RENEWABLE ENERGY IN THE AUSTRALIAN MINING SECTOR

White paper

sunSHIFT

Australian Government
Australian Renewable Energy Agency

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All currencies are provided in Australian Dollars. Currency conversion rates were sourced from published Reserve Bank of Australia data.

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1. Industry overview

The mining sector accounts for roughly 10% of Australia's total energy use. Its energy is mainly supplied by diesel (41%), natural gas (33%), and grid electricity (21%). Energy is primarily consumed as electricity for beneficiation operations and as diesel for vehicles and machinery.

The Australian mining sector consumes roughly 500 petajoules per year, 10% of Australia's total energy use, and consumption has risen at 6.0% per annum over the last decade[1], driven primarily by increased mining volumes.

The mining sector derives most of its energy from diesel (41%), natural gas (33%), and grid electricity (22%), with the remainder supplied by a mixture of other refined fuels, coal, LPG, renewables, and biofuels[2]. The percentage contribution from diesel has fallen from 49% to 41% over the last decade and been largely replaced by natural gas and grid electricity, as infrastructure develops and oil prices continue to show volatility.

Mining energy intensity – the energy required per tonne of product – is a function of definitions[3], location, mining type, and processing type. Average energy intensity is estimated at 50.5kWh/tonne for coal, 10.7kWh/tonne for minerals, and 54.5kWh/tonne for metals, with the majority consumed in diesel equipment and comminution operations[4]. The energy intensity in metals, however, ranges from 13kWh/tonne for bauxite to 210kWh/tonne for gold, due largely to differences in on-site beneficiation operations. Energy for metals with low on-site beneficiation, such as bauxite and iron ore, is predominately consumed as diesel for plant involved in extraction and transport. Energy for metals with high on-site site beneficiation, such as copper and gold, is predominantly consumed as electricity[5].

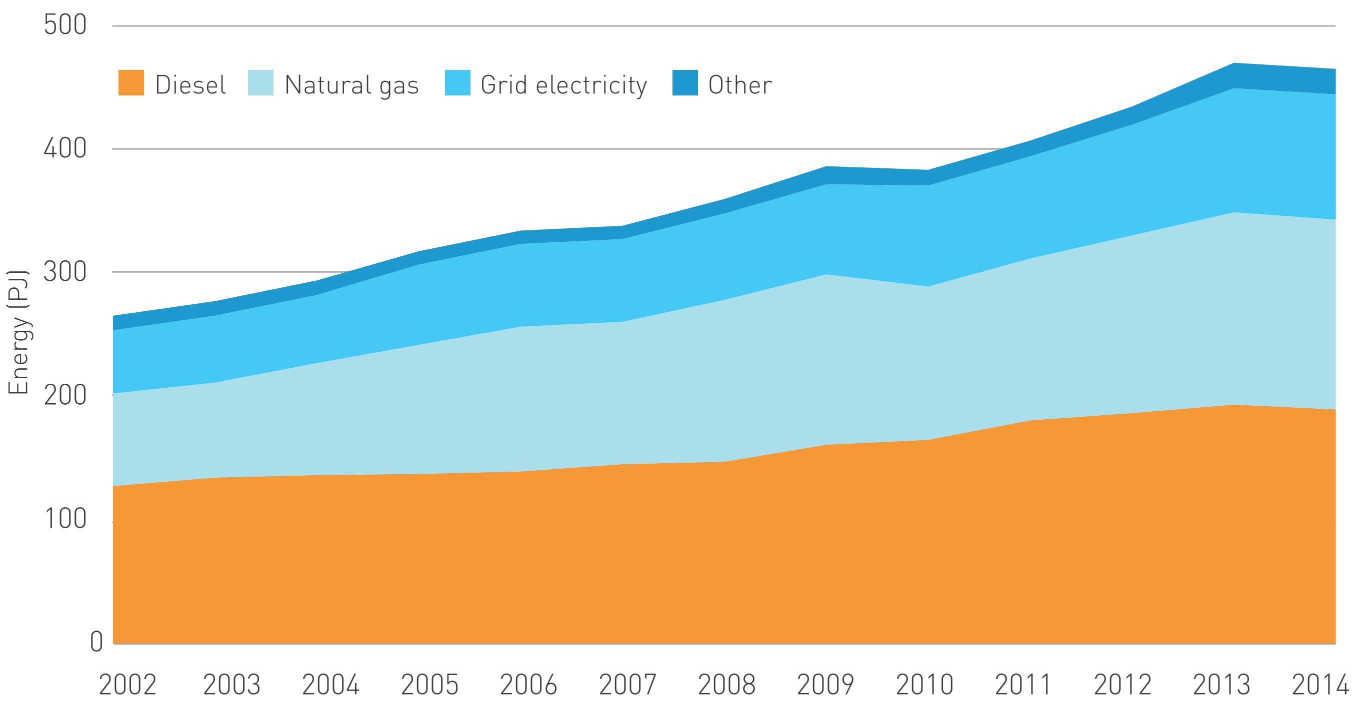

Figure 1: The Australian mining sector's energy consumption by source. 'Other' includes petrol, coal, LNG, renewables, and biofuels.

