Qualification of low environmental impact BOM for modules including a first feasibility study of wooden frames

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Objectives

- Combine available technologies to reduce environmental impact of a PV module
- We seek to manufacture a SHJ module with the highest power output and the lowest environmental impact by using European materials

LCA **Identify**

CRM **Reduce**

BOM **Demonstrate**

Duality of increasing performance and reducing Ag consumption with novel cell and module interconnection technologies

Reduction of environmental impact by bio-sourced/design- for-recycle module packaging materials

Key metric:

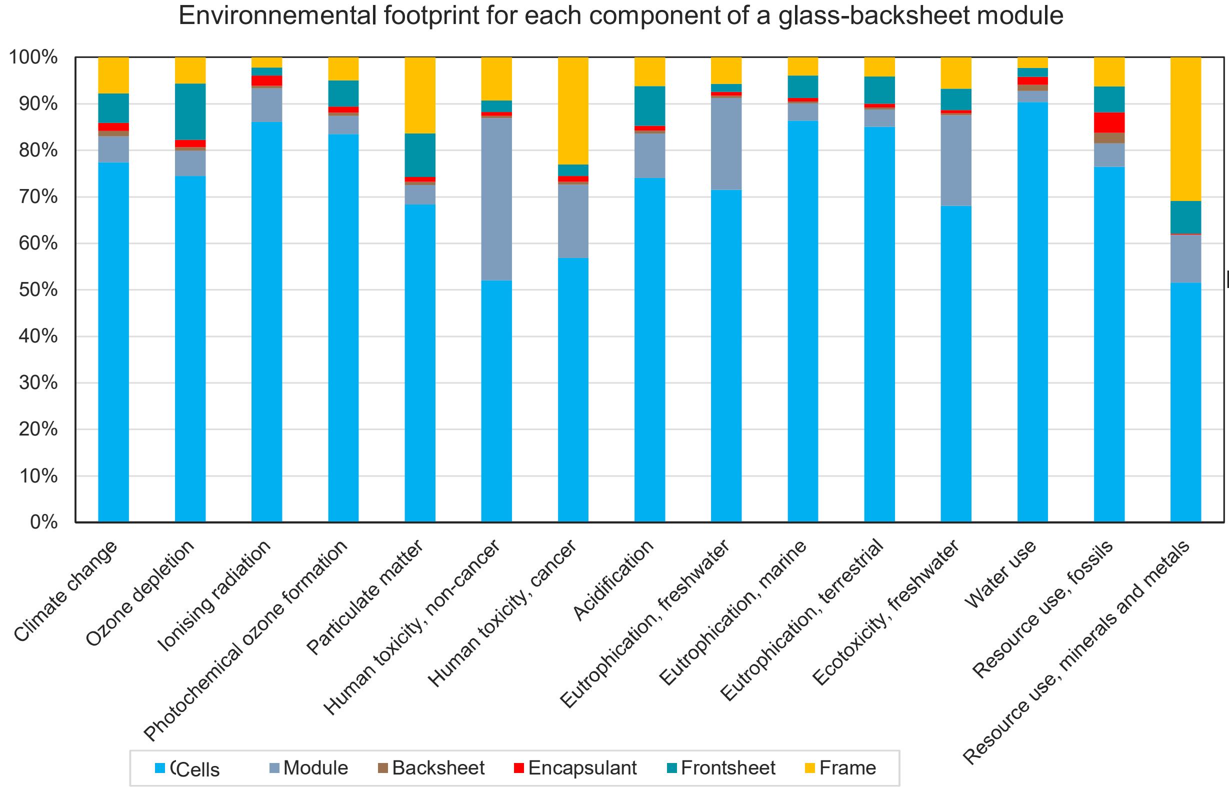
$$\frac{mg}{Wp}$$

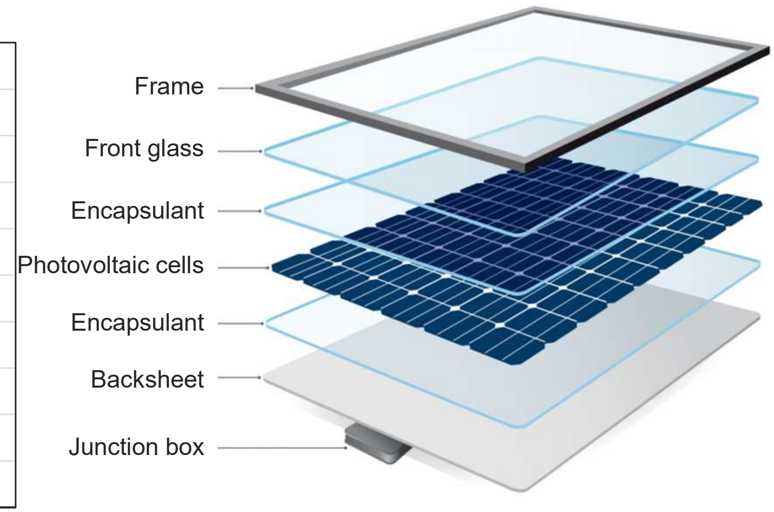
Outline

- Environmental impact analysis
  - LCA as a tool for design for recycling
- New cells and Interconnections for low carbon PV modules
- Low carbon materials in PV modules
  - BOM choice
  - Case study: Timber frame
  - BOM validation
- Conclusions

Environmental impact analysis

BOM choices: driven by environmental footprint of PV module materials





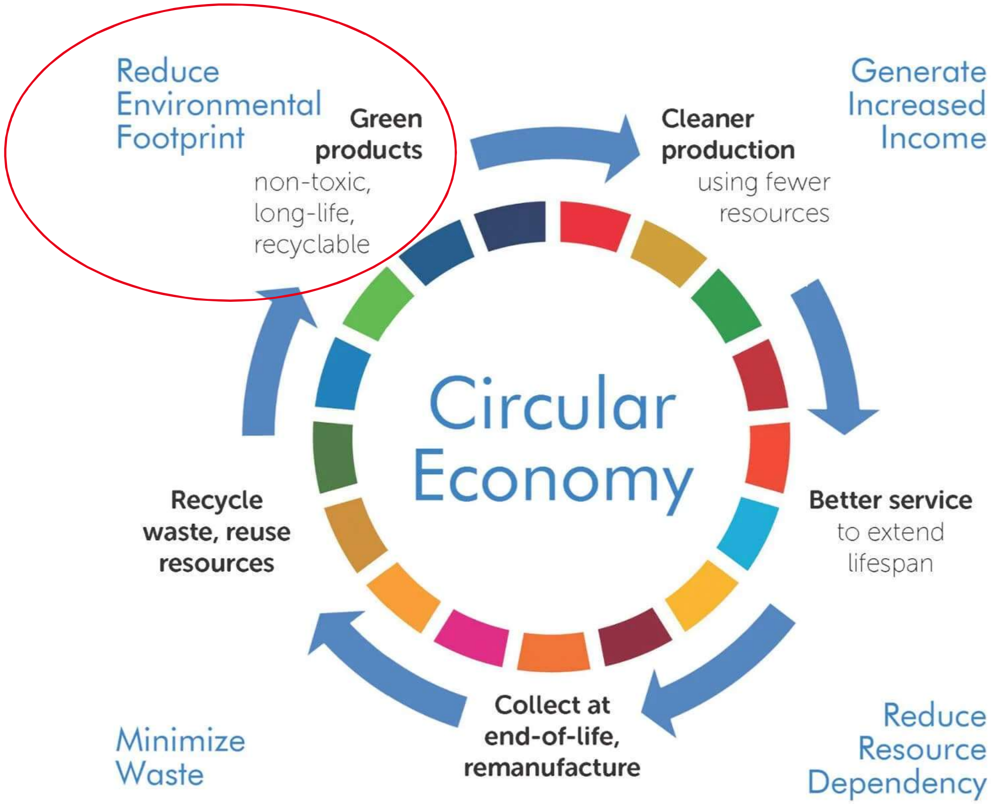
N. Gazbour, CEA-INES, 2022
Database : *Ecoinvent 3.6*
Data Source : *CEA INES*
Software : *Sima Pro 9.1 /ECO PV*
Method : *ILCD2011 Midpoint +V1,10*

