PV panel re-use around the world: State-of-the-art

Overview Report

Executive Summary

The deployment of photovoltaic (PV) systems has increased exponentially, reaching cumulative industry deployments of 890GW and is projected to reach annual installed capacity of 220GW from 2023. This has led to massive benefits such as decarbonisation of electricity generation. However, as these panels age, they will begin to be removed from service, creating a stream of decommissioned PV panels. Although PV panels are designed with a technical life of 30 years, a significant number will be decommissioned earlier. This can be for a variety of reasons such as weather damage, inverter failure, or system upgrade. Some studies have shown that new PV panels installed today have operational lifespans of less than 14 years before being decommissioned.

Decommissioned PV panels are often treated as a waste product. Regulators, when developing schemes to manage decommissioned PV panels often propose recycling as a solution. The EU's Waste Electrical and Electronic Equipment (WEEE) directive for example requires 80% of the PV panel (by weight) be recycled. This can be met by recycling only the glass and aluminium frame though (at approximately 88% of the total weight combined).

Given that many PV panels will be decommissioned before the end of their technical lives it is likely that they could continue to generate energy for longer, if used somewhere else post decommissioning. This report presents the outcomes of a desktop review on re-use of PV panels. It describes the current state of reuse of these decommissioned PV panels based on a literature review. This includes academic literature, grey literature, and a market survey.

Reuse involves two actions: testing and reuse. Testing ensures the PV panel is functional, in good condition, and safe. Refurbishment can repair some types of PV panel failures.

There is variance in the types of tests proposed by different sources, but the most common ones relate to physical condition, power output, insulation resistance, and cell condition (e.g. hot spots or cracking). Recommended tests include visual inspections, IV tests, thermal imaging, and electroluminescence tests. Not all organisations who reuse panels undertake all of these tests, and several that we found only did visual inspections. Most organisations who did test didn't specify which tests they did or what testing standards they used.

Some PV panels that are not functional have minor faults that are repairable. Common faults that are repairable include failed diodes, failed junction boxes, damaged cables, and cracked back sheets. However few organisations appear to be refurbishing PV panels today.

Our market survey found several organisations in the PV reuse space. There are six main activities they do: Collection, wholesale, retail, testing, refurbishment, and integration. Collection involves sourcing PV panels from people who have decommissioned them. Some source from PV installers, others individuals. Wholesalers and retailers sell PV panels to organisations or individuals respectively. Testing and refurbishment are validating the performance and safety of PV panels, and rectifying defects. Integrators use PV panels in various contexts including in PV arrays or different types of finished products. A summary of the organisations and their main activities is in *Table 1*.

Table 1. Organisations involved in reuse and activities.

Organisation	Continent	Collection	Wholesale	Retail	Testing	Refurbishment	Integration
SunCrafter	Europe						●
Cohousing Waasland	Europe				●		●
ScalingPSS*	Europe						●
REScoop PV*	Europe						●
Goodsun	North America	●		●			●
Fabtech solar solutions	North America	●		●	●	●	
My second life solar	Australia	●			●		●
EnergyBin	North America		●		●	●	
SanTan Solar	North America			●			
SecondSol	Europe		●		●	●	
PVXchange	Europe		●				
Repurposing for Resilience	Australia	●		●			●
PVLab	Australia				●	●	

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1. Lifespan of PV panels

Solar energy is now one of the fastest-growing sources of electricity globally, and it is playing an increasingly important role in meeting the demand for electricity. The deployment of photovoltaic (PV) systems has increased exponentially, reaching cumulative industry deployments of 890GW and is projected to reach annual installed capacity of 220GW from 2023 [1]. In many places worldwide, PV is the cheapest form of generation, which is a key contributor to its high uptake [1]. Alongside the exponential growth in new PV panels deployment, comes an exponential growth in decommissioned PV panels [2]. International Energy Agency Photovoltaic Power Systems Program (IEA PVPS) and International Renewable Energy Agency (IRENA) projected the cumulative waste volumes of decommissioned PV panels around the world. Depending upon the loss scenarios, whether "regular-loss" or early-loss" the volume of the PV waste is projected to 1.7 million tons or 8 million tons, respectively, by the year 2030.