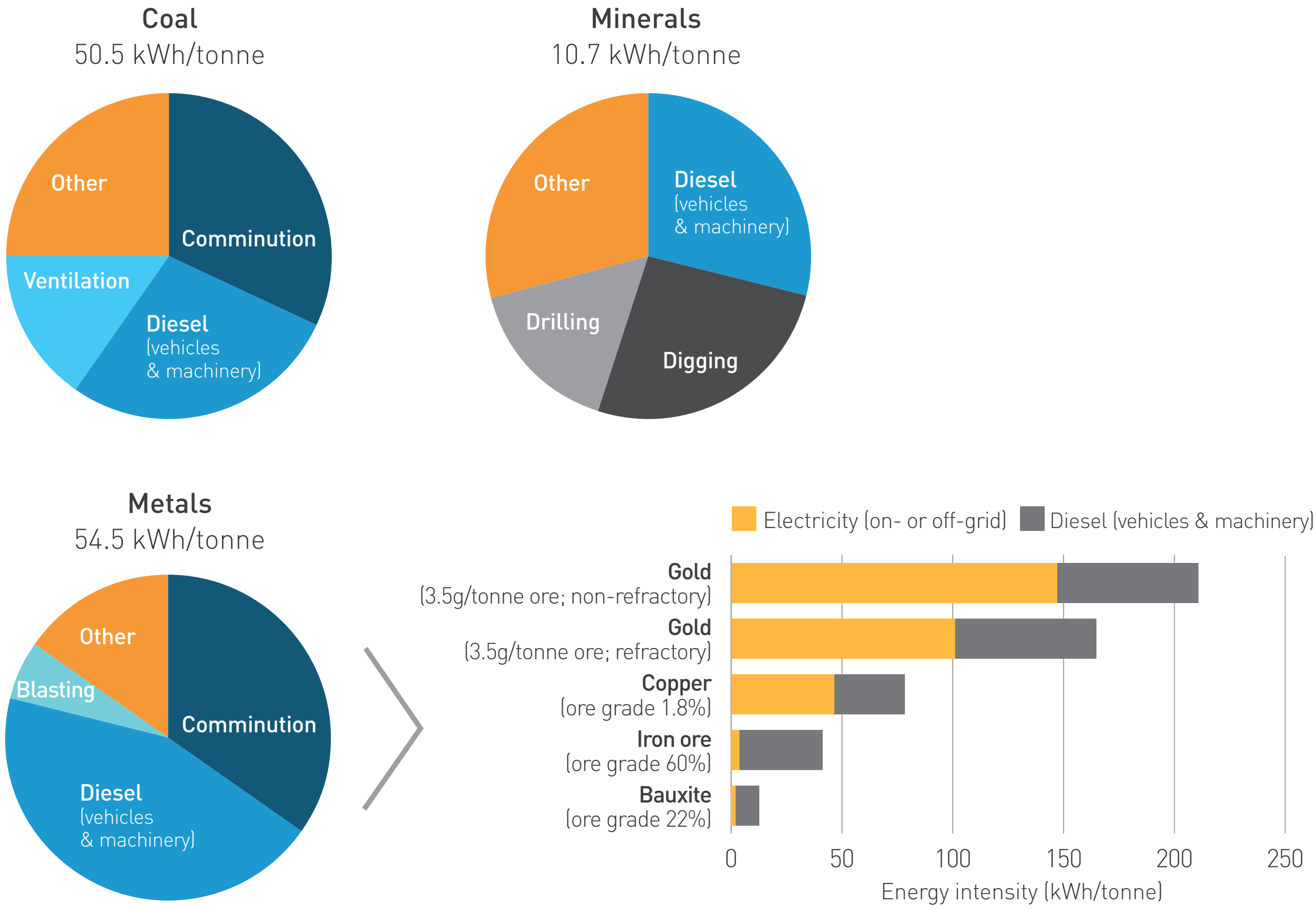

Figure 2: The estimated mining energy intensity and three most energy intensive operations for coal, metals, and minerals. The energy intensity in metals ranges from 13kWh/tonne to 210kWh/tonne, due to differences in on-site beneficiation operations. The energy for metals with low on-site site beneficiation (bauxite and iron ore) is primarily consumed as diesel in plant; the energy for metals with high on-site beneficiation (copper ore and gold ore) is primarily consumed as electricity.

The mining sector's long-term energy intensity is predicted to increase as the average ore grade falls and overburden increases – the average grade has halved and overburden doubled over the last 30 years[6].

The distinction between energy – the sum of plant diesel, electrictiy, explosives, etc. – and electricity is gradually disappearing with the development of electric equipment and batteries that allow diesel consumed in mining plant and logistics to be increasingly replaced with a combination of electricity generation and energy storage. This transition to an 'all electric' mine is expected to increase the relevative importance of electricty generation and storage in the mining sector.

The most economical source of electricity depends on a mine's proximity to electricity or gas infrastructure, life of mine, electrical demand, and mine production

1 Australian Government Department of Industry, Innovation and Science, 2016, Australian Energy Update 2016, Canberra, September.
2 Australian Bureau of Statistics, 2017, Energy Account Australia 2014-2015 (4604.0).
3 Government bodies and research bodies may include short- and long-distance materials transport, comminution, and other beneficiation processes as mining.
4 BCS Incorporated, 2007, Mining Industry Energy Bandwidth Study, U.S. Department of Energy Industrial Technologies Program. Estimates are based on data from the United States of America.
5 Norgate, T., N. Haque, 2010, Energy and greenhouse gas impacts of mining and mineral processing operations, Journal of Cleaner Production, 18, 266-274. Norgate, T., N. Haque, 2012, Using life cycle assessment to evaluate some environmental impacts of gold production, Journal of Cleaner Production, 29-30, 53-63.
6 Bye, A. R., 2011, Case Studies Demonstrating Value from Geometallurgy Initiatives, 1st AusIMM International Geometallurgy Conference (GeoMet 2011)

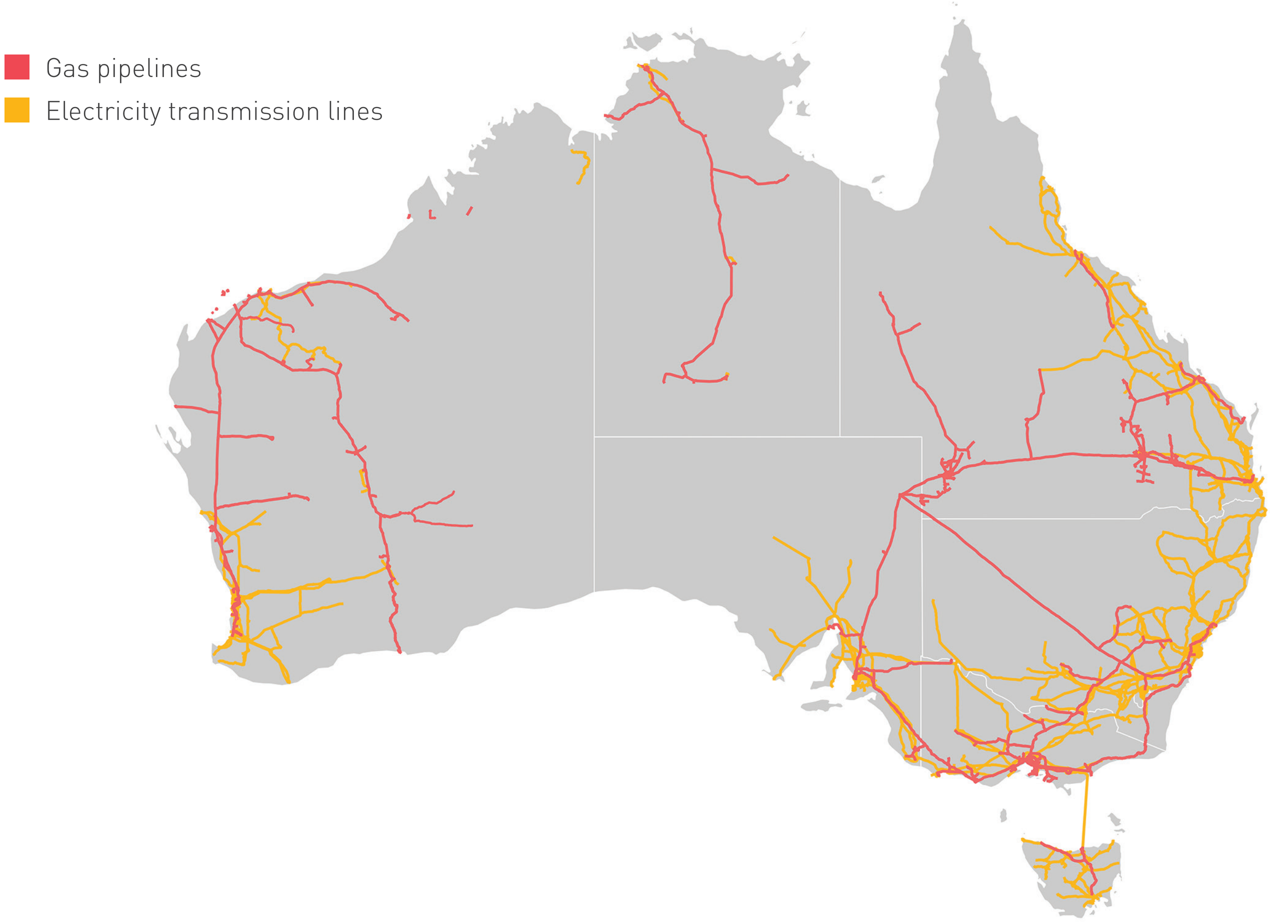

Figure 3: Australia's electricity transmission lines and onshore gas pipeline infrastructure[7].

schedule. The electricity price ranges from <$0.10/kWh for grid electricity, $0.10/kWh–$0.30/kWh for electricity derived from pipeline gas, and $0.15/kWh–$0.30/kWh (after rebates) for electricity derived from off-grid diesel or gas.

Mining operations with a high electricity demand and a long life can support the capital investment required to extend electrical or gas pipeline infrastructure. Remote locations and uncertainty favour the lower capital cost option of establishing self-contained, off-grid electrical generation and distribution infrastructure. Diesel is the historically favoured fuel source but natural gas (CNG or LNG) can also be cost competitive, depending on location.

Off-grid electricity generation and distribution assets are typically procured from Independent Power Providers (IPPs) on 5–10 year contracts as a combination of fixed monthly charge, variable charge (excluding fuel), and a fuel efficiency incentive mechanism. The fuel price is generally borne directly by the miner but the fuel efficiency incentives encourage IPPs to provide high efficiency equipment and operation. IPP procurement offers flexibility, alleviates capital constraints, and partially shifts electricity off the balance sheet, but the mine remains exposed to fuel price, which accounts for over 80% of the total electricity cost.

