Towards eco-design of scalable Perovskite/Silicon Tandem PV module, considering environmental and criticality dimensions

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Abstract

This study conducts a Life Cycle Assessment (LCA) to evaluate the environmental impacts associated with the industrial manufacturing of Perovskite/Silicon Tandem Cells (PSTCs), while also addressing the criticality of materials essential for their production. As resource availability and geopolitical supply risks become increasingly pressing challenges, the study considers the GeoPolRisk method, which evaluates Geopolitical Supply Risk from the perspective of a country, region, or economic block in a specific year. This method facilitates the integration of mineral resource supply risks into LCA, offering a more comprehensive view of sustainability. This work is part of the European-funded PEPPERONI project, which aims to advance PSTC technology to the industrial level.

PSTCs are an innovative photovoltaic (PV) technology that combines silicon and perovskite materials in a layered structure, enhancing sunlight-to-electricity conversion efficiency. While silicon solar cells dominate the PV market with mature manufacturing processes, perovskite cells are at a Technological Readiness Level (TRL) of 4, requiring significant research to achieve industrial-scale production.

The analysis employs a functional unit (FU) of 1 m^2 of PV module and evaluates its life cycle across three stages: (A) production of the silicon bottom cell, (B) manufacturing of the perovskite top cell, and (C) assembly of the complete PV module. Emphasis is placed on the innovative and evolving manufacturing processes for perovskite cells, reflecting ongoing research into various materials and deposition methods by PEPPERONI partners.

A Life Cycle Inventory (LCI) was developed using primary data provided by project partners, supplemented by secondary literature sources. Environmental impacts were assessed across 16 impact categories using the Environmental Footprint 3.1 method. Four distinct perovskite cell architectures were analyzed and compared, differing in absorber layer deposition methods, slot-die coating (solution-based) versus co-evaporation (vapor-based), and Electron Transport Layer (ETL) options, which included sputtered nickel oxide (NiOx) and evaporated 2PACz.

The results show that the environmental impacts of the perovskite top cell are mainly driven by electricity consumption during manufacturing, with material use playing a secondary role. Evaporation-based deposition processes were the most energy-intensive, while slot-die coating combined with sputtered NiOx had lower impacts. However, silicon cell production and module assembly remain the largest contributors to the overall footprint, driven by electricity use and materials like silver in metallization paste, solar glass, aluminum alloys, copper, and EVA encapsulant.

Finally, this study seeks to combine both environmental and raw materials criticality considerations in context of the technology future development, offering a broader perspective on the challenges and opportunities for scaling it up. It explores both i) the consideration of raw materials criticality within LCA using currently existing characterization methods combined with LCI data, and ii) building on a literature review of existing criticality studies in the PV sector.

It concludes on potential paths towards eco-design of the developed scalable Perovskite/Silicon Tandem PV module, in view of its induced environmental impacts and raw materials supply risks it may be faced with.

Keywords: Life Cycle Assessment, Material criticality, Eco design, Perovskite

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