THE CASE FOR

SOLAR PANEL REUSE IN AUSTRALIA

WASTE = OPPORTUNITY

thebluetribe COMPANY

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About the Authors
The Blue Tribe Company is a multi-award winning Sustainability & Innovation Consultancy who helps leading organisations to develop solutions to challenging environmental and social issues.

The authors acknowledge and respect the Aboriginal and Torres Strait Islander custodians of Australia. We continue to value the generations of knowledge Aboriginal and Torres Strait Islander Peoples embed within our community and we pay our respect to their Elders past, present and emerging.

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1. Executive Summary

Australia leads the way in rooftop solar installations with nearly one in three households owning a solar energy system[1], but solar panels are emerging as a growing source of waste and many of the solar panels currently being disposed of have many years of service life remaining.

The International Renewable Energy Agency notes that solar panels are designed to operate for 25-30 years and much of the modelling forecasting solar panel waste has assumed that these panels remain in service for the full duration of their service life.[2]

But reviews of recent literature and interviews we have conducted with consumers, solar installers, Councils, and industry experts has demonstrated that PV panels are entering the waste stream much earlier than expected due to a variety of reasons including:

- Whole system of panels gets removed when only a few panels are damaged as is often the case after storm events.
- If the panels are still under warranty, the manufacturer often pays to replace the whole set, even when only a few are faulty. This means working panels are removed alongside the faulty panels and disposed of in landfill.
- Solar panels have become a commodity. Just like upgrading your mobile phone, homeowners are upgrading their systems to larger, newer, more efficient systems with a new warranty.
- The Government small-scale technology certificate incentives aimed at rolling out more solar panels actually incentivise consumers to replace their entire solar array rather than repair.
- Roof upgrades, renovations and other building works result in systems being removed and combined with disincentives created by the Clean Energy Regulator guidelines means it can be cheaper to install a new system rather than reinstate the old one.
- Finally, the life of solar inverters is usually 10-12 years, much shorter than the 30-year life span of the panels themselves. Some people use this as an opportunity to install a new set of solar panels when they change their inverters.

Our research suggests that whilst PV panels are designed to operate for 30 years, in practice the average “in-service” life span of PV systems is closer to 15 years for many of the reasons listed above.

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[1] Roy Morgan Research, Solar Energy Systems on households more than double since 2018 – now at nearly a third of all households https://www.roymorgan.com/findings/9091-solar-energy-systems-on-households-more-than-double-since-2018-now-at-nearly-a-third-of-all-households

[2] Weckend, S., Wade, A., & Heath, G. A. (2016). End of life management: solar photovoltaic panels (No. NREL/TP-6A20-73852). National Renewable Energy Lab.(NREL), Golden, CO (United States).

In fact, 99.97% of Australia's PV capacity has been installed since 2010 meaning that it is likely that almost all of the PV panels that are being disposed of today are less than thirteen years old.

With this earlier than expected retirement of PV systems we estimate that Australia will accumulate up to 1 million tonnes of solar panel waste by 2033 — if laid down end to end these PV panels would encircle the Earth 3 times.

Many of these panels are expected to be fully serviceable and in the next 10 years we estimate that Australia is potentially set to dispose of 8.1GW worth of fully serviceable solar panels which is equivalent to all of the solar panels installed in Australia between 2017 and 2019.

In the absence of a planned and regulated PV panel reuse market Australia is potentially set to dispose of 27GW worth of fully serviceable solar panels by 2043 which is equivalent to all of the solar panels installed in Australia today.

These fully serviceable PV panels have a potential operating life of 10-15 years and represent a significant economic opportunity for Australia. We estimate that by 2030 Australia could potentially redeploy 8GW of reused PV panels that would otherwise be disposed of resulting in the generation of an estimated economic value of $38.4 Billion.

There are numerous reasons for considering PV reuse in Australia including:

- Supply and demand issues – Globally the world is moving to net zero and solar will be playing a major role in this. Australia will be competing for supply of PV panels from a global market whilst at the same time disposing of perfectly functional solar panels.
- Sovereign capability - China accounted for 75 percent of the global photovoltaic (PV) module production in 2022 and 90% of PV panels imported into Australia are manufactured in China. Global instability could compromise Australia's ability to achieve net zero and a properly regulated reuse market could provide a buffer.
- Economic value – The economic value of a reused PV panel is 133 times greater than a recycled PV panel. We estimate that a properly regulated PV reuse market could generate $167.8 Billion of economic value by 2045.

Whilst much of the conversation surrounding end-of-life solar panels has focussed on recycling, it is important to consider a fully circular solar industry which includes reuse and remanufacturing. A fully circular solar industry has the potential to generate significant economic benefits, jobs, whilst reducing supply chain risks.

2. The Scale of the Challenge

2.1. Introduction

Australia leads the way in rooftop solar installations with nearly one in three households owning a solar energy system[3], but solar panels are emerging as a growing source of waste and many of the solar panels currently being disposed of have many years of service life remaining.

