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Critical Review of Environmental LCA Methods and Their Representation of Current PV Market

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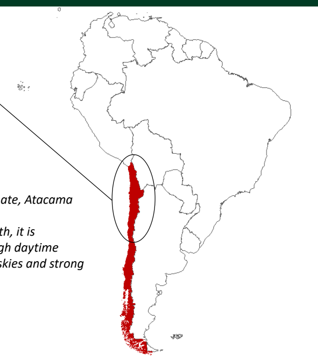
Introduction

- The aim of this study is to evaluate existing **methods and inventories** used for environmental lifecycle assessments (E-LCA) of photovoltaic (PV) systems, in particular towards identifying gaps to perform **location-specific studies,** considering all the phases from manufacturing to operation and maintenance (O&M), to end-of-life operations**.**
- The **Atacama Desert in Chile** was chosen as a **case study**, since the study is part of the **CACTUS project**, which aims to enhance collaboration between European and Latin American countries in the field of PV development.
- The case study was also selected due to a **lack of representativeness** of studies in **desert contexts**.



Atacama Desert climate:
While Chile has a very variegate climate, Atacama Desert is considered as a cold desert.
Being one of the driest places on earth, it is characterized by very low rainfall, high daytime temperatures and cold nights, clear skies and strong solar radiation.

ENVIRONMENTAL LCA HOTSPOTS PER LIFECYCLE STAGE: ATACAMA DESERT CASE STUDY

Manufacturing and system design

- The majority of LCA studies are focused on PV technologies (Al-BSF, PERC) that are **non representative of the current market** (PERC, SHJ, TOPCon)
- Only a few LCA studies adequately address the **Balance of System (BOS**).
- **Regionalization** of manufacturing processes in LCA studies is most often performed by only changing the **energy mix** of the country desired, in the manufacturing processes, without considering a **PV system design tailored** to the specific climatic conditions.

In *Table 1*, the **stress factors** affecting the operating conditions and the resulting **design requirements** of a PV system in the Atacama Desert are summarized

Table 1. *Summary of Atacama desert conditions that have an influence on PV design manufacturing requirements*

	Atacama desert conditions
Köppen-Geiger classification	• Arid Cold Desert (BWk) [1]
PV stress factors	• Accelerated wear • High UV • Saline and corrosive soil • Limited water resources [2]
PV system design	• UV resistant encapsulant (PO over EVA) and backsheet • High anti-reflective coated glass • Hydrophobic or anti-soiling coatings to reduce particle adhesion • Compatibility with ad-hoc cleaning processes • High temperature resistant BOS components [3]

O&M

- **O&M is highly site-specific**, even in desert climates with similar characteristics (hot desert (BWh), foggy desert (BWn), cold desert (BWk)).
- Specific **degradation mechanisms** occurs depending on installation location climatic conditions: the **environmental impact** is depending on the climatic stress factors.
- **O&M phase** is often neglected in LCA studies, while it can be almost **as important as the PV design phase** in LCA, especially in remote areas (e.g., desert regions) due to transport operations and faster components replacement [2].
- **Water cleaning** remains the most adequate process, equipped with water **mitigation systems to reduce water stress**, due to limited water resources of the area (e.g., recirculation and filtering, adaptive cleaning based on monitoring soiling ratio)

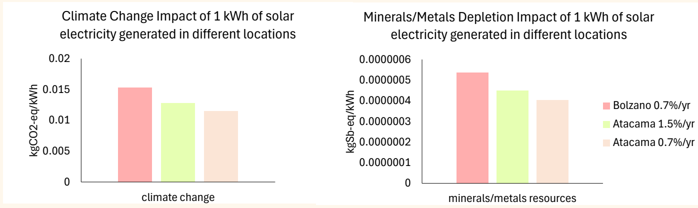


Figure 1. Cradle-to-gate Environmental impact results of 1 kWh of solar electricity, installed in different regions, reflecting the difference of results with different linear annual degradation rates assumed

End-of-life

- Different **LCA modelling methods** make LCA results difficult to compare:
  - **End-of-life approach**: evaluating the benefit from the avoided burdens thanks to the recycling;
  - **Cut-off approach**: using economic allocation to attribute the impact of the recycled co-products.
- LCA are not always reflecting the differences in **legislative requirements of different countries,** related to PV waste management and recycling processes.

A summary of legislative requirements is presented for EU and Chile in *Table 2.*

Table 2. *Comparison of legislative framework for PV waste management between Europe and Chile*

	Europe	Chile
Law	WEEE Directive [4]	REP Law (20.920) [5]
Timeline	2003 first version 2012 new version 2014 PV included in the scope	2016 passed 2023 in force
Type of waste	Electrical and electronic equipment	General waste, including electric and electronic equipment
Producer responsibility	Yes: producers must deliver PV waste to an authorised centre	Yes: producers must deliver PV waste to an authorised centre
Quantitative collection target	85% of panels recovered and 80% prepared for reuse and recycled	Not specified

Conclusions and next steps

- **LCA inventories** reflecting **up-to-date market** situation and **geographical context, adequately including O&M and end-of-life stages,** are crucial to perform reliable and accurate LCA studies.
- **Social aspects**, addressing the significant lack of methodology harmonization and available inventories, will be discussed as a next step within CACTUS project.
- For future studies it would be beneficial to provide location specific **LCA guidelines** for **other regions of the world** with different climatic conditions.
- **Environmental Product Declarations (EPDs)** can be used as a future reliable source for LCA inventories and benchmark for results comparison.
- Ad-hoc lifecycle frameworks to **include circularity aspects** in lifecycle assessment and embrace the circular economy perspective needs to be improved.

References

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[4] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE)
[5] Ley N°20.920 "REP": "Marco para la Gestión de Residuos, la Responsabilidad Extendida del Productor y Fomento al Reciclaje”

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