These decommissioned panels are commonly referred to as "end-of-life" panels, although other terms such as "mid-life" have also been used [3]. PV panels have an expected technical service life of 30 years. It has been observed, however that a significant volume of panels is decommissioned before their technical service life, for a variety of reasons. For example, Mathur et. al. found that often failure of an inverter or only a few panels from a PV array would result in the entire array being replaced [4]. Other studies showed that, the service life of panels is projected to be significantly shorter than the 30 years, as shown in *Table 2*.

IRENA and IEA-PVPS have stated that less than 10% of PV panels fail either during transportation and installation stages, soon after start-up operation, during severe weather, or due to harsh environments [2] but that the majority of panels remain in service for 25 years or more [6], [7]. Failure is not the only reason that PV panels are replaced. Economic motivation originating from government rebates and incentives lead to the early replacement of PV panel both in residential and utility scale power plants. Studies suggest that economic incentives have reduced the operational lifespan of PV panels less than 14 years, even while maintaining their initial rated power output [6][7]. Further, some of the PV panels suffer a gradual decline in power output, and once they reach 80% of their initial rated power, they are often considered to have reached their end-of-life and decommissioned [5].

Figure 1 Estimated cumulative waste volumes of decommissioned PV panels. [2]

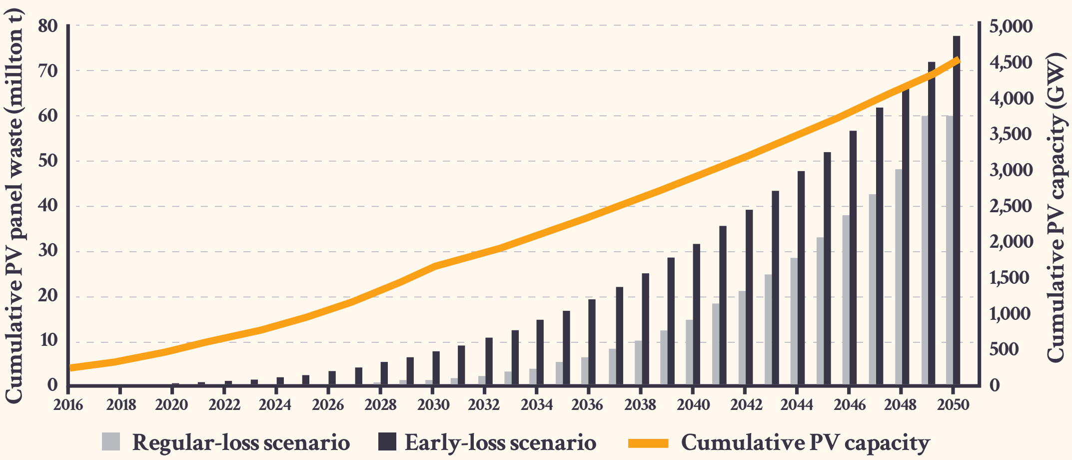


Table 2. Average lifespan of PV panels considering different decommission models.

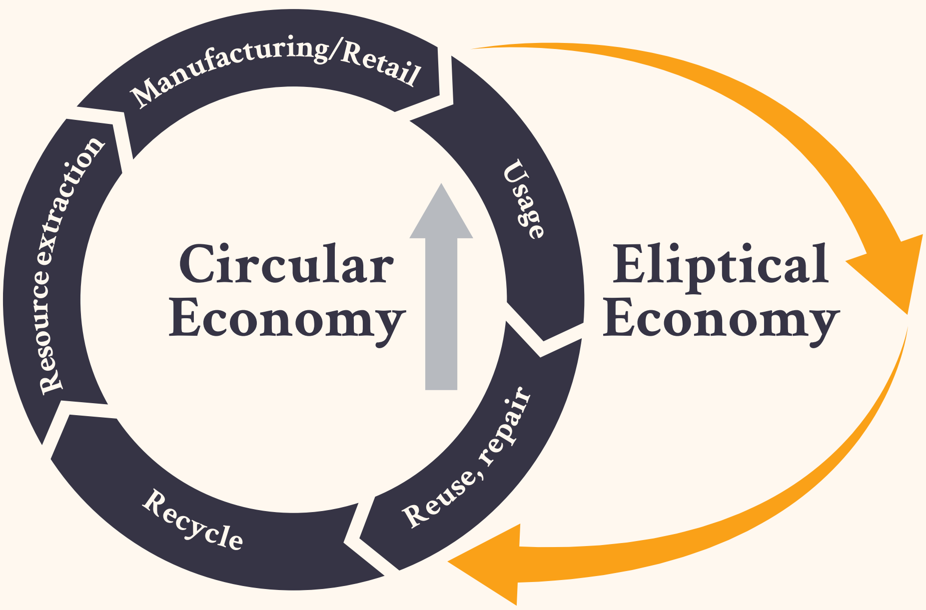
Source	Average lifespan (years)
IRENA and IEA-PVPS regular loss [5]	30
IRENA and IEA-PVPS early loss [5]	28
Power decrease [6]	24
Damage and technical failures [5]	14
Economic motivation [7], [8]	14