The International Renewable Energy Agency notes that solar panels are designed to operate for 25-30 years and much of the modelling forecasting solar panel waste has assumed that these panels remain in service for the full duration of their service life.[4]

2.2. Why fully functional solar panels are ending up in the waste stream

A review of recent literature[5] and interviews we have conducted with consumers, solar installers, Councils, and industry experts has demonstrated that PV panels are entering the waste stream much earlier than expected due to a variety of reasons including:

- Whole system of panels gets removed when only a few panels are damaged as is often the case after storm events.
- If the panels are still under warranty, the manufacturer often pays to replace the whole set, even when only a few are faulty. This means working panels are removed alongside the faulty panels and disposed of in landfill.
- Solar panels have become a commodity. Just like upgrading your mobile phone, homeowners are upgrading their systems to larger, newer, more efficient systems with a new warranty.
- The Government small-scale technology certificate incentives aimed at rolling out more solar panels actually incentivise consumers to replace their entire solar array rather than repair.
- Roof upgrades, renovations and other building works result in systems being removed and combined with disincentives created by the Clean Energy Regulator guidelines means it can be cheaper to install a new system rather than reinstate the old one.

[3] Roy Morgan Research, Solar Energy Systems on households more than double since 2018 – now at nearly a third of all households https://www.roymorgan.com/findings/9091-solar-energy-systems-on-households-more-than-double-since-2018-now-at-nearly-a-third-of-all-households

[4] Weckend, S., Wade, A., & Heath, G. A. (2016). End of life management: solar photovoltaic panels (No. NREL/TP-6A20-73852). National Renewable Energy Lab.(NREL), Golden, CO (United States).

[5] Florin, N., Wakefield-Rann, R., Dominish, E. Dwyer, S., Gertsakis, J. And Hartford, N. Scoping study for solar panels and battery system reuse and recycling in NSW. Prepared for NSW Department of Planning, Industry and Environment by UTS Institute for Sustainable Futures and Equilibrium, February 2020

- Finally, the life of solar inverters is usually 10-12 years, much shorter than the 30-year life span of the panels themselves. Some people use this as an opportunity to install a new set of solar panels when they change their inverters[6].

One of the major drivers of early PV system removal is driven by the rules set by the Clean Energy Regulator which creates an incentive for fully functioning PV systems to be replaced.

In fact under the Clean Energy Regulator guidelines if one, some or all panels are replaced on an existing system which has previously received small-scale technology certificates for the entitlement period, it is not eligible to receive additional small-scale technology certificates[7]. Yet a full replacement of the existing system generates a full allocation of small-scale technology certificates.

This creates a financial incentive to replace the entire PV system.

2.3. More Solar equals more Waste

In 2022 Australia once again claimed the title of having the most solar installed per capita of any country in the world according to a Snapshot of Global PV Markets published by the International Energy Agency and Photovoltaic Power Systems Program.

Australia had just over 1.1kW (1,166W) of solar per person at the end of 2022, giving it top spot ahead of the Netherlands and Germany.[8]

In fact, 3.2 million Australian households (32.3% of all households) now own a solar energy system[9] which is expected to rise to 50% by 2030.

[6] Deepika Mathur, Robin Gregory, Eleanor Hogan, Do solar energy systems have a mid-life crisis? Valorising renewables and ignoring waste in regional towns in Australia's Northern Territory, Energy Research & Social Science, Volume 76, 2021
[7] Clean Energy Regulator, Small-scale systems eligible for certificates https://www.cleanenergyregulator.gov.au/RET/Scheme-participants-and-industry/Agents-and-installers/Small-scale-systems-eligible-for-certificates
[8] https://iea-pvps.org/snapshot-reports/snapshot-2022/
[9]https://www.roymorgan.com/findings/9091-solar-energy-systems-on-households-more-than-double-since-2018-now-at-nearly-a-third-of-all-households

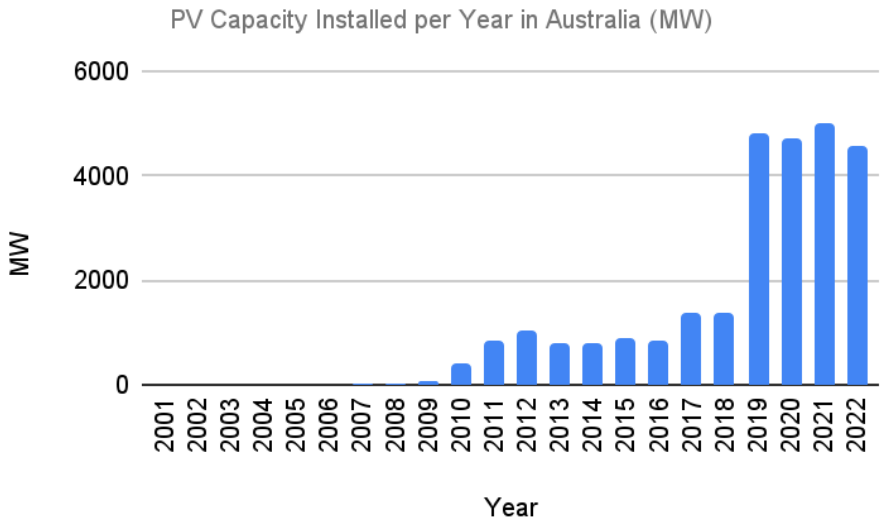

Figure 1 - PV capacity installed in Australia per year, 2001 - 2022, Source APVI

Installed PV capacity in Australia is set to grow significantly as Australia moves towards achieving its Net Zero targets. Estimates on the growth of solar PV capacity vary greatly depending on the future scenarios considered.

