Ultra-Low-Cost Solar for Economy-wide Decarbonisation

Dr Bin Lu

ANU Centre for Energy Systems

Bin.Lu@anu.edu.au

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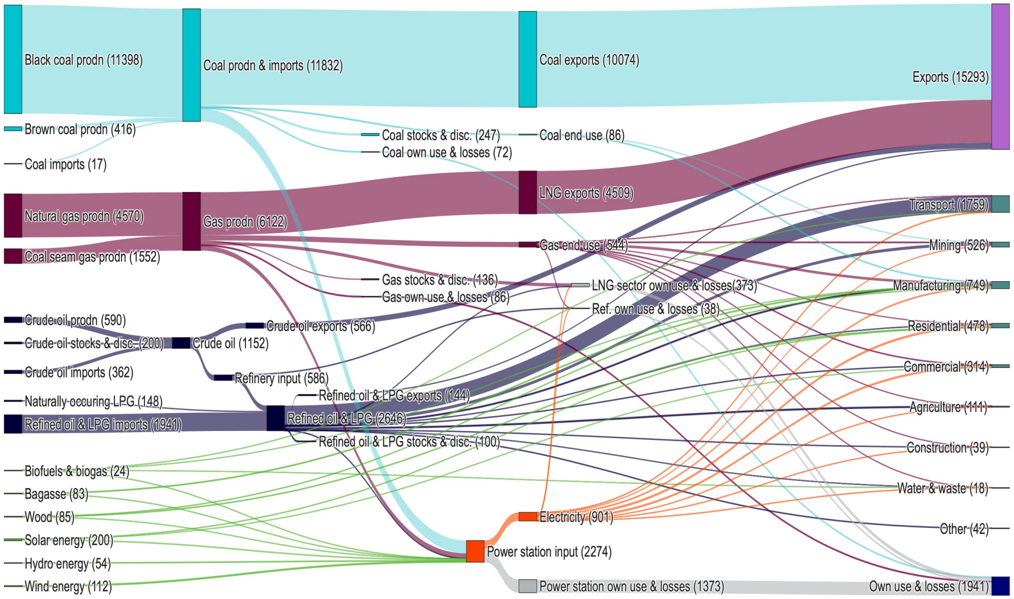
Australian National University

Australia's Terawatt-Scale PV Opportunity



Australian Energy Flows 2023–24 (Petajoules)

Source: DCCEEW, Australian Energy Update 2025

Current status

- Fossil fuels account for >90% of energy consumption and >75% of Australia's emissions.
- Enormous opportunities for solar PV to drive economy-wide decarbonisation.

Renewables + electrification

- Renewables are rapidly replacing coal power.
- EVs and electric heating are increasingly adopted across residential, commercial, industrial sectors to replace oil and gas.
- Electricity demand could double with full electrification.
  (Lu et al., Energy 220, 119678, 2021)
  (Lu et al., Renewable Energy 256, 123920, 2025)

Hard-to-abate sectors

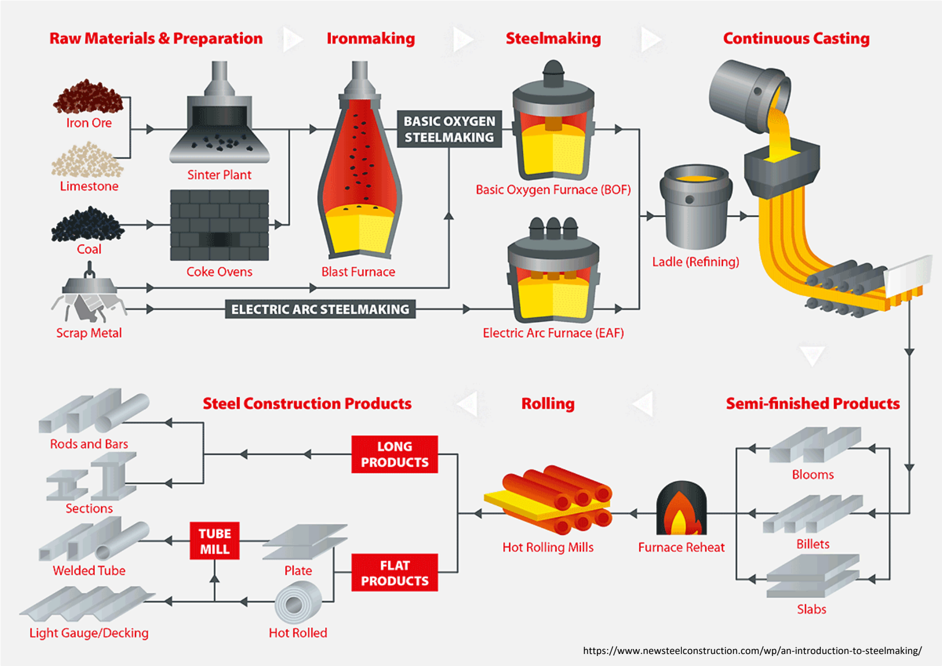
- Ultra-low-cost solar drives various decarbonisation strategies: electrification, hydrogen, carbon capture, and fuel synthesis.
- Economy-wide decarbonisation could quadruple electricity demand, unlocking a TW-scale PV market in Australia.
  (Lu et al., APSRC 2025)