Sustainability based on circular economy approach

Eco design
"Considers the environmental impact of a product throughout its life while striving to preserve its qualities or performance (efficiency, low cost …)"

(ISO 14006:2011, Revised by ISO 14006:2020)

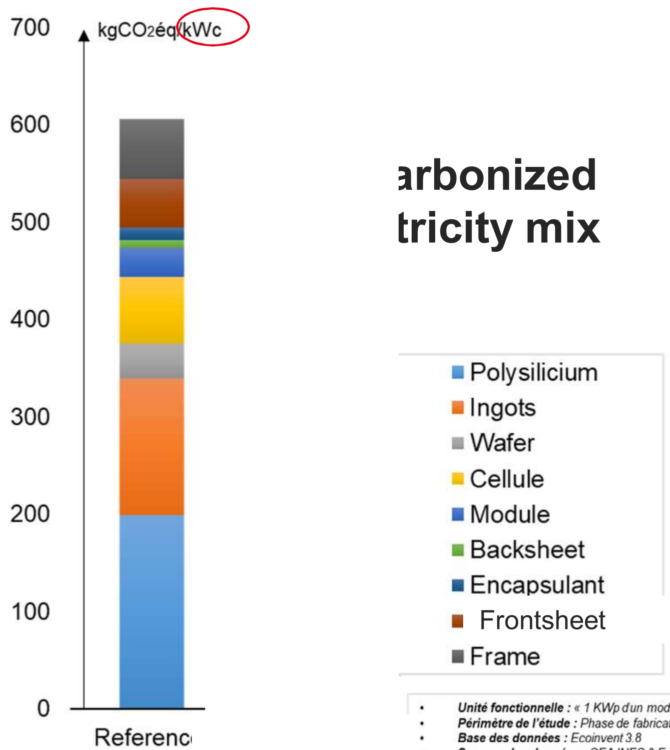
Lifecycle analysis (LCA) is one tools to quantify environmental footprint



Further reading: https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy

Source: E. Voroshazi et al.: Sustainable Silicon PV Cell and Module Materials and Technologies. IEEE Workshop, 2022

Lifecycle analysis of standard modules and its main messages for technologists



- ***Unité fonctionnelle :*** *« 1 KWp d'un module PV »*
- ***Périmètre de l'étude :*** *Phase de fabrication*
- ***Base des données :*** *Ecoinvent 3.8*
- ***Sources des données :*** *CEA INES & Ecoinvent*
- ***Méthode de calcul :*** *IPCC2021, GWP100*
- ***Logiciel :*** *Sima Pro 9.3.0*

Major levers for reduction of environmental impact of PV modules (systems):

- Increase PV module (system) performance and lifetime
- Use of low carbon electricity for manufacturing

- **Wafer level :**
  - Thinner wafers

- **Cell level :**
  - Reduce critical and toxic materials : Ag, In, Bi, Pb

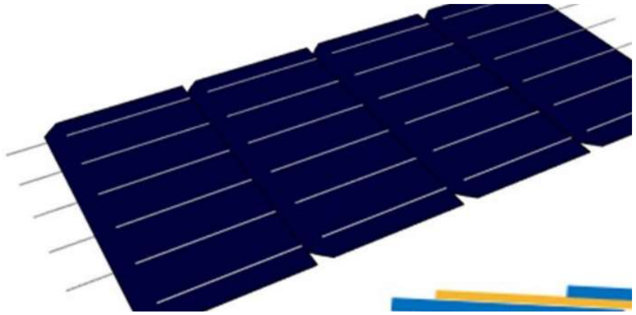
- **Module level :**
  - Replace/Re-use frame : reduce Al and high purity glass consumption
  - Design-for-recycle: module material selection