At the low end of the estimates is the Australian Energy Market Operator (AEMO) 2022 Integrated System Plan (ISP), outlining a 30-year roadmap of investments for the National Electricity Market (NEM). Under their "step change scenario", which they report as the most likely, annual electricity consumption from the grid will double by 2050, as transport, heating, cooking and industrial processes are electrified and 60% of current coal generation exits by 2030. Under this scenario solar PV capacity is set to grow to approximately 68 GW by 2030 (compared to 27GW in 2023) and 108GW by 2024[10].

According to market analysis firm GlobalData, solar installations in Australia are set to grow by a factor of four by 2030. GlobalData's report "Australia Power Market Outlook to 2030, Update 2021 – Market Trends, Regulations, and Competitive Landscape," estimates that Australia will reach a solar capacity of 80.22 GW in 2030[11].

At the high end of the modelling is Net Zero Australia's "How to make net zero happen Mobilisation" report published in July 2023. In a scenario based on full electrification of the economy and large scale green hydrogen production the modelling suggests that by 2030 there will be 98 GW of solar PV capacity spread across 135 projects.

[10] The Australian Energy Regulator (AER) 2023–24 Default Market Offer (DMO). https://www.aer.gov.au/news-release/aer-releases-final-determination-for-2023%E2%80%9324-default-market-offer

[11] GlobalData, Australia Power Market Outlook to 2030, Update 2021 – Market Trends, Regulations, and Competitive Landscape, 2021

By 2040, their modelling suggests that this will increase to 654 GW of solar PV (782 projects) and by 2050, solar PV capacity will reach a staggering 1.9 TW across 2,242 projects[12].

Table 1 - Forecasts of future solar capacity in Australia

Source	Forecast Solar Capacity 2030	Forecast Solar Capacity 2050
NEM 2022 ISP - Step Change scenario	68 GW	108 GW
GlobalData	80.22 GW	
Net Zero Australia How to make net zero happen Mobilisation report July 2023	98 GW	654 GW

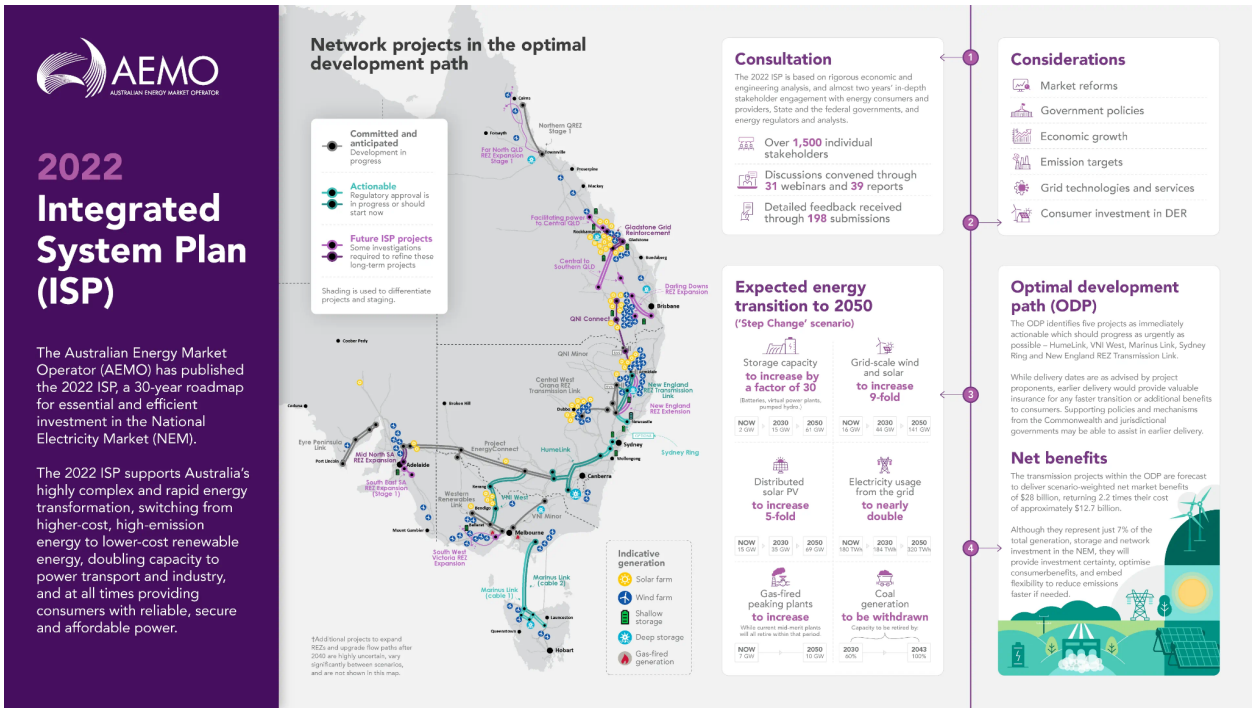

Figure 2 - AEMO 2022 Integrated System Plan (ISP) Infographic[13]

[12] Net Zero Australia, "How to make net zero happen Mobilisation" report published in July 2023 https://www.netzeroaustralia.net.au/mobilisation-report/

[13] The Australian Energy Regulator (AER) 2023–24 Default Market Offer (DMO). https://www.aer.gov.au/news-release/aer-releases-final-determination-for-2023%E2%80%9324-default-market-offer

The growth of PV capacity in Australia will have significant impacts on the infrastructure required for end of life PV system management. The following charts are based on the lower end of the projections by Australian Energy Market Operator (AEMO).