Why Are Heavy Industries Hard to Abate?

Sector	Primary emission sources
Iron and steel	❖ Blast furnace-basic oxygen furnace (BF-BOF) process, relying on coke as chemical reductant and high-temperature heat source ❖ Electricity use in electric arc furnaces (EAF)
Aluminium and alumina	❖ Fuel combustion in alumina refining ❖ Electricity use in aluminium smelting ❖ Graphite electrode consumption during smelting
Cement and lime	❖ Process emissions from carbonate decomposition of limestone ❖ Fuel combustion emissions from rotary kilns
Ammonia	❖ Hydrogen production via steam methane reforming (SMR) and coal gasification
Aviation	❖ Jet fuel combustion

Process emissions (chemistry)	Difficult-to-electrify applications	High-temperature heat	Continuous, high-capacity power

Decarbonising Iron & Steel



Conventional BF-BOF iron and steel production

Emissions from iron and steel production

- Steelmaking emits 11 Mt CO_2-e each year, 2.5% of Australia's national emissions.
- The BF-BOF route has a high emission intensity (2.2 t CO_2 per t steel), as coke is both the chemical reductant and the heat source.
- Australia produces 5.6 Mt crude steel (2022), with three-quarters made via the BF-BOF route.

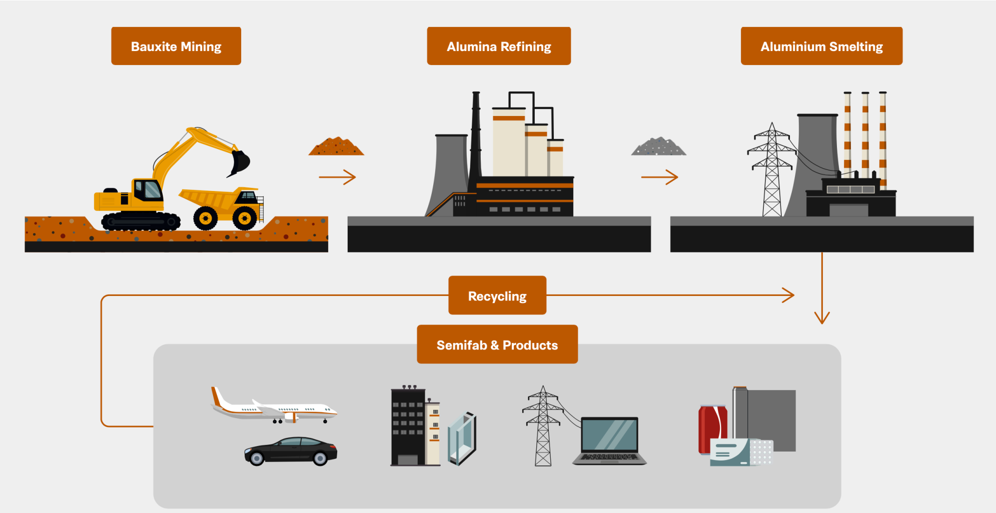
Pathways to green steel

- Hydrogen-based direct reduced iron with electric arc furnaces (H_2-DRI + EAF) replaces coke with renewable hydrogen.
- Molten oxide electrolysis (MOE) uses renewable electricity directly.
- Both require ~4 MWh of electricity per t of green steel.