2. Circular economy of PV panels

In the traditional economy, PV panels typically follow a linear "cradle to grave" path, with disposal through landfills or storage upon decommissioning [8]. The concept of circularity is emerging in the PV industry, with academic researchers proposing it to enhance the sustainability of PV technology [8]–[10]. Recycling is the prevailing strategy for handling decommissioned PV modules within the framework of the circular economy for PV panels. In this regard, the EU has taken a proactive role in promoting circularity in PV production. Since 2012, the EU's Waste Electrical and Electronic Equipment (WEEE) directive has established a separate category for PV panels [11]. Under the extended producer responsibility scheme, PV producers are mandated to retrieve and recycle decommissioned modules and achieve an 80 % (by weight) recycling rate. Unfortunately, this scheme does not address the true circularity of the PV waste. Crystalline PV modules consist of approximately 70 % glass, 18 % aluminum, 8 % plastics, 4 % silicon, and less than 1 % copper and silver [8]. Currently, most PV recycling technologies concentrate on reclaiming materials that make up most of the module's weight, namely the aluminum frame, glass, and copper, using cost-effective crushing processes to meet legal requirements. The remaining materials are often sent to landfills. Therefore, in the current market, relying solely on recycling to achieve circularity for PV waste is not effective. The PV recycling industry faces sustainability issues due to the current volume of panels and logistical complexities [9], [12], [13]. It is imperative, especially for functional PV panels, to divert them from the recycling or waste stream.

To promote circularity, efforts must be intensified to extend the use of PV panels through practices like reusing, refurbishing, and repairing for a second life. In a well-functioning circular economy, the "use phase" becomes increasingly prolonged, making the circular process more elliptical in shape, as shown in Figure 2. Therefore, the focus of the PV panel economy should shift towards a more elliptical concept, particularly emphasizing the re-use, repair, and refurbishment of panels.

Figure 2. Schematic of circular and elliptical economy concept of PV panels.



3. Reuse, repair, and refurbishment of PV panels

Silicon PV panels decommissioned primarily for economic reasons can be deemed suitable for reuse, especially after undergoing rigorous safety and performance testings. Conversely, panels decommissioned due to observed defects or faults require repair or refurbishment before they can be considered for reuse. The critical initial step in giving PV panels a second life is their decommissioning from the existing system. The quality of decommissioning work plays a pivotal role in initiating a new journey for PV panels, as mishandling during this process could cause significant damage. Once decommissioned, panels are typically either discarded (landfilled) or stored for their potential repairment or refurbishment to enable their reuse, and recycling.

To meet certain quality and safety standards, new PV panels must adhere to requirements outlined by IEC 61215 for general quality and IEC 61730 for safety, ensuring international certification before entering the market.