7 Transmission lines and gas pipeline data sourced from the Australian Government Geoscience Australia National Electricity Transmission Lines Database and National Onshore Gas Pipelines Database, respectively.

2. Fossil fuel electricity

Fossil fuel price volatility and logistics have a significant impact on mining viability but are outside the control of most miners. Industry and Government have acknowledged the risks and environmental impacts of fossil fuels and are supporting the adoption of renewable electricity and energy efficiency measures.

Electricity derived from fossil fuels is coming under increased pressure from economic, environmental, political, and social factors.

2.1 Price volatility

Fossil fuel price volatility has a significant impact on mining viability but is outside the control of most mining operations.

The Australian diesel terminal gate price is a function of global oil prices and has ranged from $0.40/L to $1.25/L (excluding GST and excise) over the last decade. Transportation costs around Australia depend on location and volume but typically add $0.15/L–$0.45/L to terminal gate prices. Domestic gas prices lack an Australian wholesale benchmark but can be linked to both oil prices and Asian gas benchmarks, particularly Japanese pricing, which has ranged from $9/GJ to $24/GJ over the last decade.

The diesel price volatility over the last decade has varied the energy cost component of metals mining, for

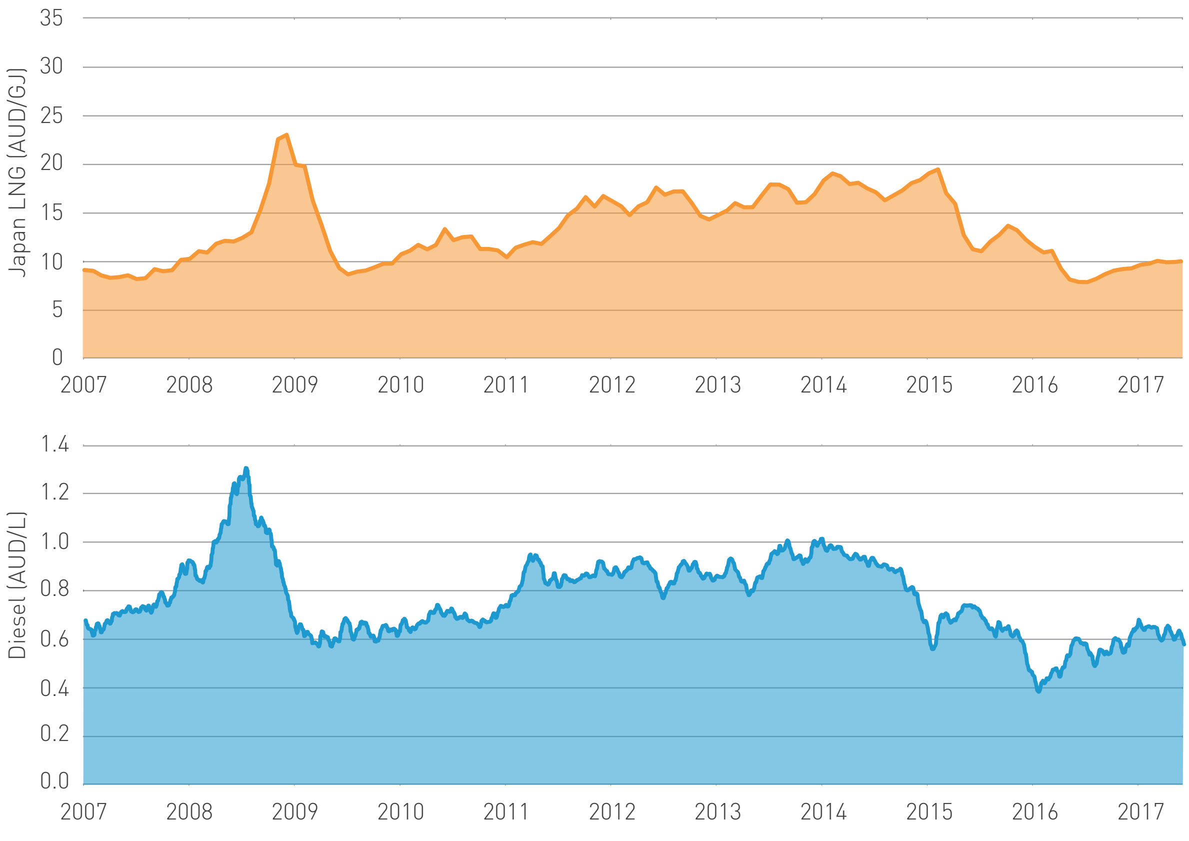

Figure 4: Historical Japanese LNG pricing (monthly) and Australian diesel terminal gate price (daily), excluding GST and excise. Diesel transportation typically adds $0.15/L–$0.45/L to diesel terminal gate prices.

example, from $5.54/tonne to $17.03/tonne. Diesel price increases in the last 12 months alone have added $2.77/tonne to the average cost of metals mining ($0.64/tonne for bauxite, $2.10/tonne for iron ore, $3.99/tonne for copper ore, and $10.73/tonne for gold ore)[8].

Current fuel prices are at near-decade lows. Hedging and fixed pricing are available to minimise the impact of future fuel price changes but these introduce additional costs and there is no consensus on future fuel price movements.

2.2 Availability and security

Fuel supply to mine sites without fixed pipeline infrastructure relies on heavy vehicle road transport – a fuel road train only provides sufficient energy to mine 7,900 tonnes of coal, 7,300 tonnes of metals, and 37,400 tonnes of minerals[9]. The logistical challenges to move large volumes of fuel are considerable and have implications for road infrastructure capital and operational costs, particularly in inclement weather. On-site storage tanks are also required to guarantee fuel security.

Oil fuel derivatives are also primarily sourced from international markets and expose operations to geopolitical energy security risks.

2.3 Environmental

The mining sector produces approximately 65,000 gigatonnes of CO_2-equivalent direct greenhouse gas emissions[10], 10% of Australia's total[11], and is a significant contributor to fugitive emissions – gases that escape from coal mines and oil wells – that are estimated to increase country-wide emissions by 7%[12]. Mining also significantly contributes to airborne particulate pollution[13], both from dust generation and fossil fuel use in vehicles and electricity generation.

2.4 Social and political

Climate change concerns are reducing the social and political acceptance of fossil fuels.

Global trends

The number of countries with policies supporting renewable energy has risen from 43 to 146 in the last decade, covering 73% of all countries and all major emitters[14].

In December 2015, the 195 participant nations at the United Nations Climate Change Conference in Paris drafted the Paris Agreement[15] with the aim to "strengthen the global response to the threat of climate change". Implementation involves:

(a) "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and,

(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development."

This places considerable pressure on entities engaging in activities that directly and indirectly result in the emission of greenhouse gases to consider low- or zero-emission practices.

Local landscape

The Australian Government is committed to reducing carbon emissions and to support the transition to cleaner energy sources. Key Government schemes include:

- Emissions Reduction Fund (ERF) – the ERF is a $2.5bn fund that incentivises emissions reductions by allowing industry to sell carbon abatement back to the Government. The Safeguard Mechanism ensures that carbon abatements sold to the Government are not offset elsewhere in the economy.

8 Energy costs are based on the cited mining energy intensity data and assume off-grid operations using diesel at terminal gate prices (without transport) for all energy (electricity generation and vehicles), with a diesel conversion efficiency of 0.25L/kWh.
9 Assuming a 100,000L road train with an average diesel conversion efficiency of 0.25L/kWh.
10 This underestimates the mining sector's true emissions because grid energy, accounting for 21% of total energy use, is recorded under electricity generation.
11 Australian Bureau of Statistics, 2016, Australian Environmental-Economic Accounts (4655.0).
12 Australian Bureau of Statistics, 2013, Towards the Australian Environmental-Economic Accounts (4655.0.55.002).
13 McIvor, A., 2010, Mining and Energy, Cleantech Magazine, September/October, 16-19.
14 REN21, 2016, Renewables 2016 Global Status Report, Paris, ISBN 978-3-9818107-0-7
15 United Nations Framework Convention on Climate Change, 2015, Paris Agreement (Article 2).

