Performance and Reliability Aspects of 2nd Life Photovoltaic Modules

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Executive Summary

This report addresses the performance, reliability, and practical feasibility of second-life photovoltaic (PV) modules, with a specific focus on repair, refurbishment, and reuse strategies. In the context of rapidly increasing global PV deployment, sustainable approaches to extend module lifetimes and manage end-of-life flows are essential to limit future waste streams and to support circular economy's objectives. The intended audience of this report is broad and includes policymakers, PV system owners and operators, manufacturers, insurers, researchers, and other stakeholders with varying levels of technical expertise.

The report consolidates technical findings, process developments, and field experience related to second-life PV. A comprehensive review of PV module repair strategies is provided (Figure 1), covering a wide range of defect types such as backsheet cracking, solder bond and interconnect failures, junction box and bypass diode issues, and localized glass damage. Repair approaches discussed in the report span laboratory-scale concepts, pilot implementations, and multi-year field demonstrations.

A key distinction is made between repair technologies that have undergone extended reliability testing or long-term field validation and those that have so far demonstrated feasibility primarily through process development or short-term post-repair performance measurements. While many repair techniques are technically feasible, the review highlights that repair remains labour-intensive and difficult to scale economically, particularly when defects are rooted in intrinsic design or manufacturing weaknesses.

Beyond repair, the report places strong emphasis on reuse pathways based on systematic testing, sorting, and qualification of decommissioned modules. Visual inspection, I–V characterization, electroluminescence imaging, and insulation resistance testing form the technical backbone of reuse-oriented triage frameworks. Automated and semi-automated testing solutions, mobile laboratories, and AI-assisted diagnostics are identified as key enablers for in-creasing throughput, consistency, and cost efficiency, allowing modules to be reliably classified into reuse, repair, or recycling streams.

Economic considerations are addressed throughout the report in a qualitative manner. In many market contexts, the declining cost of new PV modules constrains the competitiveness of labour-intensive repair approaches. Nevertheless, second-life PV can be viable in specific situations, including logistics-constrained or remote installations, repowering projects, and regions with supportive regulatory or financial frameworks. Policy instruments such as eco-contribution schemes are highlighted as effective mechanisms to stimulate reuse markets and help bridge cost gaps between new and second-life products.

From a policy and market perspective, the lack of harmonized requalification criteria, standardized testing protocols, and clear repair guidelines remains a major barrier to broader adoption of second-life PV. Ongoing standardization activities within IEC technical committees and PV quality assurance initiatives are therefore critical to improving transparency, comparability, safety, and bankability of reused PV modules.

Field experience and demonstration projects presented in the report confirm that second-life PV systems can deliver tangible benefits, including stable energy yields, reduced environ-mental impact, and contributions to local energy autonomy. At the same time, these case studies highlight persistent challenges related to module heterogeneity, certification and requalification, insurance and bankability, logistics, and regulatory compliance. The reported experiences underline the importance of robust qualification procedures and clear system integration guidelines.

This report does not aim to provide a comprehensive quantitative performance or reliability assessment of all repair technologies. Instead, it offers a structured overview of existing practices, emerging solutions, and key knowledge gaps in testing, standardization, and market frameworks. By consolidating current experience and clearly stating limitations alongside opportunities, the report seeks to inform future research, standardization activities, and policy development for second-life PV.

Repair, refurbishment, and reuse of PV modules represent technically viable and environmentally beneficial pathways to extend the operational life of solar assets and reduce waste. The review presented in this report demonstrates that a wide range of PV module defects can be addressed through repair; however, the maturity, scalability, and long-term reliability of these solutions vary significantly. Only a limited subset of repair approaches has been supported by multi-year field data or extended reliability testing, and repair should therefore be applied selectively, with careful consideration of defect type, module age, and underlying failure mechanisms.

Testing- and sorting-based reuse strategies emerge as the most robust and scalable option for second-life PV deployment. Standardized inspection and qualification procedures—prioritizing safety and traceability over marginal performance gains—are essential to ensure confidence among system owners, insurers, and investors. The absence of harmonized requalification protocols and clear pass/fail criteria remains a major barrier to market uptake and bankability of second-life PV products.

Economic feasibility remains a decisive constraint. In many regions, the low and continuously declining cost of new PV modules makes replacement more attractive than labour-intensive repair. Nevertheless, reuse and selective repair can be economically justified in specific contexts, including repowering projects, remote or hard-to-access installations, and policy-supported reuse schemes. Case studies included in this report demonstrate both the potential value of second-life PV and the practical challenges encountered in real-world implementation, including technical compatibility, logistics, regulatory uncertainty, and market acceptance.

Progress toward broader adoption of second-life PV will require coordinated advances in technology, standardization, and policy. Improved design-for-repairability, increased transparency of bills of materials, and the development of internationally harmonized standards for testing, requalification, and certification are critical enablers. Policy measures such as eco-contributions, incentives, and reporting requirements can play a key role in creating a level playing field for second-life products.