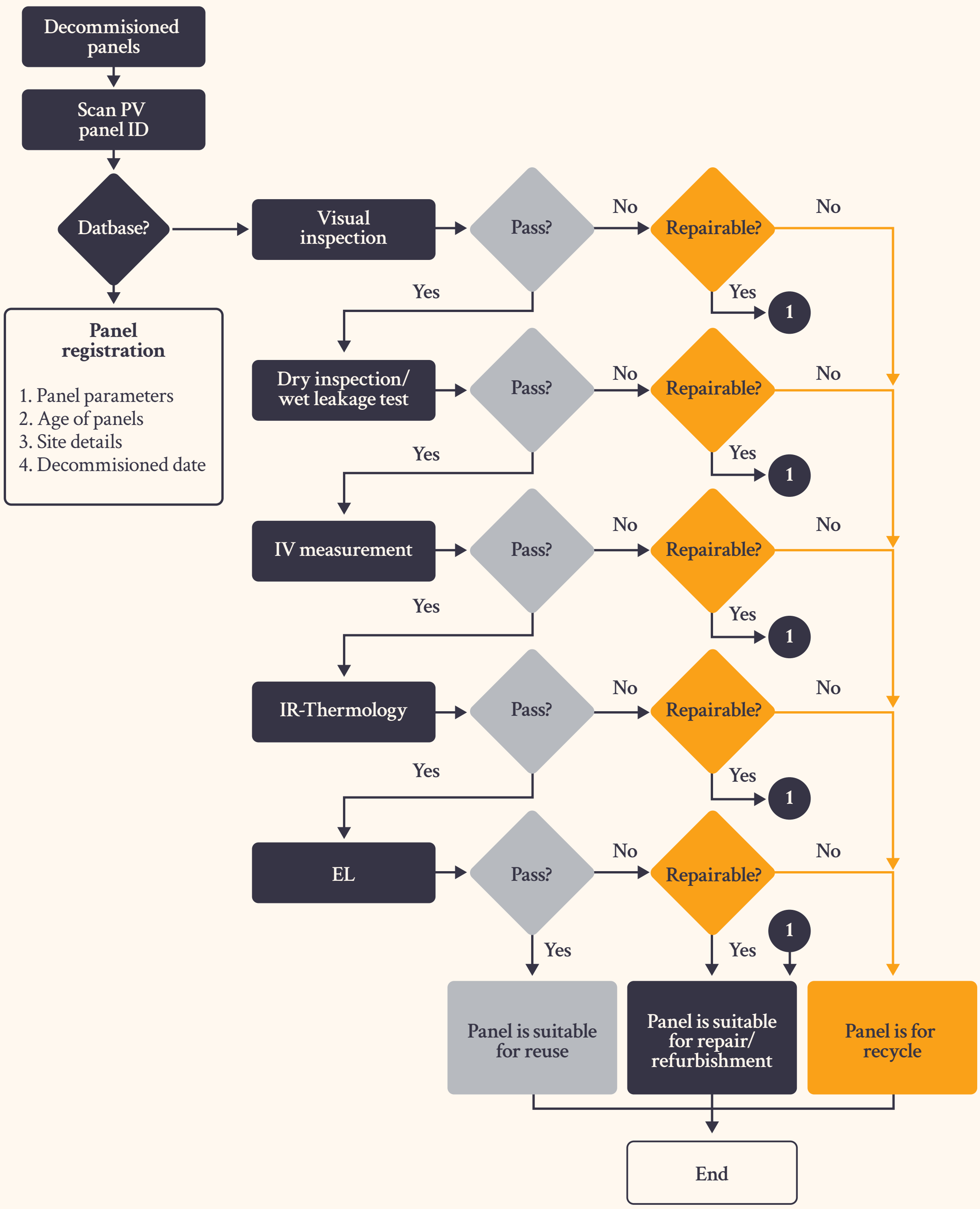
However, for decommissioned panels, no internationally agreed-upon protocols or certifications currently exist. In response to the standards set for new modules, various works have proposed and utilized a range of testing regimes to assess the quality and safety of decommissioned PV panels, as illustrated in *Figure 3*.

Common testing regimes, including visual inspection, wet/dry leakage tests, IV tests, thermal imaging, and electroluminescence (EL) imaging, are typically employed to ensure the reliability of new panels. For decommissioned panels, various combinations of these tests can be also utilized to assess the quality and performance, aiding in the sorting process for potential reuse, repair, or recycling. The fundamental information gathered from these tests (refer to Table 3) is strategically combined to make informed decisions about the fate (reuse, repair, and recycle) of decommissioned panels, as illustrated in *Figure 3*.

