Roadmap for the Photovoltaic Industry

Recommendations to help tackle end-of-life challenges

1 *Recommendation 1* | *Follow circular economy principles*

2 *Recommendation 2* | *Adopt digital materials passports to improve data standardisation and traceability*

3 *Recommendation 3* | *Prioritise design for disassembly, reuse, durability and recyclability*

4 *Recommendation 4* | *Mitigate early loss scenarios and extend lifecycle of materials*

5 *Recommendation 5* | *Explore partial repowering and cannibalisation strategies*

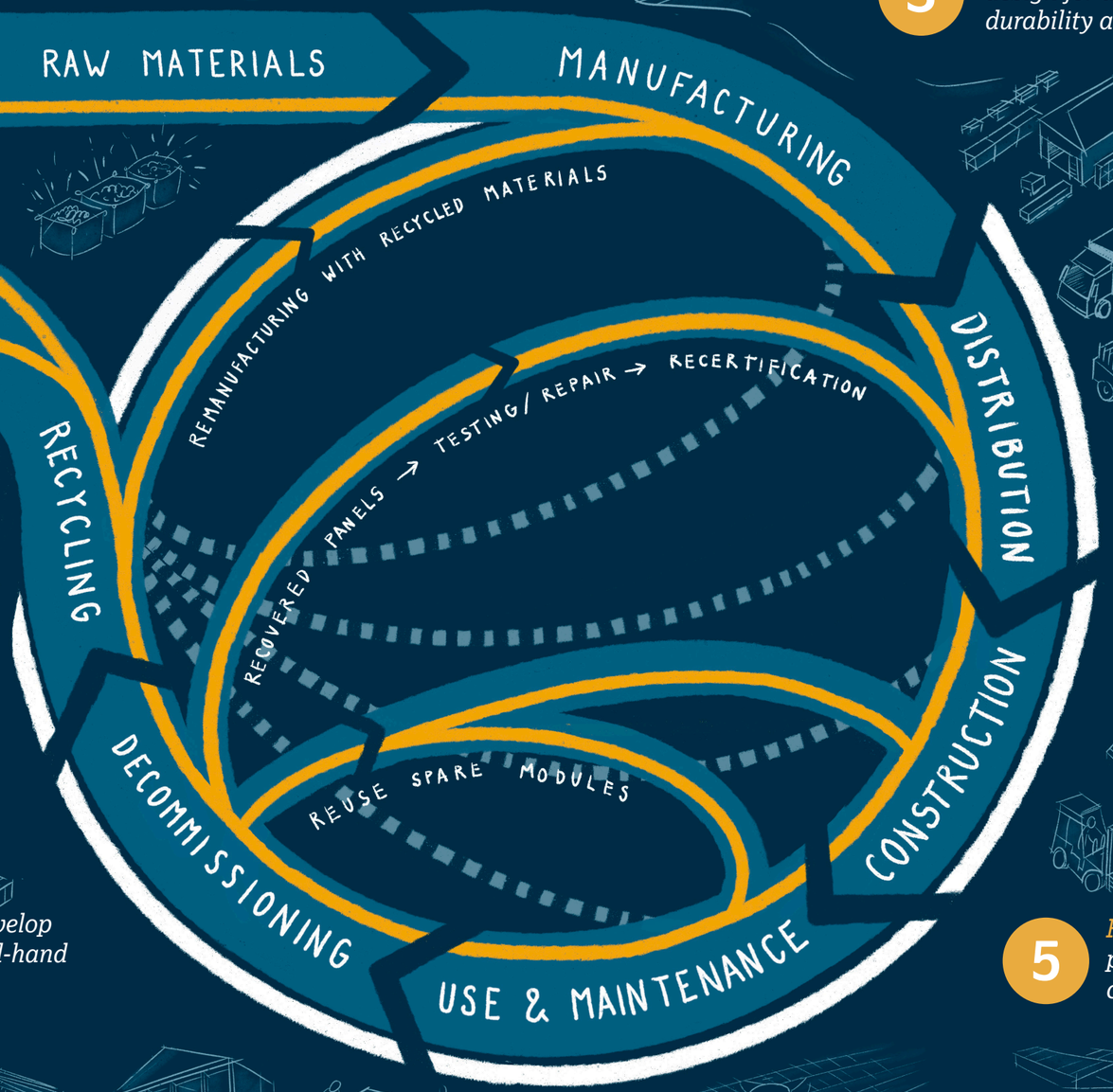
6 *Recommendation 6* | *Explore reuse potential and second-hand market opportunities*