- Large-scale Renewable Energy Target (LRET) – the LRET ensures that 33,000GWh per year is generated from renewable sources by 2020.
- Australian Renewable Energy Agency (ARENA) and Clean Energy Finance Corporation (CEFC) – ARENA and CEFC are funding and investing bodies to support the development and deployment of clean energy technology.

Mining industry

The mining industry has acknowledged the impact of fossil fuels and climate change. Organisations including International Council on Mining and Metals (ICCM), World Coal Association, IEA Coal Industry Advisory Board, South African Chamber of Mines, Ferro Alloys Producers Association, Minerals Council of Australia, and Mining Association of Canada support measures to reduce emissions and increase the use of renewable energy sources.

ICMM's published position states: "Climate change is an undeniable and critical global challenge, and its causes must be addressed by all parts of society. ICMM member companies are committed to being part of the solution." "We support greater use of renewable energy and other cost effective low-emission technologies, and improved energy efficiency, including in our own operations."[16]

16 International Council on Mining & Metals (ICMM), 2015, ICMM Statement on Climate Change.

3. Fossil fuel displacement with renewable electricity

Wind and solar PV are mature technologies that reduce a mine's electricity costs and reliance on fossil fuels. Automated hybrid energy systems ensure a reliable and low-cost electricity supply at all times. Developments in energy storage are predicted to allow significant additional reductions in fossil fuel use within five years.

3.1 Sources and cost

Renewable electricity sources are available to reduce the reliance on fossil fuels in electricity generation applications. This reduction is called fuel offset or fuel displacement.

The key economic metrics are levelised cost of electricity (LCOE) – the sum of lifetime costs divided by the total electricity produced over its lifetime[17] – and capital cost.

Renewable sources are now generally competitive with fossil fuels on an unsubsidised LCOE and capital cost basis[18]. On-grid large-scale solar PV and wind are the lowest cost electricity sources on a LCOE basis (<$80/MWh) and their capital costs are becoming competitive with diesel or gas generators, with further decreases anticipated – PV module costs have fallen 80% since 2008 and onshore wind costs have fallen by 50% since 2009[19]. The combination of low LCOE and comparable capital cost is making wind and solar PV increasingly attractive in short-term economic metrics.

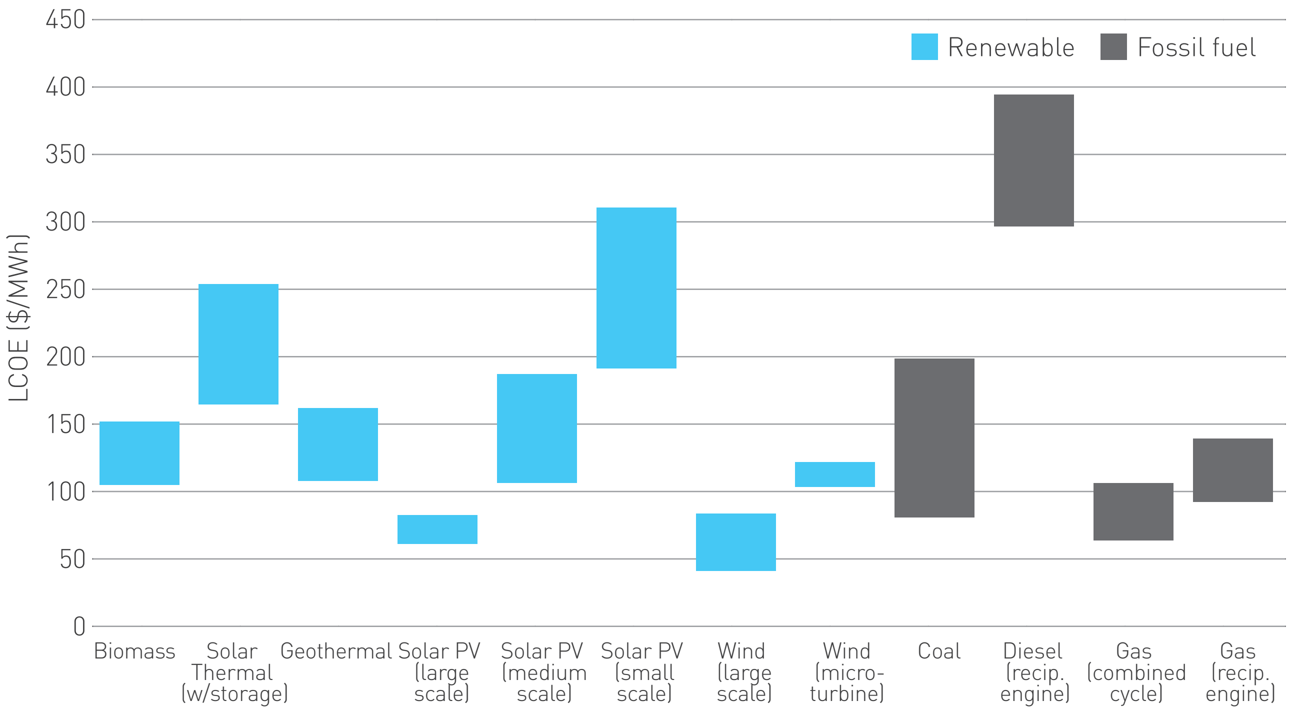

Figure 5: The current unsubsidised levelised cost of electricity (LCOE) from fossil fuel and renewable sources. Adapted from Lazard[18].

17 The industry standard asset life assumptions are 20, 25, and 30 years for small-, medium-, and large-scale solar PV; 35 years for solar thermal; 25 years for geothermal and biomass; 20 years for wind; 20 years for diesel and gas generators; and 40 years for coal and IGCC.
18 Lazard, 2016, Levelized cost of energy analysis – version 10.0.
19 Liebreich, M., 2016, Bloomberg New Energy Finance Summit – In search of the miraculous, 5/4/2016.

