FACTSHEET #9

The objective of RESiLEX is to improve the resilience and sustainability of the entire Silicon value chain and reduce EU dependence on critical raw materials for solar panel and battery production. Silicon is considered a critical raw material for the EU due to its high supply risk and economic importance, mainly because of heavy reliance on imports

Eco-Designing the Next Generation of Sustainable Solar Panels



Have you ever wondered how "green" a solar panel truly is, considering not just the energy it produces, but also how it's made and what happens at the end of its life? In a recent Resilex report done by CSEM, we offer us a clear vision of how Europe is working to make the photovoltaic industry not just powerful, but also profoundly sustainable. The core concept is "eco-design", which it's not just about producing clean energy, but doing so in the cleanest way possible, from the silicon sand to the house where the panel will be installed.

How to measure sustainability?

Sustainability is a balance between society, economy, and environment, aiming to meet the needs of the present without compromising future generations. To put this into practice, tools like the United Nations Sustainable Development Goals (SDGs) and the Circular Economy model are used. The **Circular Economy** is a true revolution: instead of the classic "take-make-dispose," the focus is on reducing, reusing, recycling, and recovering materials for as long as possible. Its seven pillars include sustainable sourcing, eco-design itself, industrial ecology, functional economy (based on use rather than ownership), responsible consumption, product life extension, and recycling. Eco-design is the starting point for addressing all these challenges.

Eco-design, according to *ISO 14006*, is a systematic approach that integrates environmental aspects into product design and development to reduce negative impacts throughout the entire life cycle. This approach is based on the "**3Rs: Reuse, Recycle, Reduce**."

- Design for Reuse: Creating products that can be easily reused or whose components can be repurposed for other applications.
- Design for Recycling: Simplifying design and using recyclable materials to facilitate disassembly and material recovery at end-of-life.
- Design for Reduce: Minimizing the use of resources, energy, and materials right from the design phase (e.g., by reducing weight and dimensions).

All these strategies are validated through Life Cycle Assessment (LCA), a tool that analyzes the environmental impacts of a product from raw material to disposal.

European directives driving the change

The European Union is introducing a series of regulations to guide this transition.

- **Critical Raw Material Act** (CRMA): the EU is highly dependent on external sources for critical raw materials (CRMs), such as rare earths from China (98%) or lithium (97% imported). The CRMA, adopted in March 2024, aims to ensure a secure and diversified supply of these materials, setting ambitious targets for extraction (at least 10% of EU consumption), processing (40%), and recycling (at least 25%) by 2030, and limiting reliance on a single country (no more than 65%).
- **Net Zero Industry Act** (NZIA): aims to strengthen the production of clean technologies in Europe, targeting a manufacturing capacity of "net-zero" technologies equal to at least 40% of the EU's annual needs by 2030. This includes simplifying procedures, integrating sustainability criteria into public procurement (carbon footprint, recyclability, biodiversity), and developing skills.
- **Eco-design Directive**: is evaluating new regulations to establish minimum energy performance and sustainability requirements for PV modules, inverters, and related systems. The goal is to reduce the carbon footprint and improve recyclability, with carbon footprint thresholds expected from 2025.
- **EPEAT Ecolabel**: an internationally recognized ecolabel that certifies electronic products based on their environmental impact. For PV modules, specific criteria have been set for "Low Carbon" (≤ 630 kg CO_2e/kWp) and "Ultra-Low Carbon" (≤ 400 kg CO_2e/kWp) based on "cradle-to-gate" life cycle assessment.

- Extended Producer Responsibility (EPR): Regulations like the AGEC law in France, which from January 2025 implements a bonus-malus system for PV panel producers, incentivizing more sustainable practices such as better recyclability and a lower carbon footprint.



Current challenges in photovoltaic production

Despite their "green" nature, PV panels do have an environmental impact, especially in the production phase. RESiLEX focuses on silicon heterojunction (SHJ) technology, which, while efficient and low-carbon, presents some material-related challenges.

