

A circular model for the PV value chain: from concept to field experience

Increasing the sustainability of the PV market as it grows is crucial. PES takes a look at some of the research and development taking place to help make this a reality. PHOTORAMA is an EU funded project focusing on improving the recycling of PV panels and recovery of raw materials. Could this circularity model be a possible long-term solution?

Solar energy has been deployed since the 1990s, reaching an impressive global capacity of more than 770GW in 2020. As renewable energy, it has been clearly identified as the best candidate to lead the energy transition, heralded as the 'king' of the electricity market by the International Energy Agency.

In the fight against climate change, solar energy has a crucial role. It will help achieve the carbon neutrality target, something which is hopefully no longer a paradigm. As such, solar energy and more globally the photovoltaic (PV) industry should be exemplary and inclusive to set up good practices and leverage other sectors.

Even though PV systems provide zero-emission green energy over their lifetime, the balance sheet should be carefully assessed over the life cycle to offer sustainable alternatives regarding resource depletion, energy-intensive manufacturing and waste management.

Considering the upcoming widespread PV energy production, it is important to start thinking globally and circular. The perspective of a green recovery after the Covid-19 pandemic calls for sound and resilient solutions to develop sustainable industries taking into account economic growth, environmental benefits and social acceptance.

Supporting such a package will require a cooperative and united effort from PV manufacturers, developers, installers, energy producers, end-users, collectors, recyclers and policy makers. It is time to reshape the system with a circular model, to develop a credible and achievable strategy for a global

and sustainable PV industry.

Circular approach in photovoltaics

The circular economy as a visionary concept emerged about 50 years ago and has developed extensively in many fields since then. It is based on three major principles: preserving natural capital, circulating resources and nurturing efficiency in a global system, by minimising negative externalities. It includes economic, environmental and social considerations.

At this stage, implementing such a model requires moving forward to field experience, to develop new business perspectives and incentivise the PV community to adhere collectively. This is the overall objective of PHOTORAMA: PHOtovoltaic waste management, advanced Technologies for recOvery & recycling of secondary RAW MAterials from end-of-life modules, project.

Funded under the European Union H2020 programme, the project gathers 13 key and complementary partners from throughout Europe. By including all stakeholders in the PV value chain, the project aims to implement a circular model from manufacturing to waste management, to reinject secondary raw materials into the economy.

Looking at the PV value chain, many avenues have been investigated at the manufacturing stage in terms of sustainability efforts, while waste management clearly lacks solutions as well as incentive. The challenge here is to connect and bridge two facing business worlds that are completely different.

From PV manufacturing which focuses on

cost of products with an international competitiveness and LCOE perspectives, to the recycling sector which is about cost per tons with a local business issue. The next step is to collaboratively develop a system-based opportunity for the dedicated sectors.