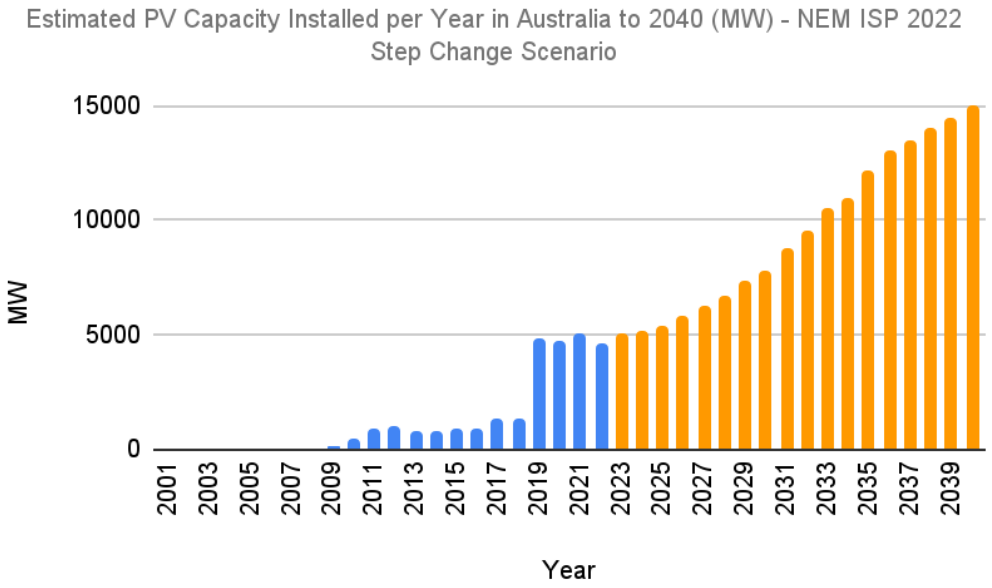

Figure 3 - Estimated future PV Capacity installed in Australia

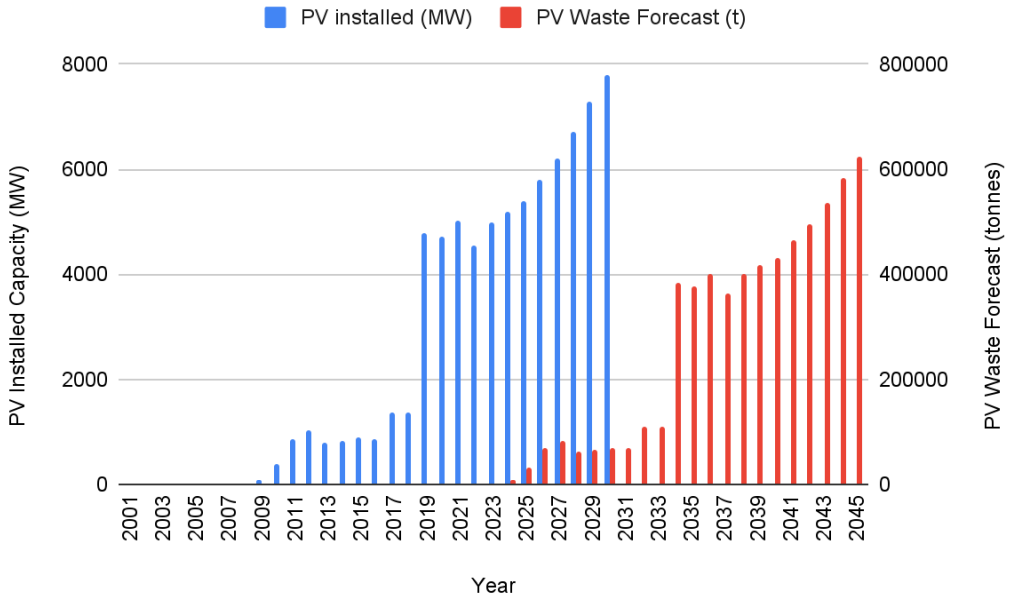

Figure 4 - PV Installed Capacity (2001-2030) and PV Waste Projections Australia (2024-2045)

With this earlier than expected retirement of PV systems we estimate that Australia will accumulate up to 1 million tonnes of solar panel waste by 2033 — if laid down end to end these PV panels would encircle the Earth 3 times.

If this early retirement trend continues and the average in service life of PV systems is 15 years then we estimate that Australia will accumulate up to 6.16 million tonnes of solar panel waste by 2045.

3. Waste Equals Opportunity

3.1. Overview

The International Renewable Energy Agency notes that solar panels are designed to operate for 25-30 years and much of the modelling forecasting solar panel waste has assumed that these panels remain in service for the full duration of their service life.

But reviews of recent literature and interviews with consumers, solar installers, Councils, and industry experts have demonstrated that PV panels are entering the waste stream much earlier than expected due to a variety of reasons discussed earlier in this report.

Our research suggests that whilst PV panels are designed to operate for 30 years, in practice the average “in-service” life span of PV systems is closer to 15 years.