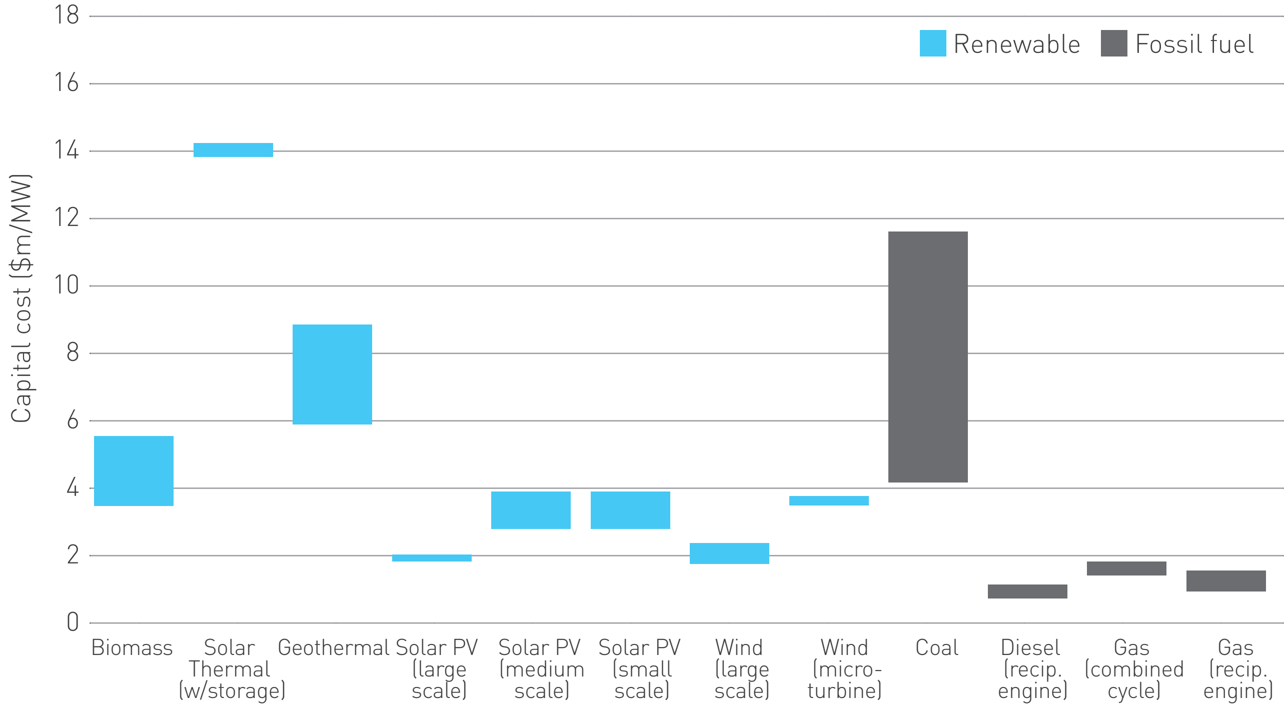

Figure 6: The current capital cost of fossil fuel and renewable sources. Adapted from Lazard[18].

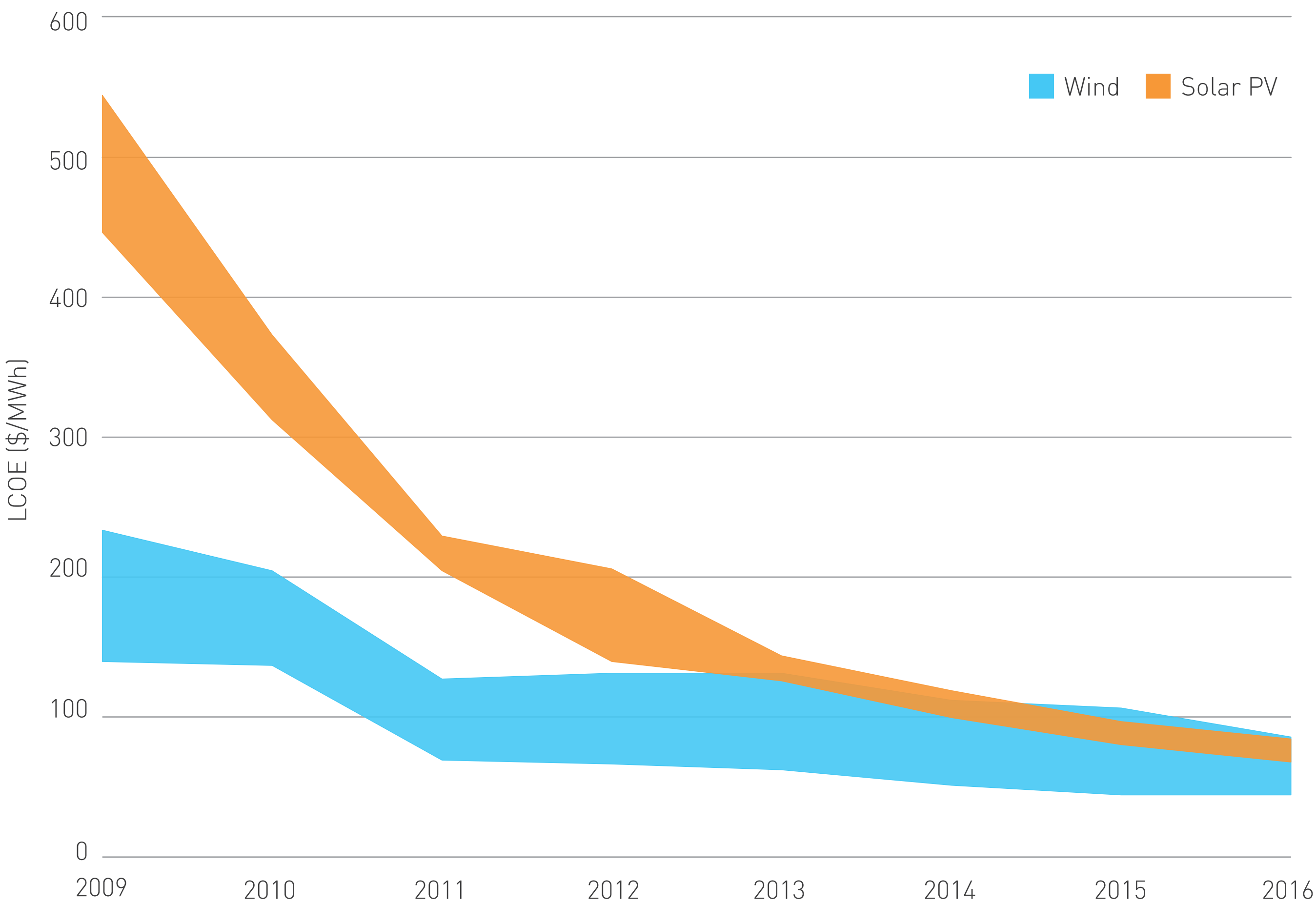

Figure 7: The historical unsubsidised levelised cost of electricity (LCOE) for large-scale wind and large-scale solar PV. Adapted from Lazard[18].

3.2 Energy reliability

Wind and solar PV are intermittent electricity sources. Hybrid systems overcome this limitation and ensure a reliable electricity supply by combining renewable sources with fossil fuel based generation.

Automated hybrid control systems minimise electricity costs by maximising the use of low-cost renewable electricity and supplementing with fossil fuel sources, retaining sufficient 'spinning reserve' to handle any sudden changes in renewable output and demand. In most cases a hybrid system can be retrofitted to existing fossil fuel energy solutions.

Large-scale hybrid systems are gaining traction in the mining sector. Recently installed systems in Australia and Canada combine diesel with solar PV or wind, with capacities up to 47MW diesel/9.2MW wind and 19MW diesel/10MW solar PV.

Table 1: Recent large-scale hybrid systems in the global mining sector.

				Fossil fuel		Alternative energy		
Project	Location	Company	Year	Type	Capacity (MW)	Type	Capacity (MW)	Energy storage (MW/MWh)
DeGrussa	WA, Australia	Sandfire Resources	2016	Diesel	19	Solar PV	10	4/1.8
Weipa	QLD, Australia	Rio Tinto	2015	Diesel	26	Solar PV	1.2	-
Raglan	Quebec, Canada	Glencore	2014	Diesel	21.6	Wind	3	0.6/4.3
Diavik	Northwest Territories, Canada	Diavik Diamond Mines	2012	Diesel	46.8	Wind	9.2	-

3.3 Renewable electricity output

Renewable electricity output can be defined by its maximum instantaneous contribution, known as power penetration, or its average fossil fuel displacement over a period, know as the energy contribution.

The commercially optimal power penetration is primarily a function of fuel cost, technology cost, load characteristics, and site resources.

A solar PV system capable of supplying up to 50% of total electrical demand, for example, has a power penetration of 50%. Grid stabilisation technologies allow the power penetration to reach and even exceed 100%, to completely offset midday fossil fuel use. This excess is curtailed[20] or directed to bulk energy storage for later use. Complete fossil fuel displacement has been demonstrated on King Island, Tasmania, Australia, which operates a microgrid of 6MW wind, 0.5MW solar PV, and 3MW/1.6MWh energy storage, enabling the diesel generator to be turned off for significant periods.