7 *Recommendation 7* | *Develop partnerships and second-hand market support*

8 *Recommendation 8* | *Improve recycling processes and technologies*

9 *Recommendation 9* | *Create specific regulations for PV panels*

10 *Recommendation 10* | *Investment in research and knowledge exchange opportunities to tackle end-of-life of PV panels*



PV Panels lifecycle to create a cicular economy

Early loss recycling loops

Digital Materials Passports

Second-hand markets, e.g. domestic use, universities, hospitals, community hub

The PV industry, government and researchers need to work together to achieve these recommendations. If we tackle the challenges that affect the end-of-life of PV panels now, we will be able to build a truly sustainable and brighter future.

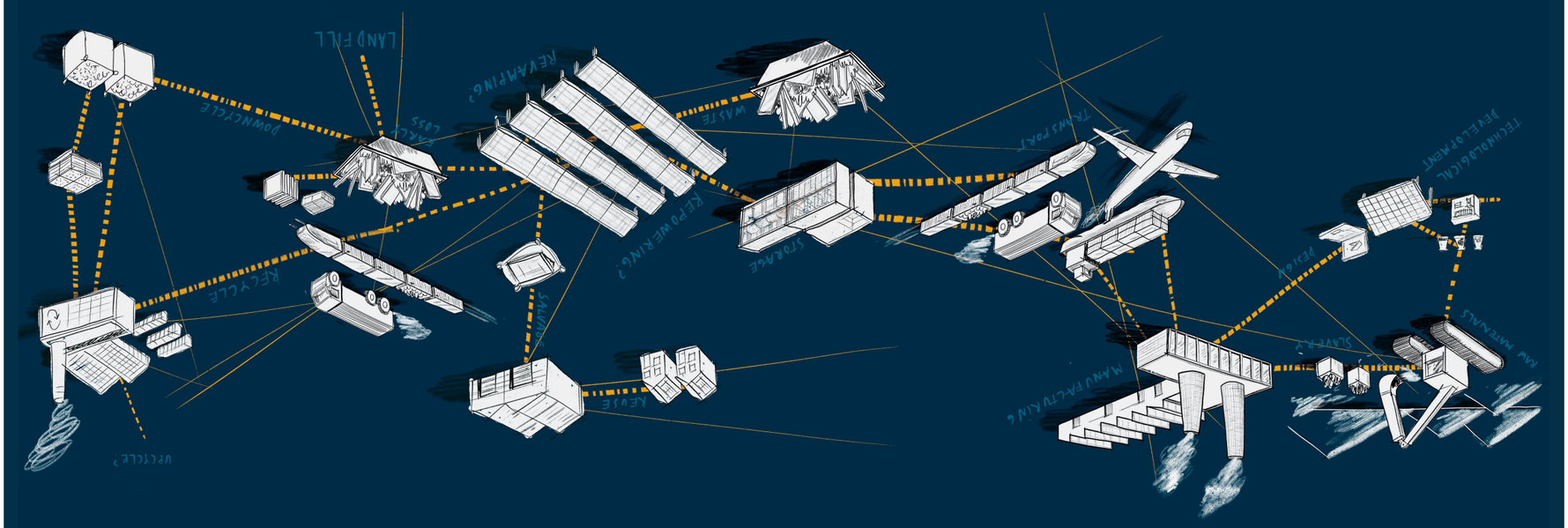
The solar photovoltaic (PV) industry plays a vital role in the global transition to low-carbon energy. With the rapid growth of installations, PV technology supports enhanced energy security, lower electricity costs, and contributes significantly to reducing greenhouse gas emissions: an essential step towards achieving net-zero energy goals.