ULCS opportunity

- Decarbonising domestic steelmaking requires 17 TWh/year → 8–10 GW PV capacity.
- Processing all exported iron ore domestically requires 2300 TWh/year → a 1050–1300 GW export-oriented PV market.

Decarbonising Alumina & Aluminium



https://aluminium.org.au/about-aluminium/how-aluminium-is-made/

https://elements.visualcapitalist.com/how-is-aluminum-made/

Aluminium value chain

Emissions from aluminium industry

- Alumina refining: 12 Mt CO_2-e/year (digestion 9.1, calcination 1.5, electricity 1.3).
- Aluminium smelting: 17.6 Mt CO_2-e/year (electricity use 14.6, carbon anodes 3).

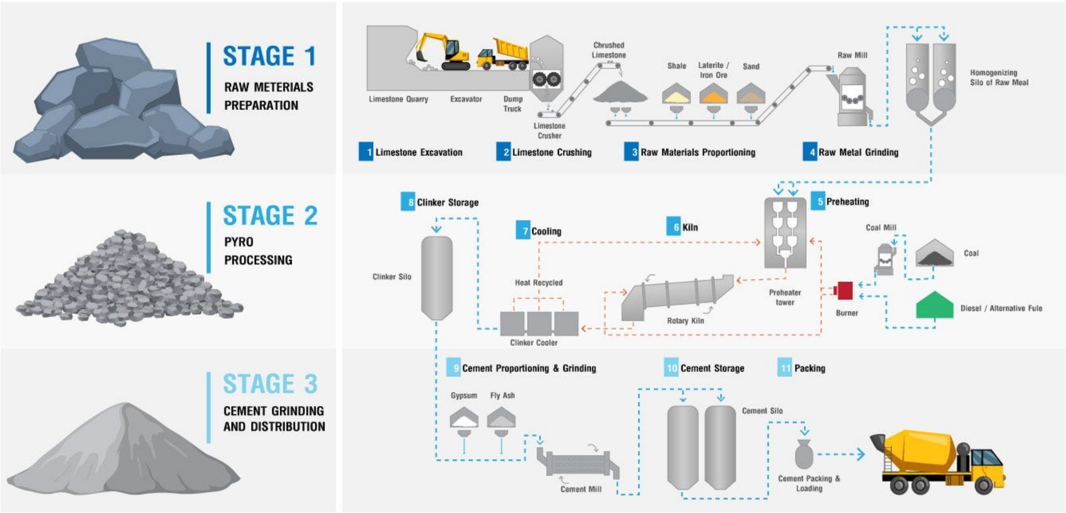
Decarbonisation solutions

- Alumina refining: electrification, hydrogen combustion, or hybrid systems.
- Aluminium smelting: renewable electricity, inert anodes to eliminate process emissions.

ULCS opportunity

- Australia produces 100 Mt bauxite, 20 Mt alumina, and 1.5 Mt aluminium each year.
- Domestic operations: Decarbonising alumina + aluminium requires 74 TWh/year → 35–40 GW PV capacity
- Value-added exports: Processing all exports in Australia requires 270 TWh/year → 120–150 GW PV capacity

Decarbonising Cement & Lime



https://medium.com/technounia/cement-production-technology-f8dbc22470fb

Cement value chain

Emissions from cement industry

- Australia produces 9.6 Mt cement and 1.5 Mt lime each year.
- Total emissions: 6.5 Mt CO_2/year (cement 4.7, lime 1.8).
- Process emissions (60%) from limestone decomposition: $CaCO_3 = CaO + CO_2$
- Fuel combustion (28%) and electricity use (12%) account for the remaining emissions.

