Environmental and Economic LCI of a micro-CPV module

Abad D.[1], San Miguel G.[1,*], Domínguez C.[2], Jost N.[2], Gutiérrez F.[1]

[1]ETSII and ETSIDI, Universidad Politécnica de Madrid (UPM), c/ José Gutiérrez Abascal, 2, Madrid, 28006 (Spain)

[2]Instituto de Energía Solar, Universidad Politécnica de Madrid (UPM), Ciudad Universitaria, Madrid 28040, Spain

*corresponding author: g.sanmiguel@upm.es

Abstract

Despite the renewable nature of solar energy, the sustainability of photovoltaic (PV) systems needs to be evaluated in order to minimize adverse environmental impacts and optimize economic performance. This piece of research represents a first approach to produce an environmental and economic assessment of a 1.0 m^2 (350 W) micro concentrator PV (microCPV) module designed at Institute of Solar Energy (IES-UPM) in Spain. The incorporation of concentrating lenses allows this technology to produce electricity from direct solar radiation at higher efficiencies than conventional PV cells. The aim of this work is to propose a representative architecture for the micro-CPV system that allows the quantification of a material, energy and economic Life Cycle Inventory (LCI), as the basis to conduct a Life Cycle Cost Assessment (LCC) and an Environmental Life Cycle Assessment (LCA).

Keywords: LCI, LCA, LCC, microCPV, sustainability.

1. Introduction

Intensive R&D efforts are being dedicated to enable the mass adoption of solar energy. Most research is aimed at either reducing the cost of photovoltaic (PV) generators or to augmenting their conversion efficiency. Concentrator photovoltaics (CPV) is an approach for the latter, based on the use of an optical system that concentrates direct sunlight onto a multi-junction PV cell. If adequately designed, concentrated light increases the efficiency of the semiconducting cell which also benefits from reduced thermal constraints, leading to greater energy yields (up to 39 %) and a lower LCOE (Riesen et al., 2015). However, the cost of CPV is still higher than that of conventional silicon flat plate devices due to reduced effects in economies of scale and learning curve. Fabrication costs range 1.4 - 2.2 €/Wp and LCOE have been estimated at 10 - 15 c€/kWh in locations with direct solar irradiances above 2000 kWh/m^2/year (Kost et al., 2013).

In order to reduce costs further, the downscaling of CPV has been proposed. In the micro-CPV modules, solar cell size is reduced to below 1.0 mm and so are the rest of the module's dimensions (volume and weight) (Paap et al., 2014). This new approach to CPV benefits from reduced optical absorption, improved cell thermal dissipation, less material intensity and reduced transportation and installation costs (Domínguez et al., 2017). On the other hand, the reduction of module size has negative consequences on manufacturability, as the number of units per area that need to be manipulated is far greater. Standard serial processes like batch processing of lenses, cell pick-and-place and electrode wire bonding are prohibitively expensive at this scale. Alternative lower-cost parallel assembly techniques are being proposed drawing experience from LED lighting or flexible display massive industries (Yoon et al., 2015).

Although PV systems are known for their clean operation, the sustainability of these systems need to be evaluated in order to minimize adverse environmental impacts and optimize economic performance (Corona et al., 2016). Considering this context, the aim of this investigation has been to propose a representative architecture for the micro-CPV system that allows an estimation of a material, energy and economic LCI, as a first step in the production of a LCA and a LCC.

2. Goal and Scope

Table 1 describes the representative architecture of a micro-CPV module with a square multijunction GaInP/GaInAs/Ge cell built on a Ge substrate of 0.45 mm in size. This includes information about the cell type and size, the optics, life cycle information, operating conditions and generation capacity. *Figure 1* shows a proposed life cycle diagram of the same technology. The functional unit is the production of 1.0 kWh, requiring the fabrication of 8.67E-05 individual 1.0 m^2 modules.