However, to fully capitalise on its benefits, there must be a focus on addressing the end-of-life of PV panels. Solar panels are generally designed to have a lifespan between 25 and 30 years. Nevertheless, PV panels can be removed after only 10 to 15 years due to early life failures, and replaced with more efficient ones. Consequently, up to 78 million tonnes of PV waste may be produced by 2050.

Improved recycling practices, better panel designs for disassembly, and the transition to a circular economy model are essential for enhancing the sustainability of the solar PV industry. The UK has a significant opportunity to lead in these efforts, both in terms of innovation and policy development.

For a Brighter and Sustainable Photovoltaic Industry

Recommendations to help tackle end-of-life challenges



The End of Renewable Asset Life Decisions (ERALD) research project was funded by EPSRC IAA at Lancaster University, and Bluefield Solar Income Fund (BSIF), a FTSE 250 solar-focused investment fund. The main output of this project is the white paper that summarises the main challenges to achieve a circular PV sector and highlights potential solutions, providing recommendations for industry and policy makers. Our primary focus is on Crystalline Silicon (c-Si) PV Panels, representing 95% of the PV industry market worldwide.

bluefield Solar Income Fund

Energy Lancaster | Lancaster University

UK Policy Context

The end-of-life of PV panels in the UK is currently regulated under the Waste Electrical and Electronic Equipment (WEEE) Regulations 2013, the UK's implementation of the EU WEEE Directive (2012/19/EU), which was designed to reduce the amount of electronic and electrical waste going to landfill and to promote reuse, recycling and recovery. These regulations place the responsibility for recycling PV panels on producers, meaning manufacturers and importers. They are required to be part of a Producer Compliance Scheme (PCS), which ensures proper collection and recycling of panels.

The UK is currently working to ensure that the increased volume of end-of-life solar panels is managed sustainably and doesn't become a significant waste problem. Aligned with the work developed by DESNZ (Solar roadmap: United Kingdom powered by solar), the recommendations presented in this paper are intended to inform the government's policy ambition and help industry and researchers to define their priorities to tackle the challenges that affect the end-of-life of PV panels.

Recommendation 1 | Follow circular economy principles

Promote industry accountability and circular practices: **(1)** Introduce clear regulations and targeted grants to mandate end-of-life planning and support circular practices across the PV sector, **(2)** Follow a revised waste hierarchy, adapted for PV panels, prioritising reuse, remanufacturing and refurbishment followed by recycling and energy recovery, **(3)** Consider decommissioning plans and circular strategies from the early stages of solar farm development, **(4)** Encourage multistakeholder participation in policy development, **(5)** Integrate the consideration of Environmental, Social and Governance (ESG) outcomes within end-of-life solutions, **(6)** Collaborate across the supply chain to drive efficiencies and enhanced transparency, accountability and value retention.

Recommendation 2 | Adopt digital materials passports to improve data standardisation and traceability

The PV industry and governments should create and implement a digital PV Materials Passport (MP) to enable **data standardisation, transparency**, custody of materials and Lifecycle Assessment (LCA) accountability without compromising technical innovation.

Recommendation 3 | Prioritise design for disassembly, reuse, durability and recyclability

The PV industry **should invest in design innovation, consider the Life Cycle Assessment (LCA) of a PV Panel, (1)** Develop holistic technical solutions that consider end-of-life management and support material value retention (enabling reuse, reparability, durability and recyclability through design), **(2)** Adopt **eco-design principles and techniques** (e.g. avoid the use of materials that are difficult to recycle and rely on the use of fossil fuels to produce - such as EVA and POE, delamination solutions).