Table 3. Testing methods for decommissioned PV panels with additional information.

Tests	Information
Visual inspection	• Integrity of glasses (front and rear) and frames • Burn spots on the front cells, the solder joints, conducting paths, busbars, close to or directly on the junction box • Deformation or bloating of the junction box. • Discolouration, cracks and bubbling of backsheet
Wet/dry leakage tests	• Electrical safety checks with leakage current. • A minimum required resistance of > 25 MΩ
IV measurements	• Electrical performance • Pmpp> 80% of nameplate Pmpp
IR-thermography	• Defects contributing to all kind of thermal anomalies and temperature gradients, such as hotspots, shunted cells, fully active bypass diode
EL	• Electrically active defects, such as cell cracks, locally increased series resistance or potential induced degradation

Figure 3. Decommissioned PV panels sorting sequence to prepare them for reuse, repair and recycle. [14], [15]



While testing regimes such as visual inspection, wet/dry leakage tests, IV tests, thermal imaging, and electroluminescence (EL) imaging are commonly employed for assessing the reliability of new panels, there is a lack of well-established protocols governing their use in determining the state of decommissioned panels for second-life usage. The EU [15] and Japan [16] have published guidelines for testing decommissioned panels for reuse, recognizing the need to balance testing efforts to ensure economic feasibility. However, this poses a trade-off with the expectations of potential buyers regarding the quality and performance of decommissioned panels, requiring testing regimes to meet these expectations.

The EU Circusolar project's guidelines suggest that PV panels intended for reuse, particularly those operating at low voltages (<125V), have lesser safety and performance requirements. Notably, the guidelines exclude wet leakage tests and only include dry insulation tests for PV panel reuse. This approach may raise concerns, as dry insulation tests might not always detect failures such as cracks in the backsheet, a potential issue with PV panels. The Japanese guidelines have outlined the necessary inspection/test regimes, packaging, storing, loading, transporting and delivery steps of PV panels to promote the appropriate reuse. This guideline is primarily targeted for Japanese business, which export PV panels overseas for the reuse. Within the Australian context, discussions about reusing, repairing, and refurbishing PV panels have been prevalent in various industry reports [17]–[19]. These reports acknowledge the numerous social, environmental, and economic benefits of establishing a second life for PV panels. However, challenges, including legal constraints, policy issues, consumer mistrust, and the industry's relatively immature state, hinder the widespread reuse of PV panels, as extensively discussed in a report from the CPVA [19].

Due to the lack of standard protocols for testing regimes for the second life of PV panels, various studies report the reusability of PV panels based

Table 4. Recent studies in reuse of PV panels.

Ref	Sample size	Panel age (years)	Tests	Country	Reusability (%)
Shah [15]	25	6-12	• Visual inspection • IV tests • Thermal imaging	Australia	NA
Stromberg [16]	221	2-20	• Visual inspection • IV tests • Thermal imaging	USA	64
Skoczek [17]	204	19-23	• Visual inspection • IV tests • Thermal imaging	Italy	65
Tsanakas [19]	NA	NA	NA		45-65
Rabanal-Arabach [20]	1000	NA	• Visual inspection • IV tests • EL • IR imaging	Chile	30-34
Nieto-Morone [21]	NA	NA	• Visual inspection • IV tests • EL • IR imaging	Spain	87

on different tests and criteria, as shown in *Table 4*. The reusability of panels is contingent on factors such as panel age, geographic location, panel technology, and the chosen testing regime. Consequently, in the current scenario, there is a potential for consumer mistrust and doubts about the reliability of these second-hand panels.

Moreover, the feasibility of repairing panels is contingent upon the type and severity of the defects or faults. Solar panels commonly encounter a range of such issues, as shown in Table 5. While some defects and faults can be easily and reliably repaired, others are more labour-intensive/or challenging. The fault related to the junction box and bypass diode, as well as cables and connectors, are commonly repaired and represent the most prevalent methods for refurbishing used panels. The extent of repair work has a direct influence on the economic viability of panel reuse. Nonetheless, the reutilization of solar panels should be also motivated by environmental considerations [25] and social factors [26].

