**Decarbonising Copper Ore Processing in Australia with Hybrid Microgrids: The Role of Dispatch Strategy and Demand-Side Flexibility**

**Abstract**

The global shift to sustainable energy has increased the demand for copper, essential for renewable energy infrastructure due to its excellent electrical and thermal properties. As a major copper producer, Australia plays a key role in this transition. Decarbonising copper mining, especially the energy-intensive ore processing stage, requires innovative renewable solutions. This paper examines the optimisation of hybrid microgrids to reduce carbon emissions in Australian copper deposits. We develop a hybrid microgrid model, applied to all known Australian copper deposits, incorporating solar PV, wind turbines, diesel generators, and battery storage. Our model focuses on optimisations through dispatch strategies and demand-side flexibility. Results show that an optimal renewable energy penetration of 80% in hybrid microgrids achieves the lowest Levelized Cost of Electricity (LCOE) at about $0.32/kWh, reducing annual carbon emissions to around 10,000 tonnes. The study highlights the significant impact of dispatch strategies and demand-side flexibility on hybrid microgrid economics. This research provides valuable insights into the large-scale implementation of hybrid microgrids in mining regions, emphasising their economic and environmental benefits.

# 1. Introduction

The growing use of renewable energy sources like solar, wind, hydro, biomass, and geothermal highlights the global move towards sustainable energy. This shift is driven by the increasing costs and environmental issues linked to fossil fuels. This transition has significantly increased the demand for copper, especially as solar PV and wind systems heavily rely on copper for effective operation (Gilmore et al., 2022; Kim and Gould, 2021; Moreno-Leiva et al., 2020). Fig. 1 illustrates the use of critical minerals, including copper, across various clean energy technologies compared to traditional fossil fuels.

A graph of minerals used in selected clean energy technologies

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**Figure 1.** Critical minerals used in the traditional fossil fuels energy technologies and clean energy technologies (Kim and Gould, 2021).

Australia’s abundant renewable energy resources offer a promising opportunity to use solar PV and wind for decarbonising its mining sector (Huang et al., 2024; Strazzabosco et al., 2022). Hybrid microgrids, which combine multiple renewable energy sources, are increasingly seen as a viable solution for powering remote mining operations (Ellabban and Alassi, 2021; Igogo et al., 2021; Strazzabosco et al., 2022). These microgrids provide flexible and customisable energy solutions that support renewables and promote sustainability in mining practices (Ellabban and Alassi, 2021; Mirzaeva and Miller, 2022).

However, there has been no comprehensive study on optimising hybrid microgrids for decarbonising mineral processing across all Australian copper deposits. This paper aims to fill this gap by exploring the roles of dispatch strategy and demand-side flexibility in optimising hybrid microgrids to reduce carbon emissions in Australia's copper mining sector.

# 2. Methods

We began by collecting data on copper deposits and the load profile for copper ore processing in Australia. Data on 135 copper deposits was sourced from Geoscience Australia's critical minerals database (Champion et al., 2021). The load profile, derived from the Semi-Autogenous Ball Mill Crusher (SABC) comminution circuit, included specific power consumption for each component (Wang et al., 2013; Zhang, 2016). A hybrid microgrid model was then designed, integrating solar PV panels, wind turbines, diesel generators, lithium-ion battery storage, and power converters for the copper processing circuit. Simulations and optimisations were conducted at 135 copper deposits in two phases:

**Dispatch Strategy Optimisation**: We evaluated three energy dispatch strategies—Cycle Charging (CC), Load Following (LF), and Predictive Dispatch (PD). The CC strategy operates generators at full capacity with excess power charging batteries. The LF strategy meets only immediate demand, while the PD strategy forecasts demand and optimises battery use. This phase aimed to determine the most cost-effective strategy, focusing on LCOE, renewable penetration, and battery management.

**Demand-Side Flexibility Optimisation**: We introduced a deferrable load component (20% of total load) to allow consumption adjustments based on demand. This flexibility helps reduce the need for full-capacity operation and lowers installed capacity requirements. The goal was to enhance system efficiency and economic performance by aligning energy consumption with availability and minimising operational costs.

Figure 2 illustrates the techno-economic optimisation process for the hybrid microgrid system.

A diagram of a process

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**Figure 2.** Summary of the methods used in the optimisation process of the hybrid microgrid model.

# 3. Results

The results of the study show that the optimal renewable energy penetration rate for hybrid microgrids is around 80%. Analysis using the 2D histogram (Figure 3) demonstrates that the LCOE decreases as renewable energy penetration increases, reaching its lowest point at approximately 80% penetration. Beyond this threshold, the LCOE begins to rise due to the additional battery storage required. The data reveals that an 80% renewable energy penetration provides the lowest LCOE (~$0.32/kWh) and is the most frequently occurring optimal solution across all copper deposit locations.

The final optimised hybrid microgrids, following the optimisation of dispatch strategy and demand-side flexibility, show significant reductions in annual carbon emissions compared to baseline diesel generators. The primary histogram (Fig. 11, green) indicates that most hybrid microgrids achieve emissions around 10,000 tonnes of CO2 per year, significantly lower than the baseline of 55,025 tonnes. The median normalised carbon emission for hybrid microgrids is 0.11 kg-CO2/kWh, reflecting an 84% reduction compared to diesel generators. The inset histogram (blue) shows a peak reduction of 80-85% in emissions, aligning with the optimal 80% renewable energy penetration identified earlier. This range demonstrates substantial emission reductions across the majority of hybrid microgrids, though some variability suggests potential for further optimisation.

Among dispatch strategies, Predictive Dispatch (PD) proved the most effective in improving the economic performance of hybrid microgrids. Additionally, incorporating a deferrable load to enable demand-side flexibility further enhanced economic outcomes by allowing better alignment of energy consumption with production.

A green and white diagram

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**Figure 3.** The results of the final optimised hybrid microgrids simulated at all copper deposits across Australia. Where the x-axis represents the renewable energy penetration, the y-axis represents the LCOE, and the colour bar represents the number of copper deposits.

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**Figure 4.** Final optimised hybrid microgrids carbon emission profiles: The primary histogram (green) shows the annual carbon emissions from optimised hybrid microgrids across all Australian copper deposits. The inset (blue) shows the reduction in emissions compared to baseline diesel generators.

# 4. Conclusion

The study highlights the significant potential of optimised hybrid microgrids in reducing carbon emissions and lowering energy costs for copper ore processing in Australia. The optimal renewable energy penetration rate is around 80%, where hybrid microgrids achieve the lowest LCOE and significant emission reductions. The Predictive Dispatch strategy, combined with demand-side flexibility through deferrable loads, further enhances economic performance. These findings support the transition towards more sustainable and decarbonised copper mining operations, emphasising the need for continued optimisation and potential integration of additional low-carbon technologies to maximise benefits.

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