Recommendation 4 | Mitigate early loss scenarios and extend the lifecycle of materials

Manufacturers and recyclers, supported by governments and research partnerships, should **(1) Explore synergies and opportunities for collaboration**, e.g. establish feedback loops between different members of the supply chain to facilitate the identification of challenges and the development of potential solutions, **(2)** Share recycling facilities among manufacturers, **(3) Develop technologies to support reuse and recycling, (4)** Suggest policy support for warranty tracking and predictive maintenance.

Recommendation 5 | Explore partial repowering and cannibalisation strategies

Manufacturers and recyclers should create research partnerships and business models to **enhance material recovery rates and reduce waste**. Supported by materials passports, the PV Industry should **create a centralised digital spare part hub** to facilitate the exchange of second-hand PV panels and extend the life of solar farms.

Recommendation 6 | Explore reuse potential and second-hand market opportunities

The PV Industry and governments should collaborate to facilitate **second-hand market opportunities**, **(1)** Develop **reuse and repair infrastructure**, **(2)** Expand upon reuse within the WEEE Regulations and create a **specific standard** for second-life PV panels, e.g. domestic use, **(3)** Create **third-party certifications** that can promote market transparency by confirming product quality, **(4)** Create financial incentives to stimulate the reuse market.

Recommendation 7 | Develop partnerships and second-hand market support

Strengthen early, cross-sector collaboration and partnerships across the PV value chain, particularly between manufacturers, recyclers, policymakers and academics to: **(1)** Scale up reuse and repair infrastructure.

Recommendation 8 | Improve recycling processes and technologies

Invest in the current PV recycling processes and technologies to: **(1) Minimise environmental impact and maximise material recovery** rates, **(2)** Inform disassembly, reuse and recyclability, **(3)** Inform and support Extended Producer Responsibility **(EPR) schemes.**

Recommendation 9 | Create specific regulations for PV panels

Strengthen and clarify PV specific regulations: Policy makers should update/revise the WEEE Directive to make it more specific to PV panels and related regulations to: **(1)** Reclassify panels as business-to-business waste, **(2)** Require early end-of-life planning and support high-quality material recovery, **(3)** Enforce Extended Producer Responsibility (EPR), **(4)** Define **standards for reuse versus recycling**, **(5)** Create a **regulatory and financial** environment that encourages innovation in recycling and the growth of the second-hand market, without burdening compliance.

Recommendation 10 | Investment in research and knowledge exchange opportunities to tackle end-of-life of PV panels

The **UK government** should provide targeted grant funding open to both academia and industry to research under three main categories: **1 - Materials (1a)** The LCA of PV panels from extraction to disposal to enable the most sustainable solution to be identified: environmentally friendly, financially viable, socially equitable, **(1b) Further advance recycling technologies** to facilitate a circular economy and recover valuable materials; **2 - Systems and digitalisation (2a) Digitalisation of the PV sector** by implementing material passports, developing systems using AI and digital trackers, **(2b)** Improved transportation, handling and storage of solar PV panels to avoid damage and early failure; **3 - Business models and design (3a) Alternative business models and markets**, **(3b)** Alternative design of PV panels, considering **Design for Disassembly**. **The PV industry and governments should provide worldwide standards, regulations, and policies** that enable material custody throughout the supply chain and provide dedicated guidance for end-of-life solar assets.

Closing Remarks

Solar panels don't just deliver clean energy; they also have the potential to contribute to a more sustainable and circular use of materials. Striking the right balance between producing renewable electricity and managing resources wisely is one of the key challenges the sector must now tackle collectively to strive towards an all-encompassing vision of sustainability.

Work with us

Professor Ana Rute Costa [a.costa@lancaster.ac.uk], Lancaster University, is an academic, chartered architect, fostering the creation of dynamic links and knowledge exchange between academia and industry. Her research focuses on materials passports in a circular economy.

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If you would like to learn more about our research and practice expertise, invite us to speak at your event, or collaborate with us to address Net Zero Targets and promote a Circular Economy across the PV industry.