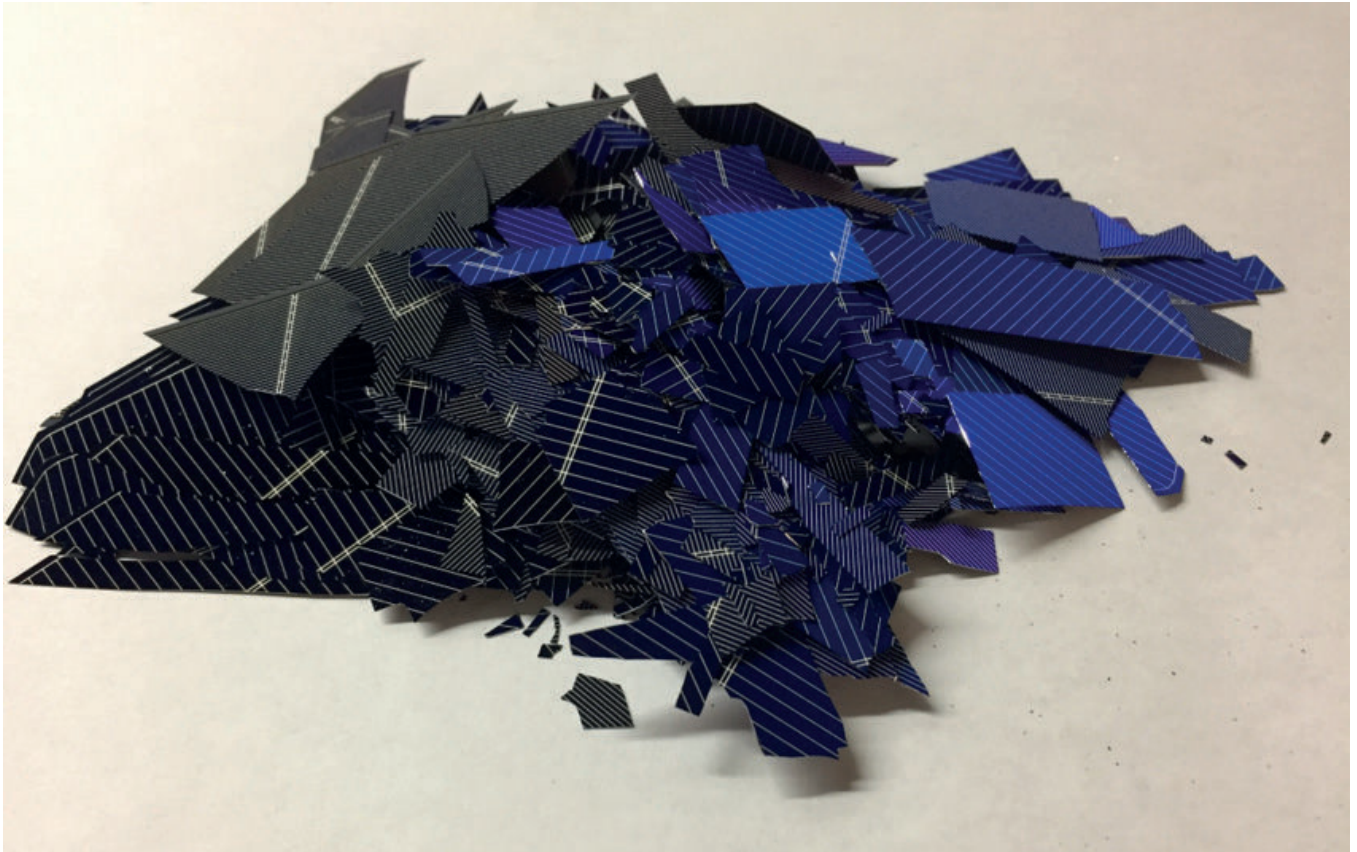
Aside from technological and market-based development, the model and its sustainability performances are assessed throughout the project. Based on economic, environmental and social analysis, the model design will be gradually adjusted to draw up and balance the guidance for circular development within the PV value chain.

The field experience of PHOTORAMA highlights the hotspots in order to shift to new logistics and approaches in terms of circularity for the PV industry. Implementing a circular model is a long-term job and PHOTORAMA as pioneer will demonstrate innovative solutions and nurture progress in the field. By trading information, knowledge and showcasing effective solutions, it will reveal new prospects for a collective and systemic vision of the future of solar energy.

The challenge of photovoltaic waste management

Waste management, including collection, recycling, recovery and production of secondary raw materials, is currently the weak link in the PV value chain. Both the average lifetime about 25-30 years and the unpredictable volume of PV waste have made it difficult to frame a long-term vision.

However, the projections from IRENA show a massive cumulative volume of PV waste expected by 2050: 60-78 million tons



worldwide and about 10 million tons in Europe. The reality of the next decades is that PV waste management is going to become a logistic priority.

Even though the regulatory framework in Europe, WEEE directive 2012/19/EU, has made recycling of PV devices mandatory, current practices are not satisfactory. PV modules are made up of conventional resources, Al, Cu, glass, critical and valuable metals, such as Si, Ag, In etc., and hazardous materials, Pb, Cd, Se.

Most of the recycling practices are based on shredding or crushing processes that are identified as down-cycling approaches. The external components such as the frame and junction box are easily isolated to be recycled, while the glass fraction is usually recovered for very low-value applications. The polymers from the sealing layers and the backsheet are at best recovered as energy fuel, but mostly landfilled and the metals are usually not recovered.

Such schemes lead alarmingly to the irreversible loss of valuable and critical metals, as well as the dispersion of toxic materials. The low amount of these materials embodied in PV modules as a very little share in percentage by mass should not be an argument when talking about million tons of waste.

To tackle the challenge, the PHOTORAMA project focuses on the development of technological solutions for efficient

recycling. The system-based PV waste management maps out different steps to preserve the purity of the materials, allowing the recovery of high purity and high-quality materials. The main challenges are to separate the layers without mixing materials and to recover the scarce and critical metals by mitigating the environmental impacts. The framework of PHOTORAMA includes the recycling of both crystalline-silicon, c-Si based and CI(G)S thin film modules.