New SHJ cells for low carbon modules

- Solar cells strongly contribute to « Climate change » of LCA balance
  - Wafer production use significant thermal energy
  - Change wafer supplier country improve « climate change » score upon national energy mix
  - We used European wafer to produce SHJ cells for this module (in M2 size)
- Solar cell thickness is a lever to reduce cells' environmental impact
  - Enables silicon quantities reduction
  - Decrease « climate change » score
- Used wafer thickness was 130µm and final cell thickness is 115µm
- Final mean cell performance was 22,57% and maximum performance was 22,91%.

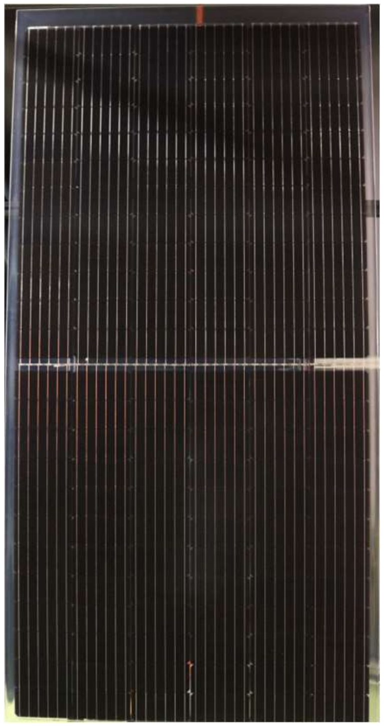
Advanced Module Interconnection Technologies for Densification

Paving

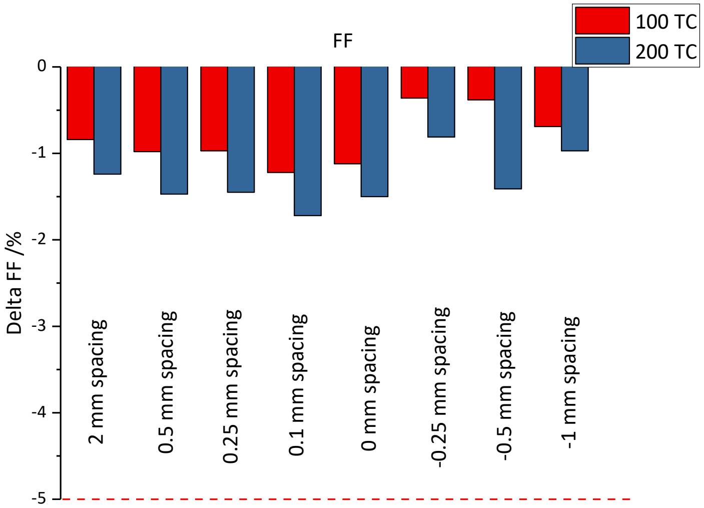


- ✓ High density interconnection
- ✓ Similar Ag consumption as BB soldering/gluing
- ✓ Adapt to high and low T process
- ! Reliability test ongoing

Paving with ECA gluing + SHJ



- 400 Wp (21.1%) with M2 cells
- CTMpower = 99.6 %
- Glass/POE/ Transparent backsheet
- TCT testing 1xIEC, 2x DH