In summary, second-life PV has clear potential but is not a universal solution. Its successful deployment depends on rigorous qualification procedures, scalable testing and reuse infra-structure, and supportive regulatory frameworks. Continued collaboration between industry, research organizations, and policymakers is essential to transition second-life PV from isolated pilot projects toward a mature, reliable, and trusted market segment.

Key Takeaways

1. The second-life PV market remains fragmented and underdeveloped. The lack of harmonized qualification criteria, standardized testing protocols, and repair guidelines significantly limits transparency, comparability, and trust in reused products.
2. Repair of PV modules - whether addressing solder bond failures, cracked backsheets, or junction box issues - has been demonstrated as technically feasible. However, field experience shows that repair is often labour-intensive, costly, and difficult to scale without automation.
3. Automated testing systems capable of IV characterization, electroluminescence imaging, and insulation resistance testing provide a scalable path for large-volume triage. This approach allows efficient classification into “reuse,” “repair,” or “recycle” streams, minimizing labour costs and ensuring greater consistency.
4. Pilot projects confirm that second-life PV systems – sometimes combined with second-life batteries systems – can deliver tangible benefits in energy autonomy, reduced emissions, and protection against electricity price volatility.
5. Economic viability is still a decisive bottleneck. Repair and reuse compete with the rapidly declining cost of new PV modules, making financial incentives or eco-contributions crucial to establish a reuse market. This underlines that regulatory clarity, funding schemes, and circular economy mandates will be central to scaling second-life PV solutions.
6. Design-for-repairability and BOM transparency are emerging as critical enablers for second-life PV. Future standards and eco-design policies should promote component accessibility, replaceability (e.g., junction boxes/diodes), and clearer BOM documentation, which in turn will reduce triage uncertainty and improve the economic feasibility of repair and reuse.

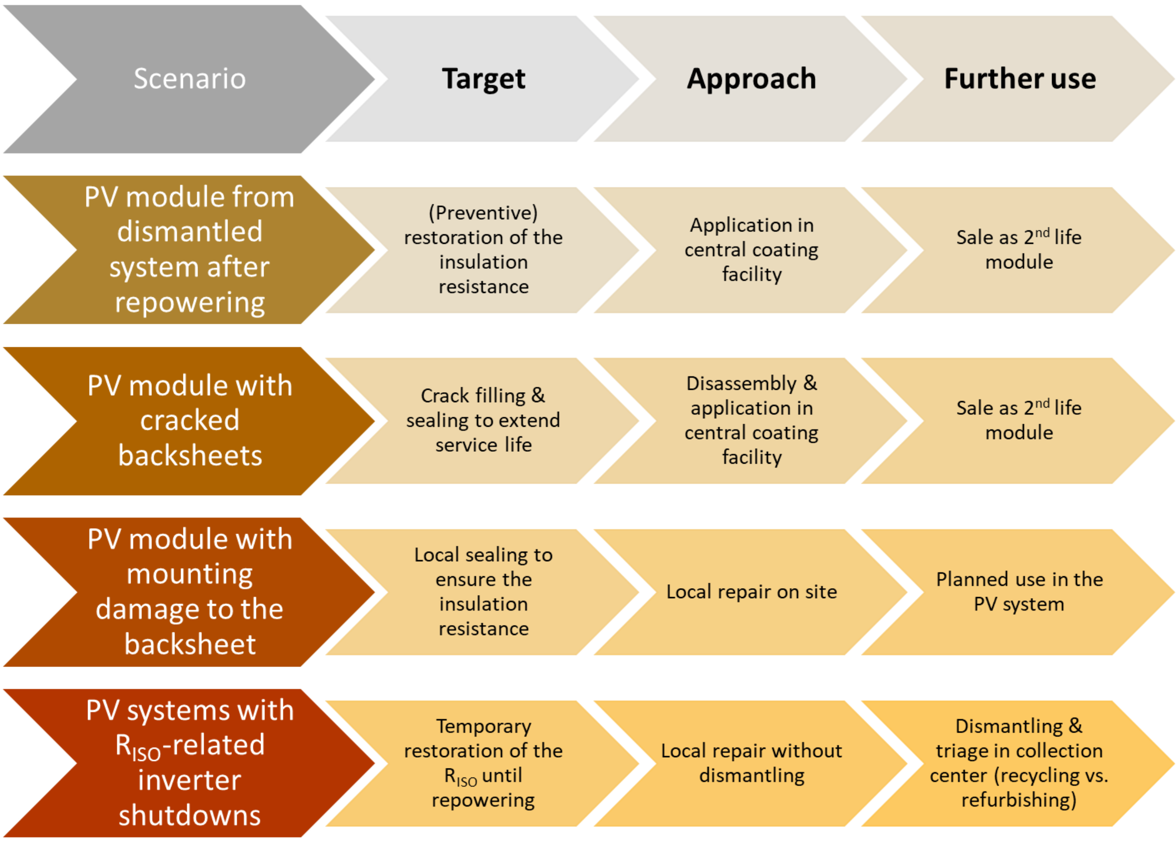

Figure 1: Repair scenarios for 2nd life PV modules with backsheet issues, as identified by the ReNew PV Project [https://projekte.ffg.at/projekt/5123552]