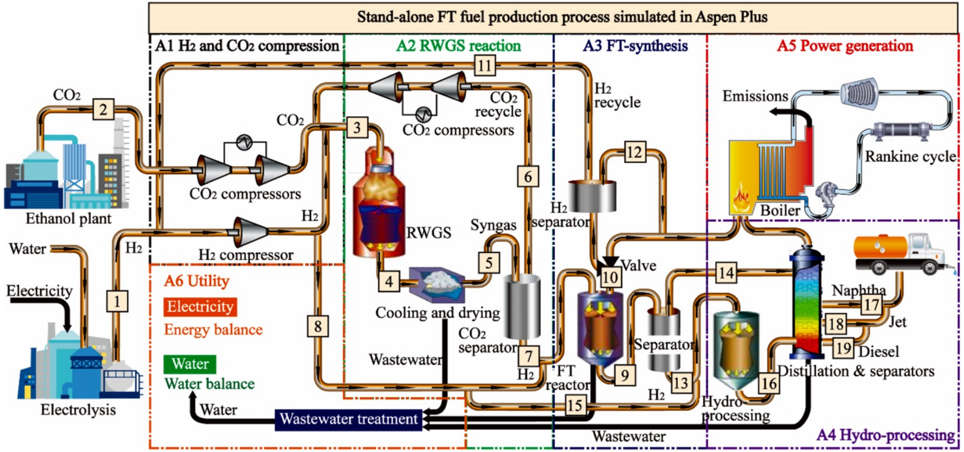
Pathways to low-carbon cement

- Capture process CO_2 via MEA absorption, oxyfuel, chilled ammonia, membrane-assisted liquefaction, or calcium looping.
- Electrify high-temperature heat, replacing fossil fuels in rotary kilns.
- Convert captured CO_2 into synthetic fuels, combined with green hydrogen via water electrolysis.

ULCS Opportunity

- Energy requirement: 33 TWh/year (CO_2 capture 4, hydrogen 14, electrification 15) → 15–20 GW PV capacity

Electro-fuels



https://doi.org/10.1016/j.jcou.2021.101459

Fig. 1. System flowchart for liquid fuel production from H_2 and CO_2 based on the FT process.

E-fuel applications

- Drop-in fuels: aviation, shipping, long-distance heavy transport
- Feedstocks for chemical (e.g., ammonia) & metal industries

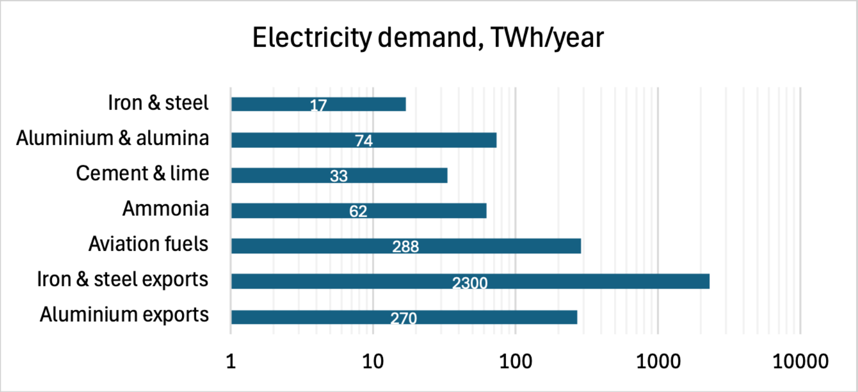
Power-to-fuel typical routes

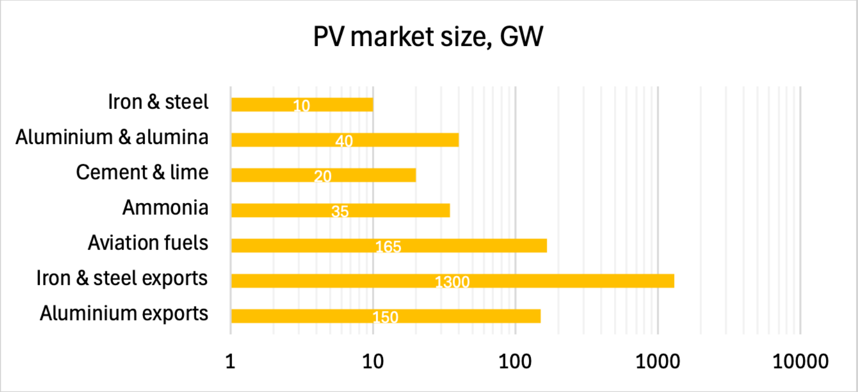
- Fischer-Tropsch: H_2 + CO (CO_2) → jet fuel, diesel
- Haber-Bosch: H_2 + N_2 → ammonia
- Sabatier reaction: H_2 + CO_2 → methane
- Methanol synthesis: H_2 + CO_2 → methanol

ULCS opportunity

- Ammonia: Green hydrogen for Haber-Bosch or electrochemical nitrogen reduction reaction (NRR)
- Shipping: Ammonia-fuelled engines and fuel cells, hydrogen fuel cells, electrification
- Aviation: E-fuels via green H_2 + CO_2 from direct air capture (DAC) or industry; hydrogen fuel cells; electrification
- Ultra-low-cost solar reduces production costs, bring e-fuels to cost parity with fossil fuels and biofuels.
- Electricity use: 350 TWh/year → 160–200 GW PV market

Powering Heavy Industry with ULCS





Heavy industry decarbonisation

- Decarbonising heavy industries (steel, aluminium, cement, ammonia, and aviation) requires a mix of strategies: electrification, hydrogen, carbon capture, and synthetic fuels.
- Ultra-low-cost solar is essential for economically viable large-scale deployment.