The model is designed to manage and monitor the combination of technologies to offer a full-package solution for developing the capital infrastructure in the next operational phase.

Advanced recycling and circular approach on the field

Collection

During the collection phase, SOREN and Enel Green Power deliver the different types of waste required for the technological development throughout the project. SOREN is also developing a harmonised characterisation methodology, built on regulatory standards, to monitor the depollution and the environmental performances of waste treatment.

Recycling and recovery

A full-management pilot line will be implemented on an industrial site at LuxChemtech in Germany for further scale-up, to operate a global recovery ratio

of 98% at 1200 ton a year. The design of the line includes the necessary steps to manage the waste from the disassembling of the external components, to the delamination and separation of the PV multi-layer sandwiches and the recovery of secondary raw materials.

Research institutes, small and medium enterprises and industrial companies are working together to develop and scale-up the technologies. From the early stage of innovation at technology readiness level 4-5, the maturity of the technology will reach TRL 6 to 7 at the end of the project.

By creating a strong team symbiosis, the collective approach enables a strategic pooling of resources at the European level. This allows the best innovative solutions to be developed under the most optimal operational conditions.

The first step of the pilot line focuses on dismantling the aluminium frame and the junction box by operating a fully automated process developed by Mondragon and LuxChemtech. This fast operation, eliminating manual labour, enables safer handling without breaking the glass front sheet, at a low cost.

A pre-unit using x-ray characterisation sorts out the panels to differentiate the c-Si based and the thin film for further treatment. The aluminium will be redirected to a metal refinery, whereas the junction box and electrical supply components will be sent for



treatment with small domestic appliances.

The second step focuses on the delamination of the multi-layer sandwich, made of a glass front sheet, solar cells layer and backsheet. It is the most critical and challenging step, as the purity of the secondary raw materials strongly depends on its performance to avoid mixing the materials layers. Therefore, several complementary technologies are in development to manage all types of PV waste.

A technology based on diamond wire cutting enables the mechanical separation of the layers for the recovery of intact glass sheets. The technology, scaled-up by CEA and Mondragon, will allow high-value recycling or direct reuse of glass, using polymers backsheet for energy fuel and solar cells for further treatment in the line.

CEA and DFD are currently developing another technology based on a physical separation using CO₂ supercritical fluid. The principle is to make the ethylene-vinyl acetate (EVA) inter-layer foam to smoothly open the sandwich. Clean, unbroken glass can be recovered, as well as the polymer backsheet and the cells residues slightly attached to the foamed layer. Importantly, CO₂ fluid is a green solvent non-toxic, non-flammable and recyclable in the process loop.

These two technologies are dedicated to the c-Si-based panels' treatment, while the third one is to operate the delamination of CI(G)S

thin-film panels. LuxChemtech is developing this, based on light radiation that damages the photoactive layer enabling the mechanical separation of CI(G)S glass sheets. The semiconductors and conductors thereby become accessible for wet-chemical treatment and can be recovered hydrometallurgically.

Finally, two technologies are being developed for metal recovery as the last and third step of the pilot line. One using green solvent, so-called ionic liquid recyclable in the closed-loop process, followed by an electrolysis process to recover Ag from the leachate containing the silicon, CEA, Sintef, IDENER R&D.

LuxChemtech scales-up the second technology using biodegradable organic sulfonic acid to extract the metals either from c-Si, such as heterojunction technology or from CI(G)S residues. Both processes allow for a high recovery ratio and high purity level of metals and are more environmentally friendly than current processes.

Re-use of secondary raw materials

As a multi-level approach integrating a circular model, the recovered metals so-called secondary raw materials are reinjected back into the industry, either in the market PV or in other value chains. RHP and LuxChemtech are working on the best approach, depending on the purity and morphology of the recovered metals.

By mixing virgin and secondary raw materials, new products will be developed and tested in operational conditions. Enel Green Power will trial and validate products dedicated to PV applications in an industrial environment using an eco-design approach.

Model assessment & development

Bifa continuously carries out economic and environmental analysis while ZSI monitors progress in terms of social acceptance by driving living Lab/co-creation workshops. The dissemination and business exploitation of the project's results led by ENEA involves the whole consortium.

Photorama refers to a photography process from the Lumières brothers to provide a panoramic view enabling the full reproduction of the horizon. Looking at the big picture, this is the approach of PHOTORAMA: to implement a circular strategy for a more sustainable PV industry.



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🌐 www.photorama-project.eu

LuxChemtech will be at Intersolar Munich, May 11th to 13th, booth A5.540