These fully serviceable PV panels have a potential operating life of 10-15 years and represent a significant economic opportunity for Australia.

In the next 10 years we estimate that Australia is potentially set to dispose of 8.1GW worth of fully serviceable solar panels which is equivalent to all of the solar panels installed in Australia between 2017 and 2019. If reused and deployed these PV panels would generate an estimated economic value of $38.4 Billion.

In the absence of a planned and regulated PV panel reuse market Australia is potentially set to dispose of 34.6 GW worth of fully serviceable solar panels by 2045 which is greater than all of the solar panels installed in Australia today with an estimated economic value of $167 Billion.

3.2. Recycling vs Reuse

Much of the discussion associated with end of life PV systems has focused on recycling.

Yet recycling is a low value activity requiring very large capital investment.

The following is a list of the raw materials that are contained in PV panel waste and the value of 1 tonne of waste PV panels if all of the commodities could be recovered from the solar panels.

Table 2 - Summary of the key raw materials and economic value of 1 tonne of waste PV panels[14]

[14] Sajjad Mahmoudi, Nazmul Huda, Zahraossadat Alavi, Masud Behnia, Material Flow Analysis of the End-of-Life Photovoltaic Waste in Australia, Macquarie University, 2018

Material	Composition by weight	Quantity (kg)	Commodity price [$/kg]	Value
Ag	0.0415%	0.41515	$646.55	$268.42
Al	14.9233%	149.23287	$1.90	$283.54
Cu	1.0736%	10.73643	$6.10	$65.49
Ni	0.0008%	0.00760	$12.60	$0.10
Ti	0.0000%	0.00004	$0.64	$0.00
Sn	0.0036%	0.03558	$15.90	$0.57
Zn	0.0036%	0.03552	$2.10	$0.07
Pb	0.0040%	0.04028	$2.05	$0.08
Mg	0.4696%	4.69585	$4.70	$22.07
Si	0.6169%	6.16903	$3.00	$18.49
Steel	9.4283%	94.28285	$3.04	$286.81
EVA	6.5227%	65.22654	$0.83	$54.14
Glass	66.8469%	668.46937	$0.79	$528.09
Fe	0.0000%	0.00048	$0.60	$0.00
Cr	0.0029%	0.02895	$9.90	$0.29
Mn	0.0001%	0.00060	$0.01	$0.00
Cd	0.0299%	0.29900	$1.10	$0.33
In	0.0025%	0.02461	$460.00	$11.32
Te	0.0194%	0.19358	$89.00	$17.23
Mo	0.0035%	0.03522	$17.80	$0.63
Se	0.0035%	0.03522	$50.30	$1.77
Ga	0.0035%	0.03522	$295.00	$10.39
Total	**100.0000%**	**1000.00000**		**$1,569.82**

In 2010 the weight to power ratio of PV panels was in the order of 90 tonnes per MW meaning an average 250W panel would have been expected to weigh 22.5kg. The power to weight ratio of panels has continued to fall and today is around 70 tonnes per MW.[15]

Based on an average 20kg mass of an older 250W PV panel, 1 tonne of waste is equivalent to 12.5kW of PV panels resulting in the economic value of a recycled solar panel being $0.126/watt.

The processing cost of recycled solar panels is approximately $0.09/watt[16] resulting in a $0.036/watt margin to make solar panel recycling economically viable.

[15] Alla, Kiran Kumar. (2018). Brief Study of Material Recycling and Energy Balance Analysis of Installed Solar PV Modules in UAE Market. 10.13140/RG.2.2.20237.38885.
[16] Kang D, White T, Thomson A. PV Module Recycling: Mining Australian Rooftops. 2015 Asia-Pacific Solar Research Conference; Brisbane, 2015.

However, this assumes the full recovery of all commodities contained in the solar panels. In reality in 2023 the only materials that can be economically recovered are the aluminium (Al), glass, copper (Cu), and steel resulting in a PV recyclate value of just $0.093/watt.

By comparison a 12.5kW PV system installed in Sydney would generate approximately 18286.5kWh of renewable energy per annum.

Applying a 12% reduction in performance to account for an average reused system (3% reduction due to age of the panels, 6% loss for shading, 3% losses for non-optimum orientation or tilt angle), and valuing the electricity generation at $0.30/kWh[17], this system would generate $72,414.54 worth of renewable energy over the remaining 15 years of its service life or $5.80/watt.

With a cost of $1/watt for installation and balance of plant (e.g. new inverters and cabling) the total economic value of the same 1 tonne of PV panels would be $4.80/watt - 133 times the value of a recycled solar panel.

3.3. Potential size of the reuse market

Data on the total volume of PV waste being disposed of is not readily available at a national scale and therefore current projections are based on estimates and a range of assumptions.

The same is true for solar panel reuse.

In order to develop an estimate we undertook a project in partnership with CSIRO with the support of the NSW EPA Circular Solar Grants program.