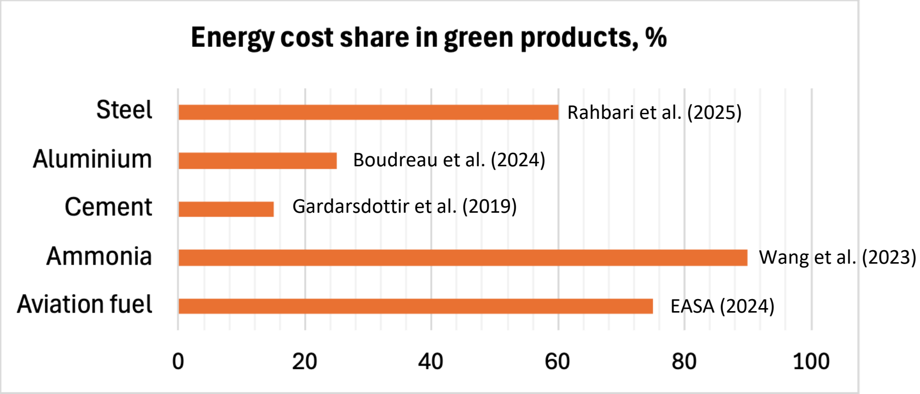
Electricity demand trajectory

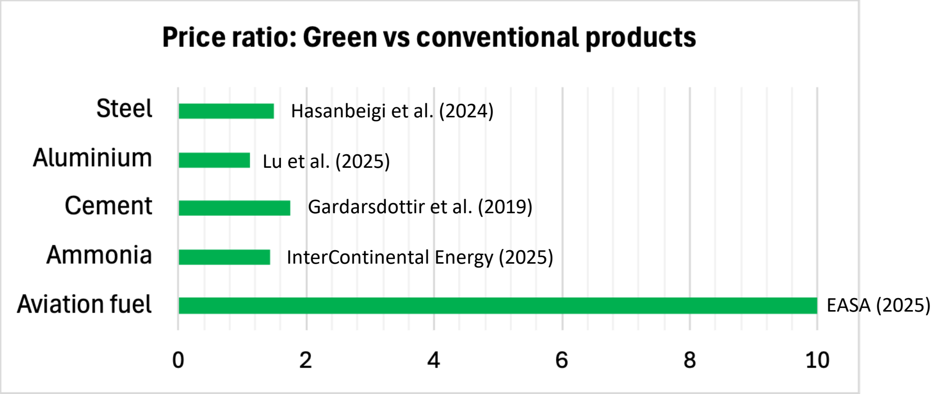
- Today: ~250 TWh/year
- With electrified transport, heating, and industry: ~500 TWh/year
- Full economy-wide decarbonisation: ~1000 TWh/year
- Refining Australia’s iron ore and bauxite into iron, steel, aluminium: another ~2500 TWh/year (export-oriented)

PV market potential

- Domestic decarbonisation: ~500 GW
- Value-added green metal exports: ~1500 GW
- Combined: ~2000 GW PV market (~70 kW of solar capacity per Australian)

Cost-Competitiveness of Green Products



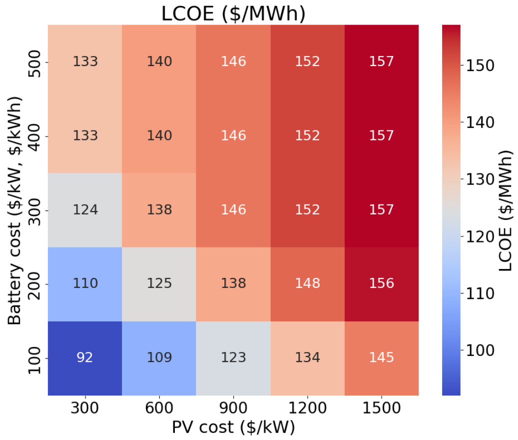


What happens if energy costs fall?

