York Times. Available at https://www.nytimes.com/2022/01/02/climate/coal-mines-solar-climate.html.

COAG Energy Council (2019) *Australia's National Hydrogen Strategy*. Commonwealth of Australia. Available at https://www.dcceew.gov.au/sites/default/files/documents/australias-national-hydrogen-strategy.pdf.

Delevinge L, Glazener W, Gregoir L and Henderson K (2020) *Climate Risk and Decarbonization: What Every Mining CEO Needs to Know*. McKinsey & Company. Available at ~https://www.mckinsey.com/$~$/media/McKinsey/BusinessFunctions/Sustainability/Our Insights/Climate risk and decarbonizationWhateveryminingCEOneedstoknow/Climate-risk-and-decarbonization-What-every-mining-CEO-needs-to-know.ashx.

Department of Planning, Lands and **Heritage WA** (2022) Exposure Draft. Proposed Policy Framework guiding the use of Diversification Leases on Crown land under the Land Administration Act 1997. Available at https://consultation.dplh.wa.gov.au/++preview++/land-use-management/diversification-lease-draft/supporting_documents/ProposedPolicyFrameworkGuidingtheuseofDiversificationLeasesonCrownlandunderLandAdAct1997.pdf.pdf.

Department of Resources (2022) *Queensland Resources Industry Development Plan*. Queensland Government. Available at https://www.resources.qld.gov.au/__data/assets/pdf_file/0005/1626647/qridp-web.pdf.

Eccles RG and Klimenko S (2019) The investor revolution. Harvard Business Review, *May-June*. https://hbr.org/2019/05/the-investor-revolution.

England P (2018) *All Stick and No Carrot – Why Landholders are Fuming about Changes to Queensland ' s Vegetation Management Act and How We Could have Done It Better* .... (pp. 1–4). Griffiith University Law School.

Environmental Defenders Office (2022) *EDO Assists Clients to Call Out Mining Giant Glencore for Potential Greenwashing*. Available at ~https://www.edo.org.au/2022/09/08/edo-assists-clients-to-call-out-mining-giant-glencore-for-potential-greenwashing/#:~:text=Glencore%20publicly%20claims%20to%20have,may%20amount%20to%20harmful%20greenwashing.

Fleming DA and Measham TG (2014) Local job multipliers of mining. *Resources Policy*, **41**(1), 9–15. https://doi.org/10.1016/j.resourpol.2014.02.005

Genex Power Ltd (2018) *Kidston Pumped Storage Hydro Project: Initial Advice Statement*. AECOM Australia Pty Ltd.

Geoscience Australia (n.d.) *Value of Australian Mineral Exports*. Available at https://www.ga.gov.au/digital-publication/aimr2020/value-of-australian-mineral-exports (accessed 15 January 2023).

Glencore PLC (2021) *Pathway to Net Zero 2021 Progress Report*. Available at https://www.glencore.com.

GlobalData (n.d.) *Decarbonization Progress in the Mining Sector*. Available at https://www.mining-technology.com/downloads/whitepapers/data/decarbonization-progress-in-the-mining-sector/.

Gluyas A (2021) Ethical investments surge past $1 trillion mark. Australian Financial Review, 2 September.

Kabir SMZ, Rabbi F and Chowdhury MB (2015) Mine closure planning and practice in Canada and Australia: A comparative review. *World Review of Business Research* **5**(3), 1–22.

Ketzer D (2020) Land use conflicts between agriculture and energy production: Systems approaches to allocate potentials for bioenergy and agrophotovoltaics. In *Dissertations in Physical Geography No. 4*. Stockholm University.

Kung A, Everingham J and Vivoda V (2020) *Social Aspects of Mine Closure: Governance & Regulation* (Issue March, pp. 1–42). Sustainable Minerals Institute, University of Queensland.

Manero A, Standish R and Young R (2021) Mine completion criteria defined by best-practice: A global meta-analysis and Western Australian case studies. *Journal of Environmental Management* **282**, 12. https://doi.org/10.1016/j.jenvman.2020.111912

McBain B, Lenzen M, Albrecht G and Wackernagel M (2021) Future transitions to a renewable stationary energy sector: Implications of the future ecological footprint and land use. In *Agroecological Footprints Management for Sustainable Food Systems*. Springer.