A total of 93 modules were received for testing. The locations and dates of installation and removal were as follows:

- 14x Schott 235W from Balgowlah Heights (installed Nov 2010; uninstalled 19/6/21)
- 24x Sunpower 210W from Gordon West (installed March 2011; uninstalled 19/6/21)
- 23x Sunpower 210W from Sydney (installed sometime 2008-2012; uninstalled sometime in 2020)
- 23x Sungrid 170W from Kincumber (installed sometime prior to May 2010; uninstalled mid July 2019)
- 9x Eco-kinetics 170W from Newcastle (installed May 2010; uninstalled November 2020)

[17] The average electricity tariff is $0.4927/kWh according to The Australian Energy Regulator (AER) 2023–24 Default Market Offer (DMO) - https://www.aer.gov.au/news-release/aer-releases-final-determination-for-2023%E2%80%9324-default-market-offer

A recertification and testing method was developed during the project. The methodology allows the fast execution of two key measurements to determine the state of a PV module: (1) electroluminescence imaging identifies cell cracks or damaged electrodes or solder joints; (2) current-voltage testing which is an electrical diagnostic tool from which many aspects of the module performance can be inferred.

These panels were then graded based on the test results with panels deemed suitable for reuse if their performance was within 3% of the original power rating as identified from the panel labels.

Ultimately 85 of the panels were tested using this methodology with 39 panels identified as fully functional and suitable for reuse (45.8%).

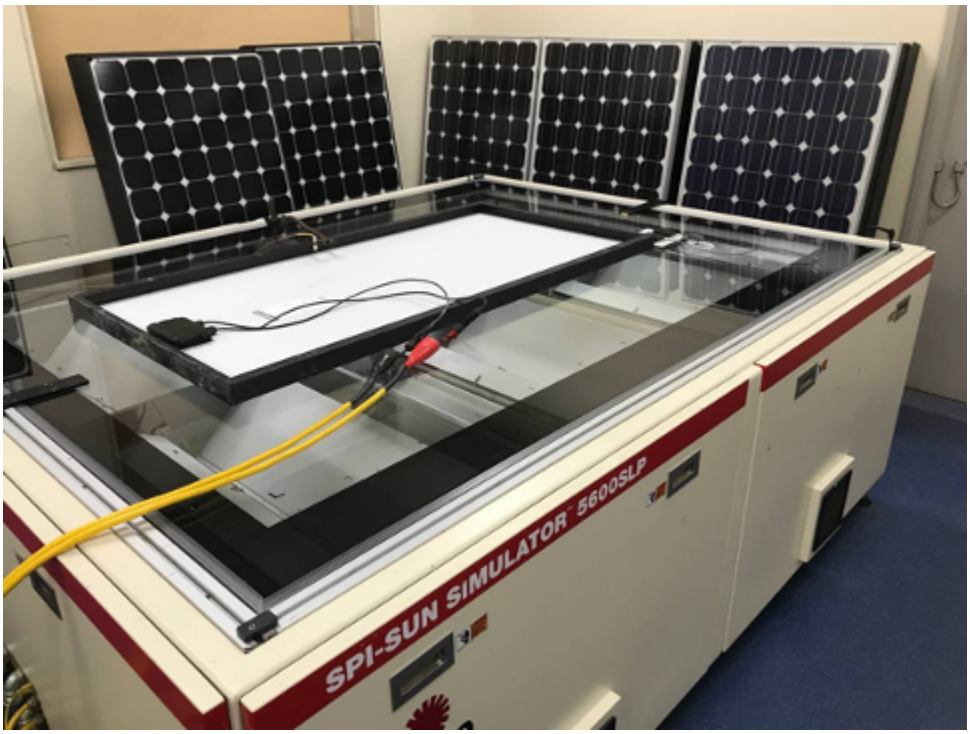

Figure 5. One of the PV modules being current-voltage tested on the flash solar simulator at CSIRO