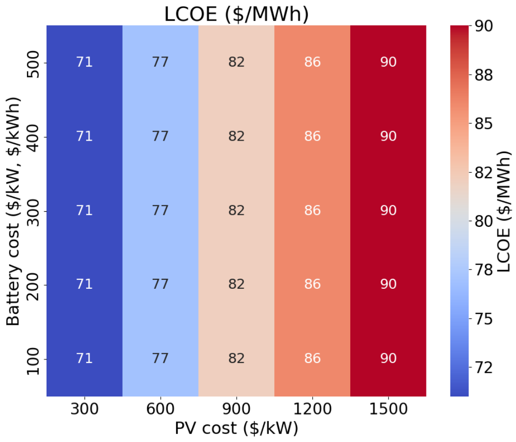
- At a 33% reduction, green ammonia become cost-competitive.
- At a 50% reduction, green iron, steel, and aluminium reach cost parity.
- At a 90% reduction, aviation e-fuels become competitive with biofuels, while low-carbon cement narrows its cost gap by 1/3.

Cheap PV & Batteries = Low Electricity Cost?

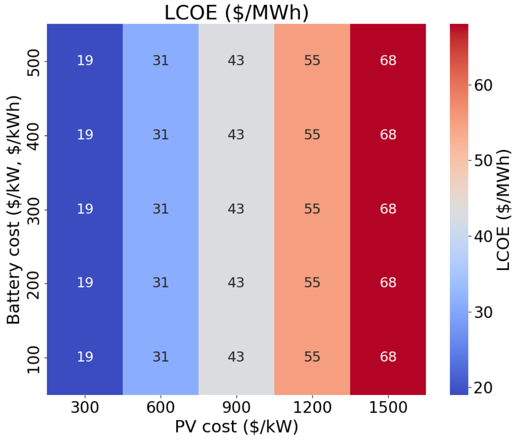
PV + Storage (standalone)



PV + 100% Grid connectivity



PV + 100% Load flexibility



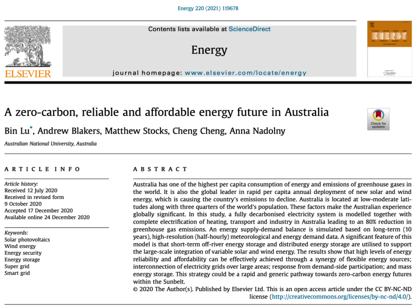
Quantitative insights from modelling industrial electricity supply

Source: Lu et al., Solar Energy 303, 114104, 2025

The real breakthrough won't come from cheaper technologies alone, but from using them more smartly.

Summary

1. Economy-wide decarbonisation requires various strategies: electrification, hydrogen, high-temperature heat, carbon capture, and synthetic fuels.
2. Ultra-low-cost solar enables these strategies at scale, especially for heavy industries such as steel, aluminium, cement, ammonia, and aviation.
3. Australia's annual electricity demand could increase from ~250 TWh today to ~500 TWh with electrified transport and heating, and to ~1000 TWh with decarbonising hard-to-abate sectors, equivalent to a 500 GW PV market for domestic industries.
4. Value-adding Australia's iron ore and bauxite requires ~2500 TWh of renewable electricity annually, creating a 1500 GW PV market for clean export industries.
5. Technology cost declines are important, but smart grid integration and load flexibility are essential for turning cheap solar into low energy costs.


Energy 220 (2021) 119678

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

A zero-carbon, reliable and affordable energy future in Australia

Bin Lu*, Andrew Blakers, Matthew Stocks, Cheng Cheng, Anna Nadolny

Australian National University, Australia

ARTICLE INFO

Article history:
Received 12 July 2020
Received in revised form 9 October 2020
Accepted 17 December 2020
Available online 24 December 2020

Keywords:
Solar photovoltaics
Wind energy
Energy security
Energy storage
Super grid
Smart grid