Solar panel failures are often linked to the deterioration of backsheet materials, particularly in more extreme climate conditions, such as hot and humid environments. Cracking of these backsheet materials can compromise electrical insulation, thereby posing safety risks. Failures have been reported across various types of backsheet materials, including polyvinylidene fluoride (PVDF) [28], polyethylene terephthalate (PET) [29], and notably, co-extruded polyamide AAA backsheets installed between 2010 and 2015 [30], [31]. Consequently, efforts have been made to repair these backsheets and prevent premature solar panel failure.

Researchers have proposed various coating materials, such as epoxy, polyurethane, acrylic, nitrile rubber, and silicone, for mending cracked backsheets [27], [32]. Notably, flowable silicone sealants, developed by DOW Chemicals, have proven effective in repairing backsheets, even in cases of deeper cracks, with the ability to withstand leakage testing and accelerated aging [27]. This versatile sealant can be applied as a spray or with a brush, making it suitable for both workshop and in-field repairs. These advancements provide promising solutions for the maintenance and extended lifespan of solar panels.

Table 5. Panels defect/fault types and their repair solutions.

Panel defect/faut type	Repair solution
Glass breakage	Less desirable
Junction box and bypass diode failures (e.g. loose contact, burnt diode, etc)	Remove junction box and replace with equivalent new one
Cell interconnect (e.g. burn marks)	Less desirable
Water ingress and internal corrosion	Less desirable
Cell discolouration	Less desirable
Encapsulant discolouration	Less desirable
Damaged/missing cables and connectors	· Replace cables · Mount new connectors on cables
Backsheet (e.g. cracks, bubbling)	Clean backsheet and apply a coating on top of the original backsheet [24]

4. PV reuse commercial cases

PV reuse is a nascent but growing industry. This section describes case studies of some organisations that are reusing PV panels today. There are likely other organisations that are not listed here, but this section summarises them and their activities.

PV reuse organisations do several activities, which we have summarised as collection, wholesale, retail, testing, refurbishment, and integration. These are described in *Table 6*.

The organisations are listed in *Table 7* and described further below. Ones marked with an asterisk (*) do not appear to be actively engaged in PV reuse currently however had reuse as part of their initial business model. In both cases they found their potential customers were not receptive to reused PV panels.

Table 6. Second-life PV activity model.

Activity	Description
Collection	Collection of decommissioned PV panels
Wholesale	Reselling second-life PV panels to businesses
Retail	Reselling second-life PV panels to individuals
Testing	Testing decommissioned PV panels
Refurbishment	Refurbishing or repairing damaged decommissioned PV panels
Integration	Integrating second life PV into products or installing second-life PV in PV arrays

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SecondSol	Europe		●		●	●	
PVXchange	Europe		●				
Repurposing for Resilience	Australia	●		●			●
PVLab	Australia				●	●	

4.1 Circusol

www.circusol.eu/en

The Circusol project was "An Innovation Action project funded by the Horizon 2020 program of the European Commission" [33]. It acted as an incubator for a series of commercial initiatives in the solar power sector., bringing together 15 partners from 8 countries. of these, 5 were research centres or university, 9 were industrial partners, and one was a consultancy.

Their final report described 5 demonstrations which were led by five organisations. 3 of these included second life PV systems, described in *Table 8*.

Table 8. Circusol demonstrations. [34]