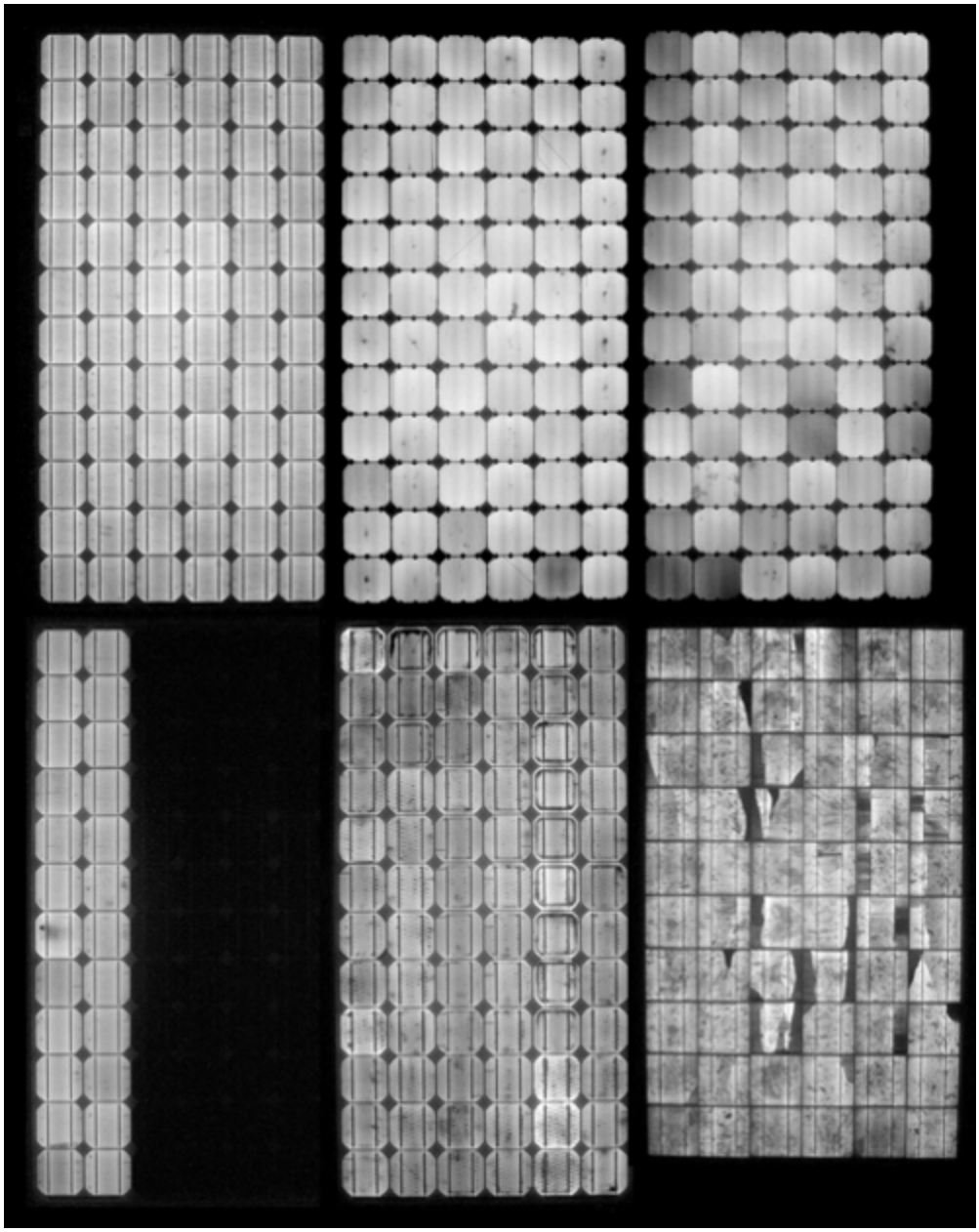

Figure 6. Example electroluminescence images of used PV modules with various forms of degradation: (Clockwise from top left) normal; minor (acceptable) cell cracking; damage due to potential-induced degradation; severe cell cracking; material degradation; lost cell strings due to bad bypass diodes. Note some differences are due to the modules being different types, e.g. the background pattern in the bottom right module is normal, since the cells are multicrystalline.

We are currently working on stage 2 of this project where we will undertake testing of 600 panels to gain a larger sample size. This project is due to be completed in March 2024.

Based on this sample size and an assumed average ‘in service’ life of 15 years we believe basing the estimate of the number of panels that are suitable for reuse at 45% is reasonable.

The chart below provides an estimate of the estimated size of the reuse market per annum based on the expected retirement age of existing systems installed since 2011.

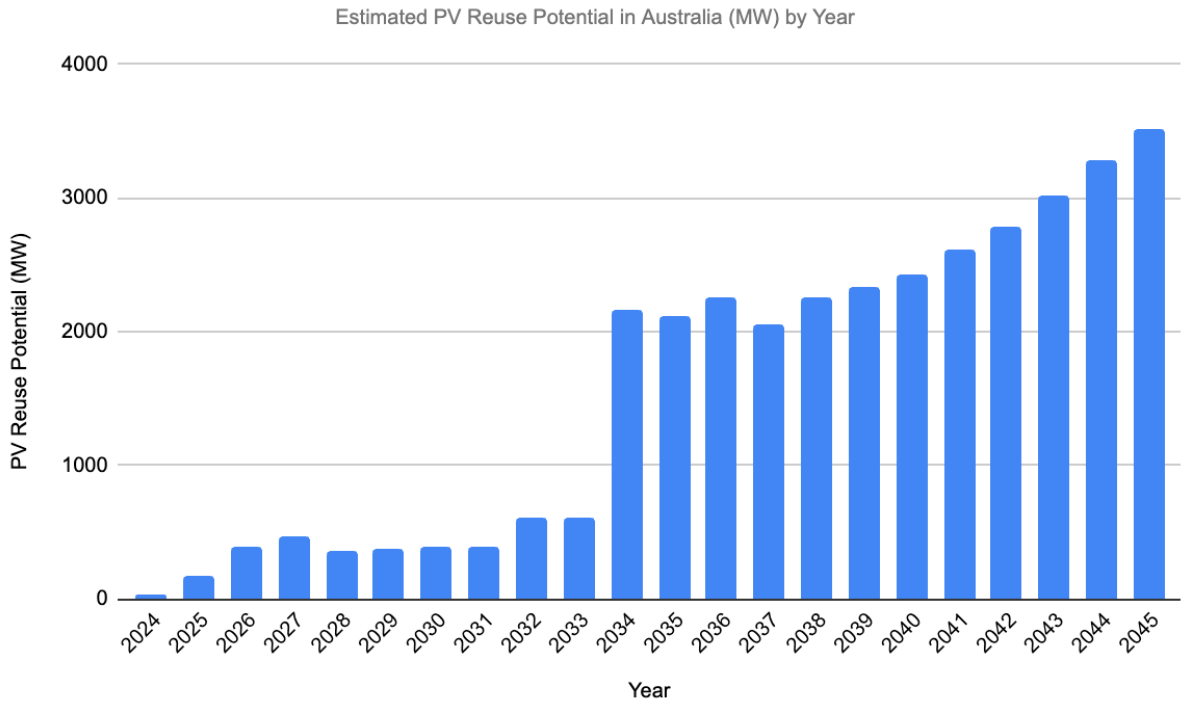

Figure 7 - Estimated PV reuse potential in Australia (2024-2045)

We estimate that by 2030 Australia could potentially redeploy 8GW of reused PV from panels that would otherwise be disposed of by 2035 generating an estimated economic value of $38.4 Billion.