Minerals Council of Australia (2022) *2022-23 Pre-Budget Submission*. Available at https://minerals.org.au/wp-content/uploads/2022/12/MCA-pre-Budget-submission-2023-24-FINAL.pdf.

Peabody Energy Inc. (2023) *Environmental, Social and Governance Report*. Available at https://www.peabodyenergy.com/Peabody/media/MediaLibrary/2023_Peabody_ESG_Report.pdf.

Poruschi L, Fleming-Munoz D and Haslam-Mackenzie F (n.d.) *Identifying Future Economic Development Pathways for Mining Regions and Increasing Transition Capacity*. Available at https://crctime.com.au/macwp/wp-content/uploads/2023/07/Project-1.8-Identifying-future-economic-development-pathways-for-mining-regions-and-increasing-transition-capacity.pdf (accessed 23 April 2024).

Powerlink (n.d.) *Renewable Energy Zones*. 23 April 2024 https://www.powerlink.com.au/queensland-renewable-energy-zones (accessed 2 May 2024).

PWC (2022) *Mine 2022* (Issue June).

Queensland Department of Energy and Public Works (2022) *The Queensland Energy and Jobs Plan – Electricity Market and Economic Modelling Outcomes*. Queensland Government. Available at https://www.epw.qld.gov.au/__data/assets/pdf_file/0010/33130/queensland-energy-plan-electricity-market-and-economic-modelling.pdf.

Queensland Government (2021) *Queensland Sustainability Report (Issue October)*. Queensland Government. Available at https://s3.treasury.qld.gov.au/files/Queensland-Sustainability-Report-November-2021-1.pdf.

Queensland Government (2022) *Queensland Energy and Jobs Plan*. Queensland Government. Available at https://www.epw.qld.gov.au/__data/assets/pdf_file/0029/32987/queensland-energy-and-jobs-plan.pdf.

Queensland Government (2023) Business Queensland. Available at https://www.business.qld.gov.au/industries/mining-energy-water/energy/electricity/queensland/generation.

Queensland Mine Rehabilitation Commissioner (2023) *2022-23 Report*. Available at https://www.qmrc.qld.gov.au/__data/assets/pdf_file/0023/326570/qmrc-2022-23-annual-report.pdf.

Queensland Resources Council (2022) *Contribution to Queensland*. Available at https://www.qrc.org.au/contributiontoqueensland/.

Rio Tinto Australia (n.d.) *Rio Tinto to invest $600m in Pilbara renewable projects*. Available at ~https://www.mining-technology.com/news/rio-tinto-pilbara-renewable/#:~:text=Anglo-Australian, mining company Rio, the end of this decade (accessed 20 January 2023).

Saffron BD (2022) Converting an idle coal mine into a renewable energy complex. In *Proceedings of the International Conference on Mine Closure*, *1*, 1231–1236. https://doi.org/10.36487/ACG_repo/2215_91

Squadron Energy (2022) *Construction Begins on Australia's Largest Renewable Energy Project Clarke Creek To Help Meet Soaring Demand For Renewables*. Available at ~https://www.squadronenergy.com/news/2022/construction-begins-on-australias-largest-renewable-energy-project-clarke-creek-to-help-meet-soaring-demand-for-renewables/#:~:text=Clarke, Creek is the largest,nation%27s net-zero emissions targets.

The Department of State Development, Manufacturing, Infrastructure and Planning (2019) Kidston Pumped Storage Hydro project Coordinator-General's evaluation report on the impact assessment report. Available at 'https://eisdocs.dsdip.qld.gov.au/Kidston%20Pumped%20Storage%20Hydro%20Project/Coordinator-General's%20evaluation%20report/Coordinator-General%20evaluation%20report%20for%20K2H%20project.pdf.

The State of Queensland (Department of Energy and & Climate) (2024) *Queensland Renewable Energy Roadmap*. https://www.epw.qld.gov.au/__data/assets/pdf_file/0036/49599/REZ-roadmap.pdf.

Worden S, Côte C, Svobodova K, Arratia-Solar A, Everingham J, Asmussen P, Edraki M and Erskine P (2021) *Baseline Works for Mine Rehabilitation and Closure Collaboration Project*. Sustainable Minerals Institute, The University of Queensland: Brisbane, Australia.

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