Demonstration (organisation name)	Plans and findings
SunCrafter (Germany) **www.suncrafter.de/en-gb**	The SunCrafter project integrated second-life PV modules into light electric vehicle charging stations using 200-250W second-life PV modules. PV modules were sourced from recyclers, remanufacturers, and online platforms. Panels sourced form remanufacturers had been refurbished as part of remanufacturing. Modules are used individually or in small groups (up to four) per charging station. They retain ownership of the charging stations and lease them to customers. SunCrafter worked with Veolia to provide standardised testing and validation of their re-used panels.
Cohousing Waasland (Belgium)	The Cohousing Waasland project installed a 59.91 kW second-life PV plant at their 22-household facility. PV panels were collected through PV Cycle, a Belgian PV recycling organisation. They were then sorted, and electroluminescence tested. The source modules had mostly originated from rooftop PV systems where some modules from an array had been damaged (e.g. due to weather) but the entire array was replaced. They found the largest challenge was managing the different module electrical characteristics. This required additional Maximum Power Point Tracker (MPPT) controls.
ScalingPSS (Switzerland)	ScalingPSS was planned to be a solar PV group purchase model using second life PV panels. They found the group purchase business model was attractive, but their prospective customers preferred new to re-used PV panels. Therefore their offering at this stage is includes new panels only.
REScoop PV (Belgium)	The REScoop PV project aimed to test a solar PV and battery as a service business model where residential customers could have purchased PV energy from a second life PV system called "Eco Fix". They found that Flemish PV owners were receptive to second-life PV systems, but the project ultimately did not proceed due to a perceived unattractiveness of the financial proposition. They found that: • Changes in regulatory conditions (removal of net metering) reduced the value proposition of PV • Home owners preferred to own their PV systems • Lack of solar installers and panel sources • Unfavourable economics

4.2 Goodsun

www.goodsun.life

Goodsun is a nonprofit who aims to increase the sustainability of solar power. They take used PV panels from residential installations that have been upgraded. The donation of the used PV modules is a tax deduction for the donor. The used panels are deployed in projects In the US and overseas. They also offer used panels for sale on their website. These panels are sold as untested.

4.3 Fabtech solar solutions

fabtech.net

Fabtech solar solutions are a US electronics and PV panel refurbishment, recycling, and resale business.

Fabtech pay for solar panels on the basis of a visual assessment. Panels are suitable for reuse if:

- Glass is not broken
- They are physically in good condition, although they can have broken frames, slight backsheet cracking, snail trails, or broken wires or junction boxes
- They prefer panels over 230W.

Fabtech repair and test solar panels and offer a one-year warranty on used panels they sell. They say they have diverted 201,000 solar panels for reuse since 2019.

Fabtech propose that refurbished solar panels are suitable for DIY, recreational vehicles, farms, pumps or off-grid applications.

4.4 My second life solar

www.mysecondlifesolar.com

My Second Life Solar is a solar installation company that specialises in upgraded systems. PV panels they remove during upgrades are reinstalled in other locations. They have installed their first array: an 8 kW system, but do not appear to be actively accepting panels currently [31]. PV panels are tested before re-use using a proprietary technology developed by CSIRO [32].

4.5 EnergyBin

energybin.com

EnergyBin are a US based exchange for repair, resale, and recycling of PV hardware [37]. They have a membership based model in which prospective buyers and sellers join to gain access to their marketplace [37]. EnergyBin has over 1,000 members [37]. It is unclear how many of them are involved in PV refurbishment or reuse

4.6 SanTan Solar

www.santansolar.com

SanTan Solar are a US based reseller of PV panels, inverters, and other related hardware to the DIY community. Many of the panels they sell are used [38]. PV panels they sell are inspected for quality [39], although it is unclear exactly what inspections are undertaken. Panels are listed in various conditions. They list PV panels in various conditions. Some have no noted faults, while others have various descriptions of faults. Inspection of their website shows damage such as “blemished”, “cracked vinyl”, “frame damage”, and “brown”. They offer a one year warranty on panels they sell.

4.7 SecondSol

www.secondsol.com

SecondSol are a German marketplace for new, used, and factory second PV modules. They state they have over 45, 000 users, 4,000 active sellers, 1,000,000 listings, and 250,000 spare parts in stock [40]. SecondSol do not offer any warranty however they do offer repair and test services. They say they can repair most used PV modules, and provide examples of repair such as replacement of diodes, junction boxes, and removing soiling. Post repair they do wet leakage and performance tests [41]. They also offer test services including performance, electroluminescence, and thermography. They say they can test 80-100 modules a day and propose a cost of 16-24€ ($27-40) per module to test depending on volume [42].

4.8 PVXchange

www.pvxchange.com

PVXchange are a German PV brokerage company who offer used PV modules [43]. Some of these modules are listed as inspected, although details of inspection are not publicly available.

