# Environmental techno-economic assessment of printed Carbon-Based Perovskite Solar Cells

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## 1. Introduction

Perovskite solar cells (PSC) have shown considerable growth in power conversion efficiency (PCE), jumping from 3,8% to 25,5% in the last ten years (NREL, 2020). However, the successful commercialization of perovskite PVs depends not only on high PCE but also on long-lifetime, low-cost production, and environmental sustainability (Meng et al., 2018).

This study evaluates a carbon-based perovskite solar cell (CPSC) employing an environmental techno-economic assessment (ETEA) that integrates life cycle assessment (LCA) and techno-economic assessment (TEA) to (i) provide quantitative insights on the economic and environmental sustainability of CPSCs and (ii) thereby contributing to better understanding the commercialization prospects of different perovskite PV device candidates.

## 2. Methods

### 2.1. Device configuration and manufacturing process

We evaluate a monolithic CPSC with carbon-electrode fabricated with low-cost materials and fast solution-processing techniques. This configuration has achieved high PCEs and improved cell stability and duration in lab-scale devices (Hadadian et al., 2020). Moreover, due to its solution-deposition techniques, it is expected to lower the production costs.

### 2.2. Environmental Techno-economic assessment

To evaluate the economic and environmental sustainability, we propose the ETEA as a novel approach for PV assessments. The ETEA provides a detailed screening of the technology with aligned data and harmonized functional unit (FU) and system boundaries of TEA and LCA (Thomassen et al., 2017; Wunderlich et al., 2021). The modeled environmental and economic indicators are then used to compare the selected PV configuration to traditional alternatives already established in the PV market.

This method consists of constructing a bottom-up model that comprises cost and environmental impact information of the technology assessed. The ETEA model includes the process flow diagram (PFD) and mass and energy balance (M&E); furthermore, environmental impact and cost data are linked to the PFD and the M&E balance to perform the environmental and economic analysis. Technical and cost data are obtained primarily from a PV manufacturer located in Europe. The environmental impact assessment is conducted using the Environmental Footprint (EF) method 3.0 developed by the European Commission (European Commission (EC), 2016). The model's dynamic functionality allows to efficiently evaluate the effect of input changes on the M&E balance and environmental/economic indicators. Environmental indicators include the effect on impact categories per $m^2$ and the computation of energy payback time (EBPT). Economic analysis computes module cost (EUR/$m^2$), minimum-sustainable price (MSP), and the Levelized cost of electricity (LCOE). The analysis further calculates the annual power output based on realistic irradiation conditions modeled by a state-of-the-art energy yield platform (Schmager et al., 2019).

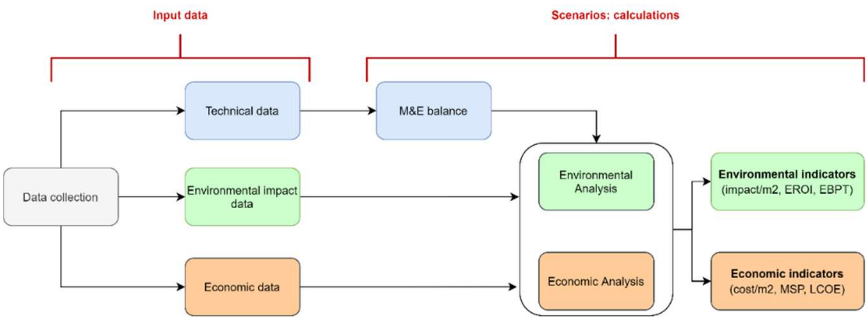


***Figure 1: Overview of the bottom-up model for the ETEA assessment of carbon-based perovskite solar cells***

## 3. Results

### 3.1. Environmental analysis

The FTO glass deposition constitutes the most impactful processing step as it accounts for more than 50% of the total contribution in each impact category considered except resource use (minerals and metals), where silver is the major contributor. The large quantity of the FTO glass and the electricity required for the FTO process contribute to high impact in all impact categories.

### 3.2. Economic analysis

The economic evaluation of the CPSC manufacturing shows that about 92% of costs are attributed to the operational expenditure (OPEX). Materials constitute the largest share of OPEX, and in particular, the FTO glass has the highest cost share. A preliminary analysis of MSP and LCOE highlights that PSCs can be cost-competitive with conventional PVs such as crystalline-silicon (c-Si) and CIGS.

## 4. Conclusions

The study quantifies the environmental and economic sustainability of CPSC in an integrated assessment. The preliminary results show that the environmental/economic indicators are found in the range of traditional PV technologies (e.g., c-Si, CIGS). This indicates that solution-processed carbon-based perovskite PV can be a low-cost competitor if the technology advancements continue, and it would stimulate larger PV deployment.

## 5. References

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