20 Curtailment in the renewable energy industry refers to dumping 'excess' energy to ground.

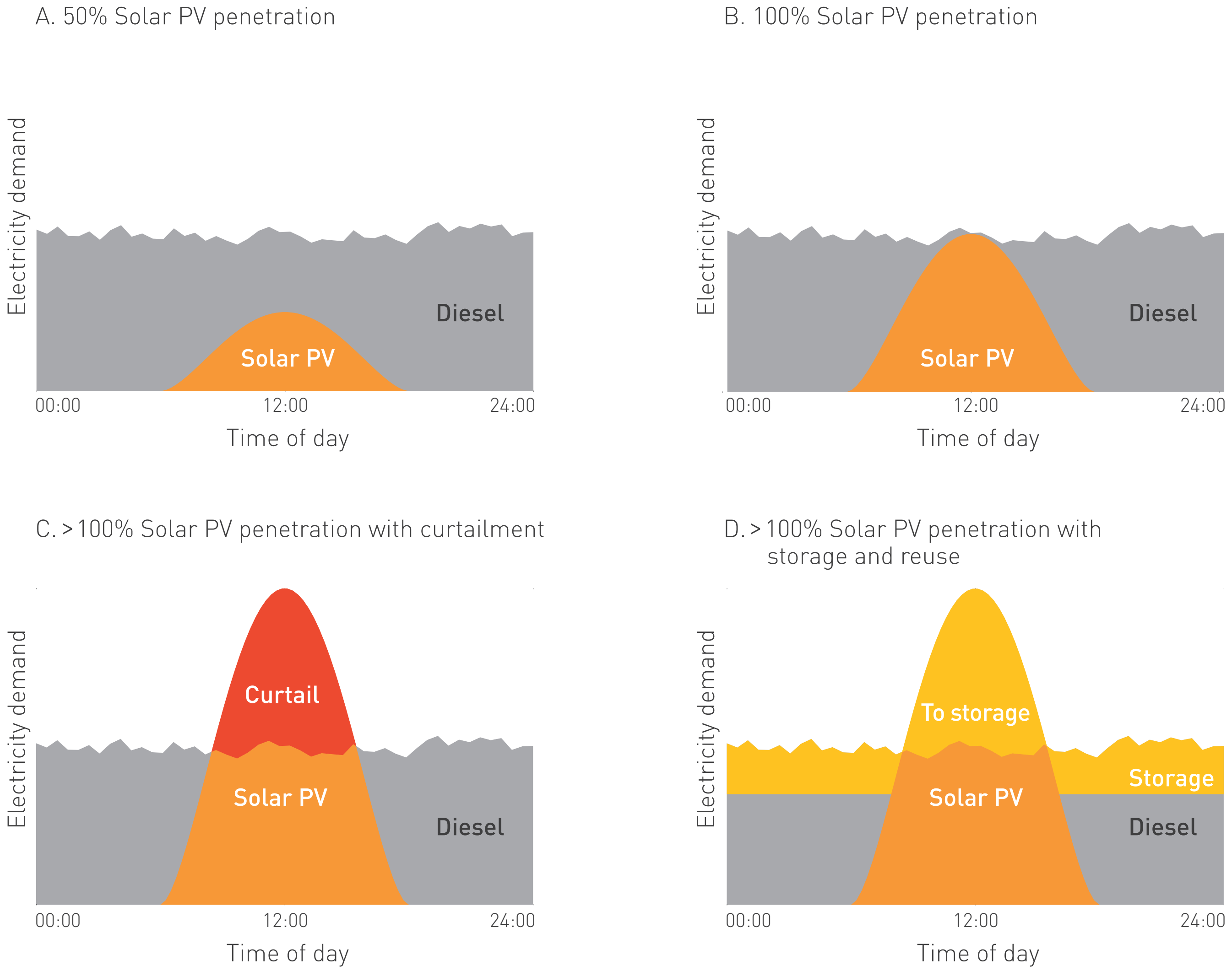

Figure 8: Potential solar PV energy penetration: a) solar PV offsetting 50% of midday load; b) solar PV offsetting 100% of the midday load; c) solar PV providing >100% midday load to increase the total solar PV contribution, with the excess curtailed; d) solar PV 'excess' stored and used to offset night-time load.

Energy storage in renewable applications can refer to two different functions.

- Power response provides 'spinning reserve' for sudden increases in demand or temporary drops in renewable output – a cloud passing over a solar PV farm, for example – and allows fossil fuel generators to maintain a stable or smoothed output. This allows generators to operate at peak efficiency for longer, increasing fuel efficiency and asset life. Power response is provided by high cycling, relatively small energy capacity systems, such as lithium-ion power batteries and small flywheels. The current levelised cost of storage (LCOS) for power response technologies is $500/MWh–$700/MWh[21].
- Energy shifting captures 'excess' renewable electricity and stores it for later use. This bulk energy storage is provided by low cycling, large capacity systems, such as flow batteries, large flywheels, and chemical batteries. The current LCOS for energy shifting technologies is $850/MWh–$1750/MWh[21].

Energy storage is currently only economically viable for some power response applications and is generally uncompetitive with fossil fuels for most energy shifting applications. However, the global uptake of renewables and electric vehicles has led to significant research and development in the energy storage field. Capital costs are forecast to fall by around 25%–50% over the next 5 years for most technologies, thanks to increased manufacturing scale, a reduction in material costs, and design and chemistry improvements[22]. The combination of <$80/MWh renewable electricity and <$500/MWh energy shifting will allow the displacement of fossil fuel generators without introducing any economic penalty or reliability risk.

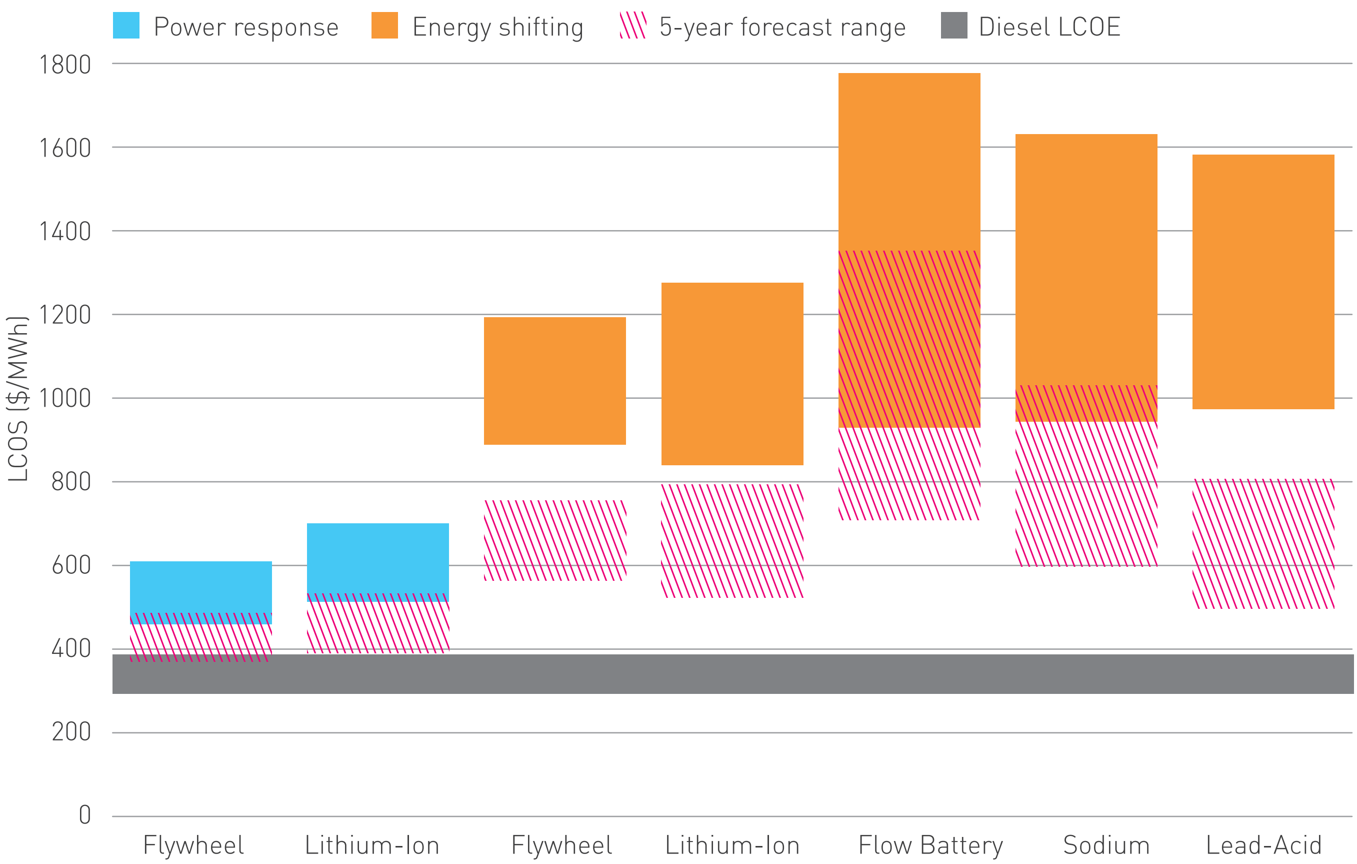

Figure 9: Current and forecast unsubsidised levelised cost of storage (LCOS) for major battery technologies compared to the unsubsidised levelised cost of electricity (LCOE) for diesel. Adapted from Lazard[21].