- **Silicon**: it's a critical raw material for the EU, and its purification and processing into ingots and wafers require a lot of energy, significantly contributing to the PV module's carbon footprint.
- **Silver** (Ag): it's a limiting factor for large-scale production. SHJ consumes more of it than other technologies (24.6 mgAg/W in 2023) due to low processing temperatures requiring specific silver pastes. Reducing its consumption to below 5 mgAg/W is crucial to achieve multi-terawatt production targets.
- **Indium** (In): although removed from the EU's CRM list due to domestic production, it remains critical for the PV industry due to high consumption (4.23 mg/Watt in SHJ cells) compared to global supply. Its availability is limited by zinc production, of which it is a byproduct.
- **Glass and Aluminum Frame**: significantly contribute to the CO2 footprint in the module production phase. Solar glass can contain antimony, which complicates recycling.
- **Encapsulants** (e.g., EVA): While having a low impact in the production phase, their chemical nature (cross-linked polymers) makes separation and end-of-life recycling difficult, as they are irreversible.
- **Backsheet**: can contain fluoropolymers (PVF, PVDF), classified as PFAS. These materials, due to their toxicity and difficulty of end-of-life disposal, are under review for a potential ban in the EU.
- **Interconnections**: often use silver and lead-based solders, both problematic for sustainability.

It's also important to consider the trade-offs of eco-design: choosing "greener" materials must not compromise the module's durability and performance, as a long lifespan is essential to reduce the environmental impact of solar electricity per kWh.

Resilex prosposed solutions for solar cells

- Silicon Reduction: exploring the use of silicon recovered from revalued waste and thinner wafers to reduce material consumption and carbon footprint (a 10 µm thinning can reduce the footprint by about 20 kg CO_2e/kWp). Also studying the reuse of "kerf" (silicon dust lost during wafer cutting) to reduce GHG emissions by up to 77%.

- Indium Reduction: Three approaches are being studied:
  - "In-less SHJ": drastically reducing the thickness of the indium tin oxide (ITO) layer, compensating with a silicon nitride dielectric layer. This aims to reduce indium by 70%.
  - "Indium-free" Transparent Conductive Oxides (TCOs): Developing aluminum-doped zinc oxide (AZO) layers as an alternative to ITO.
  - "Indium-free" TCOs with non-vacuum techniques: using spatial atomic layer deposition (SALD), which doesn't require vacuum chambers, reducing costs and energy consumption.

- Silver Reduction:
  - Copper-based pastes (silver-coated copper): partially or completely replacing silver with copper in pastes for screen printing electrodes.
  - Copper electrodeposition: a "silver-free" process based on screen printing a copper base grid followed by copper electrodeposition.

The project defines three main scenarios for solar cells: a reference configuration, one with indium and silver reduction, and one completely indium-free and silver-free.

Resilex proposed solutions for PV modules:

- Bio-based Materials: replacing PV components with biomass-derived materials to reduce reliance on fossil fuels and greenhouse gas emissions.
- Aluminum-free Modules: replacing the aluminum frame with bio-based materials like wood, although this requires additional testing (e.g., fire resistance).
- Glass-free Modules: using polymeric front sheets (preferably non-fluorinated) to replace glass, to reduce the module's global warming potential.

The first prototypes of eco-designed mini-modules have shown promising results.

- **Mini-modules with eco-designed backsheet** (CSEM): modules were created with a rigid composite backsheet based on flax fibers and polypropylene, a non-fluorinated polymeric front sheet, and a PO-based encapsulant. These modules passed standard IEC humidity and thermal cycling tests, demonstrating the compatibility of the new materials. A preliminary analysis showed that these eco-designed modules have a lower global warming potential than conventional glass/glass or glass/backsheet modules. Although the flax backsheet had a higher CO2 equivalent impact than a conventional backsheet, its rigidity allowed the removal of the front glass, significantly reducing the module's total GWP.

- **Modules with low-Indium and low-Silver cells** (CEA): modules with bio-based encapsulants and SHJ cells with reduced silver and indium content were tested in glass/glass and glass/backsheet configurations. These modules showed excellent results in aging tests, exceeding standard IEC requirements.



Wrap up

The eco-design strategies of the RESiLEX project aim to reduce CO2 emissions, minimize the consumption of critical resources, and promote the reuse and recycling of materials. Innovation in SHJ solar cells and the use of alternative materials are essential to achieve sustainable multi-terawatt production. With regulatory support and continuous research, the European PV industry is moving towards a more sustainable and resilient future.

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