4.9 Repurposing for Resilience

rfreurobodalla.com.au

Repurposing for resilience are a PV re-use organisation in the Eurobodalla region of Victoria. They have integrated reused PV panels into a number of devices such as rubbish bins and an off-grid emergency power trailer. They accept PV panels either at their reuse centre or can remove them if required.

4.10 PVLab

pv-lab.com.au

PVLab are a PV test lab in Australia. They primarily focus on testing and validation of new PV panels. They are currently undertaking a PV refurbishment and reuse research and development project of which this report is part of.

5. Summary

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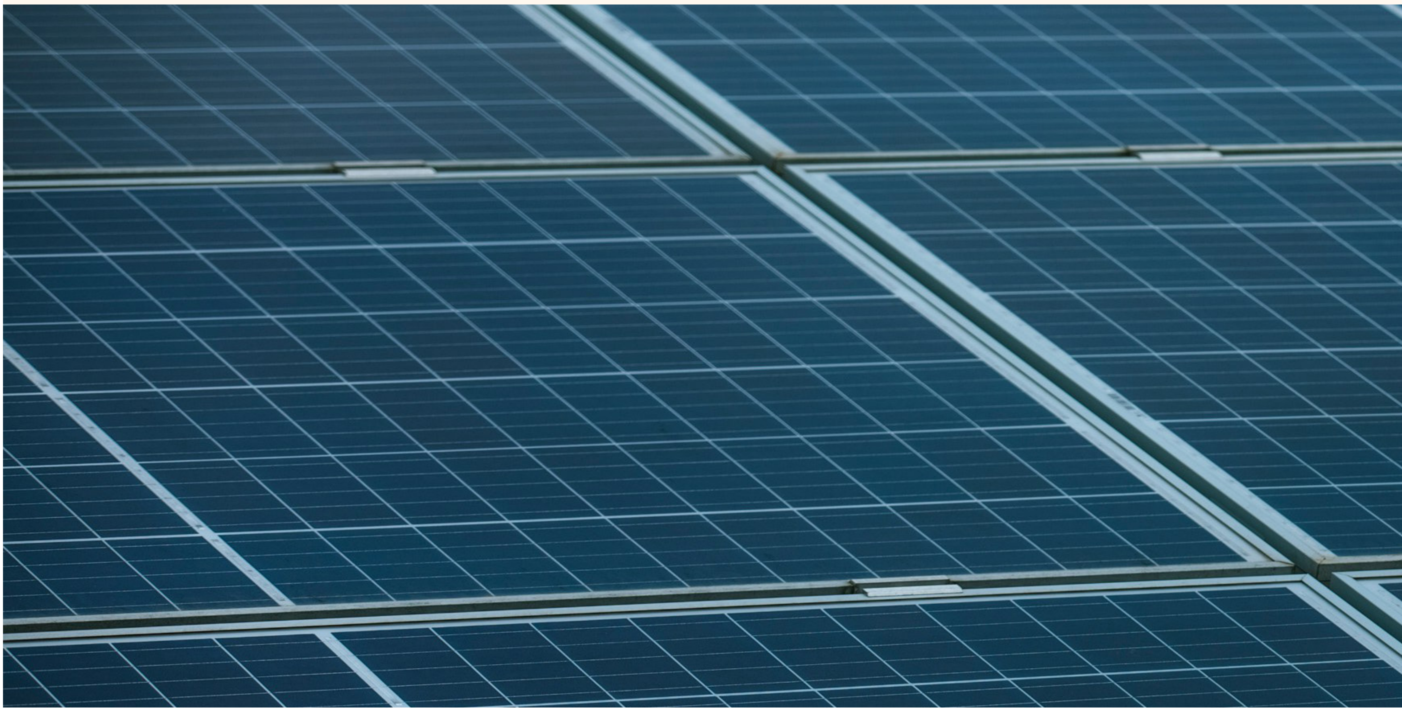

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SecondSol	Europe		●		●	●	
PVXchange	Europe		●				
Repurposing for Resilience	Australia	●		●			●
PVLab	Australia				●	●	

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