21 Lazard, 2016, Levelized cost of storage analysis – version 2.0.
22 Ibid.

4. Adopting renewable electricity

Solar PV has some practical advantages over wind in mining applications but the adoption is currently limited by technical and commercial considerations.

4.1 Selecting a suitable technology

Large-scale solar PV and wind are currently economically viable and technically mature solutions to reduce a mine's reliance on fossil fuels for electricity generation.

Despite the comparable LCOE, capital costs, and output limitations, solar PV has some practical advantages over wind for mining applications.

	Solar PV	Wind
Planning data	Accurate and reliable satellite-derived solar data readily available.	>18 months site-specific wind data required.
Availability	'Excellent' resource widely available[23].	'Excellent' resource predominantly concentrated in southern and coastal regions[24] and much of this has already been developed.
Output	Daytime generation only.	All day generation.
Approvals (planning and environmental)	<12 months.	>18 months.
Capital costs	Low-medium.	Low.
Operating costs	Low.	Low–medium.

23 Solar availability data sourced from the Australian Government Bureau of Meteorology Average daily solar exposure dataset.
24 Wind availability data sourced from the CSIRO DATA61 Mesoscale Wind Atlas Data dataset. Wind maps at a height of 100m were used for wind availability estimation.

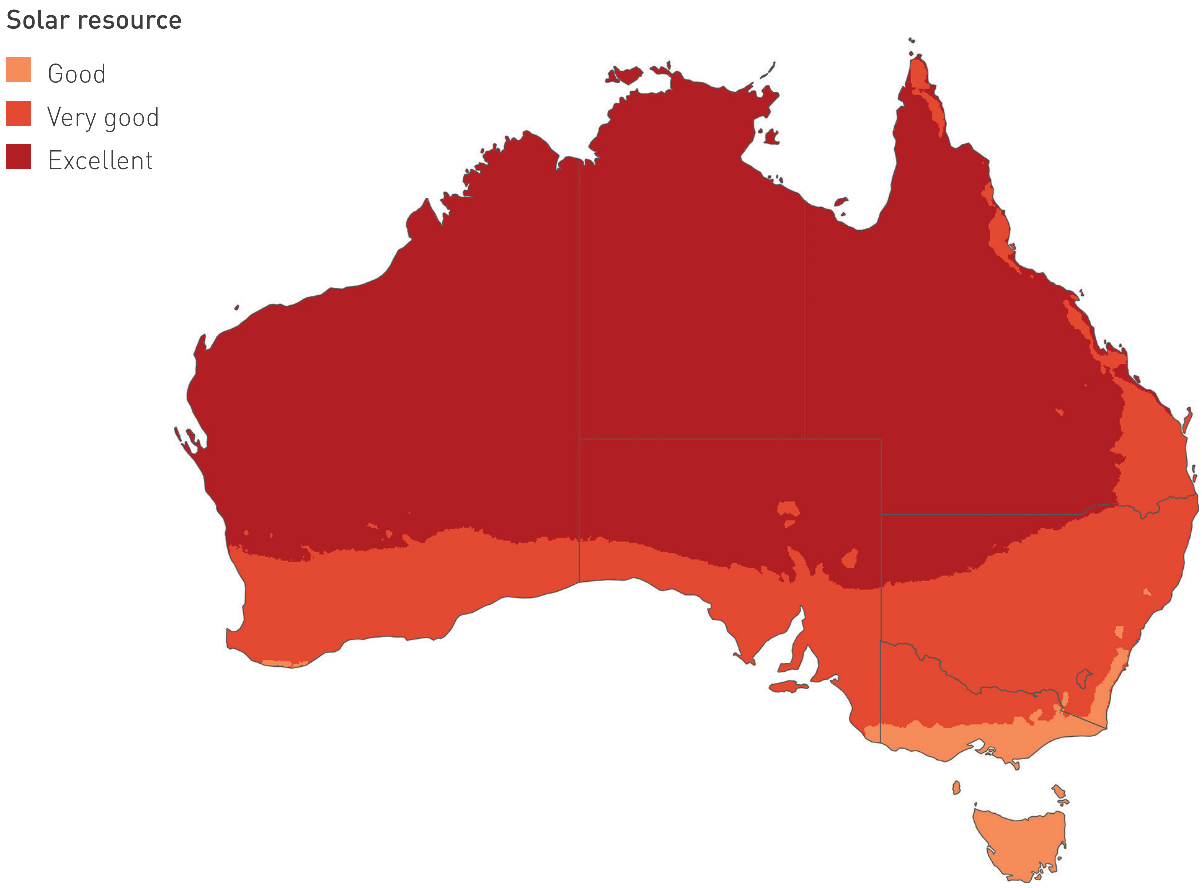

Figure 10: Solar availability. Good 1,200–1,600MWh/m^2, very good 1,600–2,000MWh/m^2, and excellent 2,000–2,400MWh/m^2.