Table 1: Characteristics of the micro-CPV module

Nominal power of the module	W_p	350
Photovoltaic conversion efficiency	%	35
Concentration factor	X	500
Cell size	mm^2	0.45 x 0.45
Optic size	mm^2	10 x 10
Total aperture area	m^2	1.0
Type of tracking system		Dual axis
Life expectancy	yr	20
Location		Madrid
Normal direct radiation	kWh/m^2 year	2076
Power self-consumption	kWh/year	3.50
Capacity factor	%	18.82
Annual power generation	kWh/year	577.0
Life cycle power generation	MWh	11.54

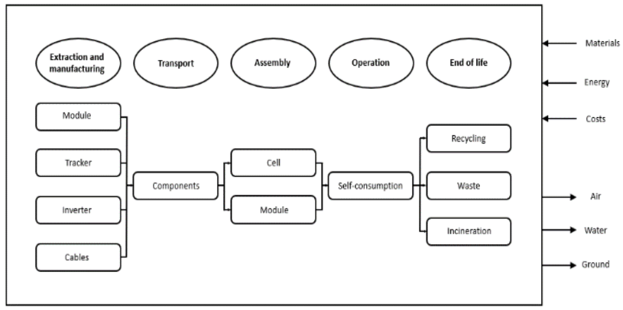

Figure 1. Life cycle processes, system boundaries and flows considered in the LCI of the micro-CPV module

3. Life Cycle Inventory

Table 2 shows the components, materials and monetary inventory of the microCPV module. The information shows that the material intensity of the system amounts to 39.6 kg/m^2 and it is dominated by the PET back plate (34.9 %), the solar tracker (25.3 %) and the PMMA lenses (14.9 %). In contrast, the monetary cost is ruled primarily by the tracker (38.6 %), with a smaller contribution from the inverter (16.7 %) and the semiconductor cells (22.8 %).

Table 2. Inventory for extraction and manufacturing phase

Component	**Material**	**Mass (kg/m^2)**	**Cost (€/m^2)**	**Mass (%)**	**Monetary (%)**
Lens	PMMA	5.90	40.0	14.9	7.02
Cells	Semiconductor	0.001	130	0.00	22.8
Back plate	PET	13.80	40.0	34.9	7.02
Frame	Aluminium	0.97	2.33	2.45	0.41
Bypass diodes	Semiconductor	0.32	10.0	0.81	1.75
PCB	Various	3.26	3.00	8.24	0.53
Silver printing	Silver	0.026		0.07	
Solar connector	Various	0.023	2.00	0.06	0.35
Tracker	Various	10.00	220	25.28	38.6
Inverter	Various	3.90	95	9.86	16.7
Cables	Various	1.35	24.8	3.41	4.35
Total		**39.6**	**570.1**	**100 %**	**100 %**

Transport loadings per module are estimated at 19.8 t·km, considering a distance between the assembly plant and a deployment location in Southern Spain (500 km). Manufacturing inputs are primarily attributable to acquisition of components, power use in the assembly plant, and waste and wastewater management. Module operation inputs include power use by the solar tracker, which may be deducted from the gross electricity output of the module. Finally, module design, disassembly and materials recyclability will need to be considered when modelling the end of life phase.

4. Conclusion

This investigation provides a representative architecture and a preliminary environmental and economic LCI for a micro-CPV module produced in Madrid. This information may be used to complete a LCA and a LCC assessment that evaluates the sustainability of this novel technology. This work needs to be completed with a full description of the material intensity of each of the module's components. Additional tasks should include producing LCA models in SimaPro using generic LCI databases (Ecoinvent), describing and analyzing specific scenarios (regarding the use of alternative raw materials, geographic locations, operating strategies), and interpretation of results.

References

Corona, B., Escudero, L., Quéméré, G., Luque-Heredia, I., & San Miguel, G. 2016. *Energy and environmental life cycle assessment of a high.* Int J Life Cycle Assess (2017) 22: 364

Domínguez, C., Jost, N., Askins, S., Victoria, M., & Antón, I. 2017. *A review of the promises and challenges of micro-concentrator photovoltaics.* Presented at the AIP Conference Proceedings, 1881:080003.

Kost, C., et al. 2013. *Levelized cost of electricity renewable energy technologies*. Fraunhofer Institute for Solar Energy Systems ISE https://www.ise.fraunhofer.de/en/publications/studies/cost-of-electricity.html

Paap, S., et al., 2014. C*ost analysis of flat-plate concentrators employing microscale photovoltaic cells for high energy per unit area applications*. 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC), pp. 2926–2929.

Riesen, S., et al. 2015. *New module design with 4-junction solar cells for high efficiencies*. AIP Conference Proceedings, 1679:100006-1, 100006-8.

Yoon, J., et al., 2015. *Heterogeneously Integrated Optoelectronic Devices Enabled by Micro-Transfer Printing*. Advanced Optical Materials, 3: 1313-1335