FACTSHEET #7

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

Life Cycle Assessment for new and innovative eco-designed solar cells and modules



This document summarizes a more extensive analysis carried out by Ghent University that assesses the environmental sustainability of two innovative technologies (ITs) developed to enhance the resilience and sustainability of the European silicon value chain and photovoltaic (PV) industry. These are eco-designed solar cells (IT1) and modules (IT2) developed by the Resilex project.

Life Cycle Assessment (LCA): the key tool

To evaluate the environmental sustainability of these innovations, RESiLEX uses Life Cycle Assessment (LCA), a globally recognized methodology. LCA quantifies the environmental impacts of a product or process from raw material extraction to final disposal, identifying "hotspots" in terms of emissions and resource consumption. The phases of LCA are:

1. **Goal and Scope Definition**: This step establishes what will be evaluated and why, defining the functional unit (the reference for comparison) and the system boundaries.
2. **Inventory Analysis** (LCI): Quantitative data on all material flows, energy, products, waste, and emissions are collected and calculated.
3. **Life Cycle Impact Assessment** (LCIA): This phase quantifies potential environmental impacts, such as climate change (e.g., kg CO2-eq), ecotoxicity, caused by production systems.

Environmental Impact of Reference for PV Module Production

The first part of the analysis focuses on the environmental impact of a 1 m² silicon heterojunction (SHJ) PV module produced in Europe.

Carbon Footprint (Climate Change):

- The total impact is 65.7 kg CO2-eq per m² of SHJ module.
- Nearly half of this impact (46%) is attributable to module production itself.
- This is followed by silicon refining (28%), cell production (7.9%), crystallization (7.3%), and reduction (6.5%). The slicing section has a minor impact (4.4%).
- This finding, which identifies module production as the main contributor, differs from the prevailing view in the literature, which often points to wafer manufacturing. The reason lies in the use of recent, specific data for solar-grade silicon (SG-Si) production in Norway, which has a lower climate impact than Chinese production, and specific primary data for module production obtained from consortium partners, which might be at a smaller scale than generally assessed.

Other Environmental Impacts:

- For categories like freshwater ecotoxicity and human toxicity, wafer production contributes most (73-92%).
- Mineral and metal resource use is dominated by cell fabrication (69%).
- Module production is also a significant contributor to fossil resource use (44%) and mineral/metal resources (30%).

Comparison of Eco-Designed Cells (IT1-Scenario 1 vs. Reference)

This analysis focuses on the cell manufacturing phase, comparing reference cells with an eco-designed alternative (IT1-Scenario 1) that uses less indium tin oxide (ITO) and less silver, requiring an additional step. The results indicate a clear preference for Scenario 1 across all impact categories considered. The most significant reductions are:

- Mineral and metal resource use: -44%
- Non-carcinogenic human toxicity: -36%
- Climate change, freshwater ecotoxicity, and fossil resource use: approximately -30%

These improvements are mainly attributed to the replacement of silver with copper in the metallization paste and the reduction in the amount of ITO, leading to lower energy consumption. The silver reduction particularly decreases mineral and metal resource use and the impact of the cell manufacturing on human toxicity.

Comparison of Eco-Designed Modules (IT2-Scenario 1 and 2 vs. Reference)

Two eco-designed module alternatives (IT2-Scenario 1 and 2) were compared to the reference module, introducing alternative materials for interconnections, backsheet, and frame (in wood).

- *Climate Change*: Scenario 2 (with a wooden frame) shows a drastic reduction (46%) compared to the reference (30.1 kg CO2-eq). Scenario 1 (with less plastic in the encapsulant) also shows a small reduction (2%). The aluminum frame is the main impact factor in the reference and Scenario 1.
- *Freshwater Ecotoxicity:* Differences are less pronounced. Interconnections, particularly the use of silver, are a key factor. Again, the wooden frame is advantageous.
- *Human Toxicity (Carcinogenic and Non-Carcinogenic)*: The wooden frame in Scenario 2 contributes significantly to the reduction of carcinogenic impact. For non-carcinogenic toxicity, interconnections (mainly copper use) dominate the impact (75-93% of the total impact).
- *Fossil Resource Use*: A similar trend to climate change is observed, with the frame being the most influential factor.
- *Mineral and Metal Resource Use*: Interconnections are the primary contributors to the impact, although they represent only 1% of the module's weight. Increased silver quantities in Scenarios 1 and 2 significantly contribute to the increased impact in this category. This highlights the high environmental impact associated with the use of copper and silver.
- *Land Use*: The wooden frame (IT6-Scenario 2) causes almost three times higher impact than the reference, due to wood production.

Preliminary conclusions and next steps

The innovations assessed so far, particularly the eco-designed cells and modules, appear promising for reducing the environmental impact of PV technology. However, results can differ across impact categories, emphasizing the importance of a broad environmental assessment. Further scenarios and more complete data from ongoing experiments will be needed to refine the evaluations. The ultimate goal is to establish a closed-loop system for silicon, recovering and reusing this valuable metal for greater circularity in the PV sector. Future work will also include a circularity and criticality assessment to provide a broader picture of environmental performance.

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