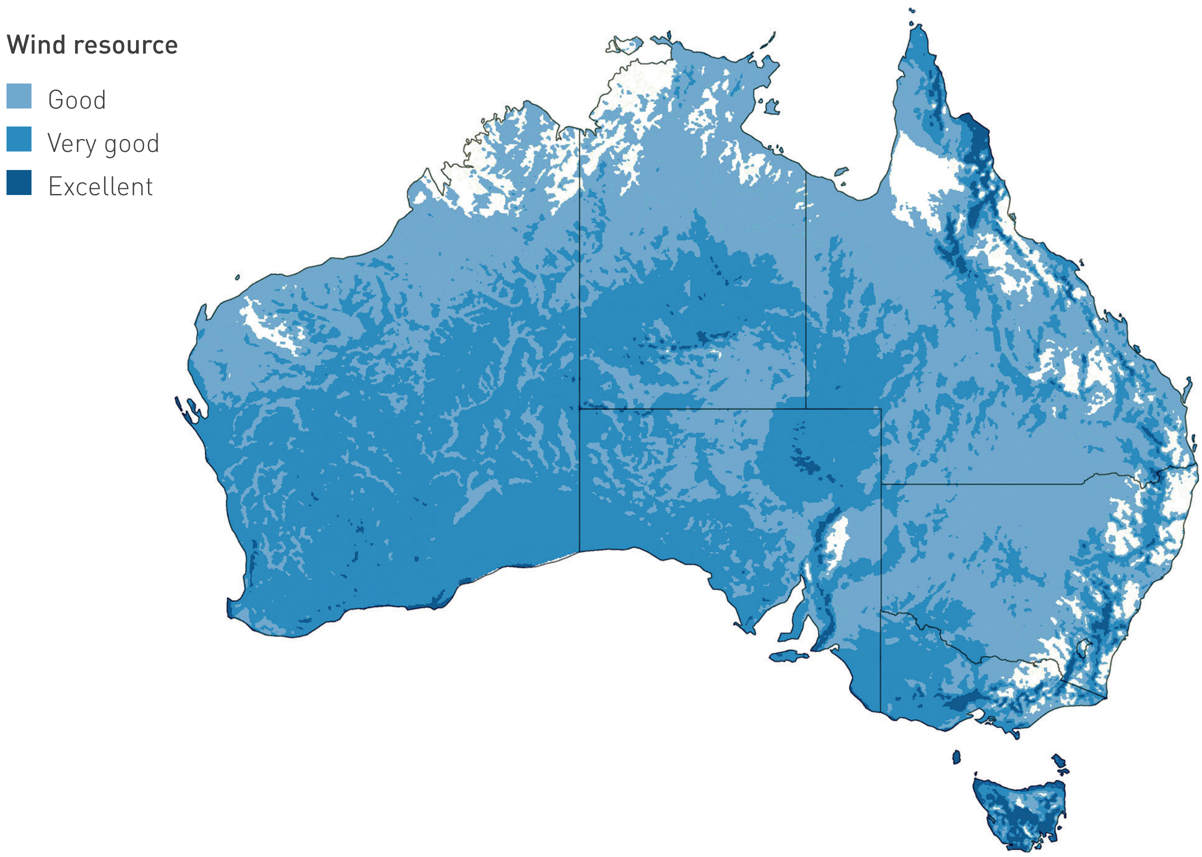

Figure 11: Wind availability. Good 6–7m/s, very good 7–8m/s, and excellent 8–9m/s. (Wind speed measured at 100m)

4.2 Limitations of renewable electricity in the mining sector

Several factors have, to date, prevented the mining sector from more widely adopting renewable electricity solutions.

- **A mismatch between contract duration and asset life.** Operational flexibility and mine life uncertainty considerations drive 5–10 year electricity contracts. These durations strongly favour traditional fossil fuel electricity sources, despite a higher LCOE. Fossil fuel generators have an asset life of 20 years for LCOE calculations but the life is comprised of multiple rebuild phases. A generator is generally amortised over a typical contract, and subsequent decisions to write off or 'reseed' the asset do not impact the LCOE or economic viability of the initial deployment. Asset 'reseeding' can occur multiple times and in multiple locations because generators are modular and mobile. In contrast, traditional solar PV assets are amortised over a true 30-year period but relocation is not economically viable because the disassembly, transport, and reassembly costs approach the initial capital cost of the entire asset. The risk of a 'stranded' solar PV asset with negligible residual value forces the capital cost, which constitutes most the lifetime cost, to be completely amortised over the first energy off-take duration. The impact on LCOE is considerable and illustrated by electricity pricing in recent large-scale off-grid solar PV systems: ~$380/MWh for a 6-year agreement, ~$270/MWh for a 15-year agreement, and <$100/MWh for a 30-year off-take agreement.
- **Operating lease vs capital lease.** Fossil fuel generator assets are currently recognised by offtakers as operating leases. In contrast, conventional renewable electricity assets may require capitalisation on the balance sheet because the underlying asset is fixed and has negligible value at the end of the first offtake contract. Impending changes to accounting rules (see IFRS16) may recognise both as capital leases but conventional renewables remain at a disadvantage because 1) the fossil fuel is provided by the offtaker and therefore does not factor in the present value of the lease obligation being capitalised and 2) balance sheet implications can be reduced with shorter power purchase agreements.
- **Technical integration.** Hybridisation technology and understanding has rapidly matured but most offtakers have no firsthand experience and are reticent to adopt a new technology in critical systems. A staged approach to de-risk the adoption of renewable electricity is therefore required by the mining community.
- **Commercial integration**. A single point of accountability for electricity is a requirement for most operations. Renewable solutions must therefore commercially integrate through incumbent electricity providers and associated contracts or offer a complete hybrid energy solution aligned to procurement cycles.

5. SunSHIFT

SunSHIFT is designed to overcome the limitations of traditional solar PV and enable the mining sector to adopt renewable electricity.

SunSHIFT is a pre-engineered, pre-fabricated, modular, and moveable turnkey solar PV solution, specifically designed to overcome the limitations of traditional solar PV and enable the mining sector to adopt renewable electricity.

SunSHIFT was developed by global construction and engineering company Laing O'Rourke, in collaboration with partners SunPower and ABB, and supported by the Australian Renewable Energy Agency (ARENA).

SunSHIFT is designed to be moveable, which allows the asset life to be decoupled from the first offtake agreement and achieve a LCOE closer to the cited 30-year figures. This allows miners to enjoy the benefits of low-cost solar PV electricity on contract durations equivalent to fossil fuel agreements.

SunSHIFT is structurally and electrically pre-engineered to lower the development time and cost of solar PV. SunSHIFT's building block is the 2kW Module, which are combined to form 50kW Arrays, and then 1MW Blocks. Blocks are simply added to achieve the desired solar PV output. Blocks readily integrate with fossil fuel generators and energy storage (as power response and/or energy shifting) for turnkey energy supply solutions. Additional Blocks and energy storage modules can be incrementally introduced as mine operations become comfortable with a hybrid approach and economics favour a greater adoption of renewable technologies.

Traditional 'stick-built' solar PV, where the system is largely assembled on site, is labour intensive. Australia has high labour costs and often limited labour availability in remote mining regions, making solar PV installation costs among the highest in the world[25]. SunSHIFT Modules are instead pre-fabricated in an off-site factory environment, lowering assembly costs, improving safety and quality, and reducing exposure to inclement weather. The Modules are transported to site in ISO standard shipping containers or racks and quickly installed on ground supports with minimal site labour or equipment. The Modules and supports can be quickly moved or removed as required.

SunSHIFT is available to purchase, rent, or through power purchase agreements with a range of durations and options. SunSHIFT and its technology partners can offer a suite of technical and financial services – design, transport, installation, integration, commissioning, relocation, and funding – to enable the adoption of low-cost renewable electricity in any off-grid mining operation.

SunSHIFT Module 2kW	**SunSHIFT Array** 50kW	**SunSHIFT Block** 1MW	**SunSHIFT System** Multiple 1MW Blocks	**Energy supply** Solar, generators, storage

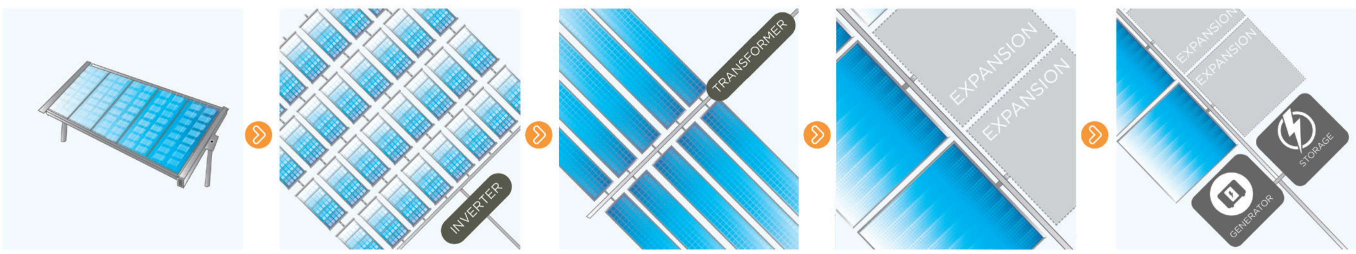

Figure 12: The SunSHIFT Module, Array, Block, System, and integrated energy supply.

25 International Renewable Energy Agency (IRENA), 2016, The Power to Change: Solar and Wind Cost Reduction Potential to 2025.

“A PORTABLE HYBRID SYSTEM, CONSTRUCTED OFF-SITE AND EASILY TRANSPORTABLE, COULD BE A REAL GAME CHANGER FOR OFF-GRID LOCATIONS IN AUSTRALIA AND BEYOND”

ARENA Chief Executive, Ivor Frischknecht

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