ABSTRACT

Australia has one of the highest per capita consumption of energy and emissions of greenhouse gases in the world. It is also the global leader in rapid per capita annual deployment of new solar and wind energy, which is causing the country's emissions to decline. Australia is located at low-moderate latitudes along with three quarters of the world's population. These factors make the Australian experience globally significant. In this study, a fully decarbonised electricity system is modelled together with complete electrification of heating, transport and industry in Australia leading to an 80% reduction in greenhouse gas emissions. An energy supply-demand balance is simulated based on long-term (10 years), high-resolution (half-hourly) meteorological and energy demand data. A significant feature of this model is that short-term off-river energy storage and distributed energy storage are utilised to support the large-scale integration of variable solar and wind energy. The results show that high levels of energy reliability and affordability can be effectively achieved through a synergy of flexible energy sources; interconnection of electricity grids over large areas; response from demand-side participation; and mass energy storage. This strategy could be a rapid and generic pathway towards zero-carbon energy futures within the Sunbelt.

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Solar Energy 303 (2026) 114104

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Decarbonising heavy industry operations with low-cost onsite photovoltaics and battery storage

Bin Lu*, Charlie Joyce Thomson, Shuang Wang, Alireza Rahbari, Lorrae McArthur, Anyao Liu, John Pye

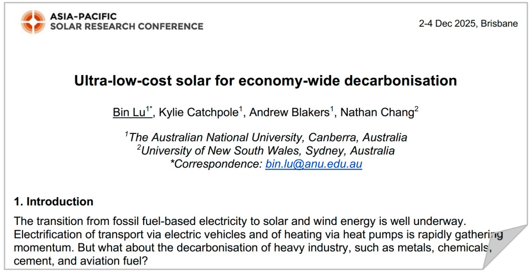
The Australian National University, Australia

ARTICLE INFO

Keywords:
Heavy industry
Decarbonisation
Photovoltaic
Battery
Grid interaction
Load flexibility

ABSTRACT

Decarbonising heavy industries, e.g., steel, aluminium, and cement, present unique challenges due to their high energy intensity and reliance on 24/7 continuous power supply. With volatile fossil fuel prices and increasing carbon regulations, the transition to renewable energy is critical for long-term economic and environmental sustainability. This study develops a new high-resolution energy modelling framework to assess the techno-economic feasibility of supplying 24/7 industrial electricity using low-cost onsite photovoltaic (PV) and battery storage systems. The model incorporates lifecycle degradation and intermittency with an hourly temporal resolution over a 25-year time horizon, integrated with grid interaction and load flexibility strategies. The results show that projected declines in PV and battery costs could lower electricity costs by 41% from $157/MWh to $92/MWh, though energy spillage constrains further savings. Grid interaction through bidirectional electricity exchange with the grid could reduce electricity costs by up to 42% and increase renewable energy integration from 37% to 100%. Load flexibility could reduce electricity costs by up to 80%, while achieving 100% renewable energy integration. Sensitivity analysis suggests that electricity costs are most sensitive to natural gas price and discount rate, while PV and battery degradation also have a measurable impact of $2–$5/MWh. The research findings provide quantitative evidence on the techno-economic feasibility of PV and battery integration for heavy industry operations, supporting strategic decisions for industrial decarbonisation.


ASIA-PACIFIC SOLAR RESEARCH CONFERENCE

2-4 Dec 2025, Brisbane

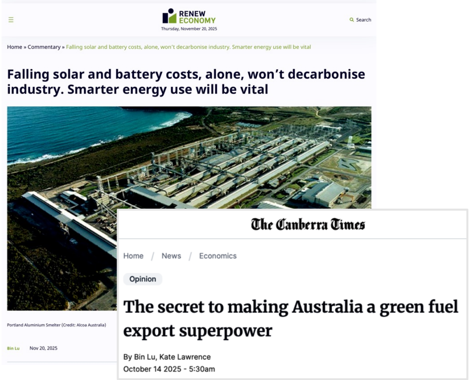
Ultra-low-cost solar for economy-wide decarbonisation

Bin Lu[1*], Kylie Catchpole[1], Andrew Blakers[1], Nathan Chang[2]

[1]The Australian National University, Canberra, Australia
[2]University of New South Wales, Sydney, Australia
*Correspondence: bin.lu@anu.edu.au

1. Introduction

The transition from fossil fuel-based electricity to solar and wind energy is well underway. Electrification of transport via electric vehicles and of heating via heat pumps is rapidly gathering momentum. But what about the decarbonisation of heavy industry, such as metals, chemicals, cement, and aviation fuel?



Questions?

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