In the absence of a planned and regulated PV panel reuse market Australia is potentially set to dispose of 34.6 GW worth of fully serviceable solar panels by 2045 which is equivalent to all of the solar panels installed in Australia today with an estimated economic value of $167 Billion.

Further, retaining these fully serviceable PV panels for continued renewable energy production could increase Australia’s PV installed capacity by up to 17% by 2035 based on the AMEO ISP 2022 Step Change Scenario.

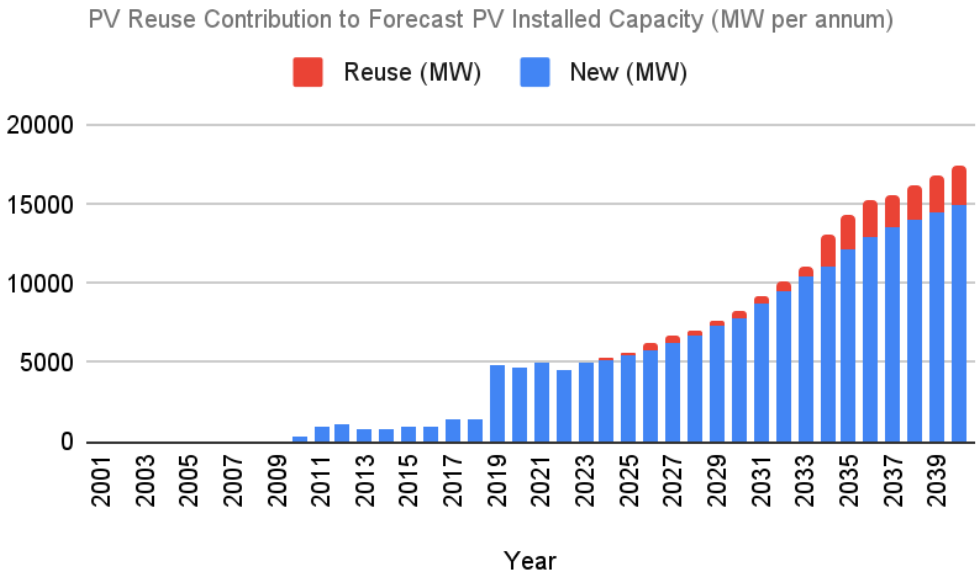

Figure 8 - PV PV Reuse Contribution to future solar capacity in Australia (2024-2040)

3.4. Broader Benefits of Solar Panel Reuse

There are numerous reasons for considering PV reuse in Australia.

- Supply and demand issues – Globally the world is moving to net zero and solar will be playing a major role in this. Australia will be competing for supply of PV panels from a global market whilst at the same time disposing of perfectly functional solar panels.
- Sovereign capability - China accounted for 75 percent of the global photovoltaic (PV) module production in 2022 and 90% of PV panels imported into Australia are manufactured in China. Global instability could compromise Australia's ability to achieve net zero and a properly regulated reuse market could provide a buffer.
- Economic value – we believe that a properly regulated PV reuse market could generate $167 Billion of economic value by 2045.
- Supports the activation of a circular economy
- Support low cost green hydrogen production

3.4.1. Ease Supply and Demand Issues

Globally the world is moving to net zero and solar will be playing a major role in this. Australia will be competing for supply of PV panels from a global market whilst at the same time disposing of perfectly functional solar panels.

Solar panel reuse has the potential to contribute up to 17% of system installations by 2035.

3.4.2. Sovereign capability

China accounted for 75 percent of the global photovoltaic (PV) module production in 2022 and 90% of PV panels imported into Australia are manufactured in China. Global instability or unforeseen disruptions like COVID could compromise Australia's ability to achieve net zero if this supply chain were disrupted.

A properly regulated reuse market could provide a domestic source of renewable energy production.

3.4.3. Economic Value

We believe that a properly regulated PV reuse market could generate up to $167 Billion of economic value by 2045.

3.4.4. Activating a Circular Economy

Many businesses and Governments have focussed their plans for achieving net-zero emissions on an energy transition, boosting energy efficiency and increasing the use of renewable energy.

However, leading businesses also realise that the production, use, and eventual disposal of materials can account for up to 45% global CO2 emissions and are therefore setting ambitious circular economy goals.

The challenge they face is that there are very few low cost and easy to implement circular economy solutions.

Solar panel reuse allows businesses and Government to achieve net zero and circular economy outcomes in a single project.

3.4.5. Support Low Cost Hydrogen Production

The cost of renewable energy is one of the largest input costs to the production of green hydrogen. A solar panel reuse market provides a low cost source of renewable energy to support lowering the cost of the solar energy to produce hydrogen bringing Australia closer to the $2/kg cost target for hydrogen.

Second Life Solar testing and reuse facilities could be located near key hydrogen hubs to provide low cost renewable energy inputs

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