Source: V. Barth et al., MIW 2022

Low carbon materials in PV modules

- BOM choice
- Case study
- BOM validation

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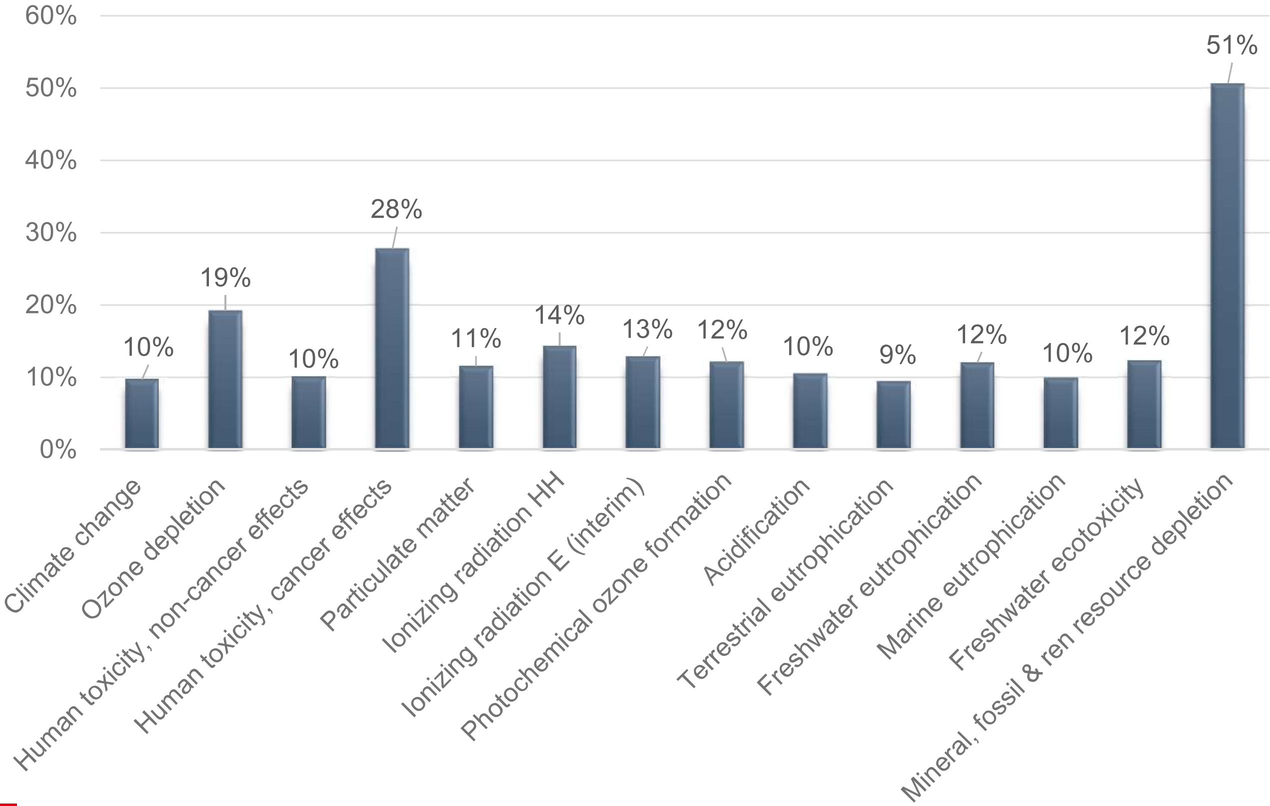
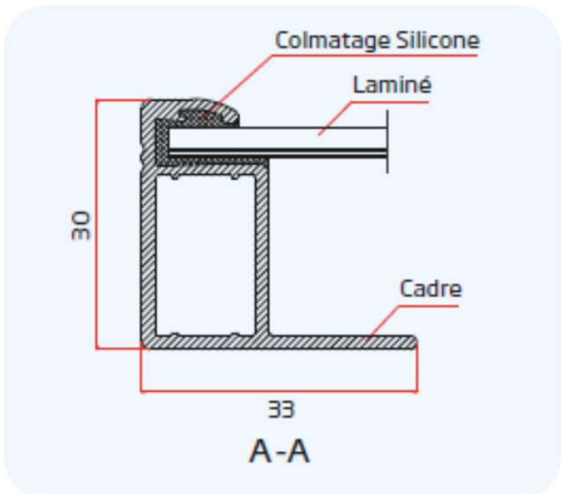
BOM choice

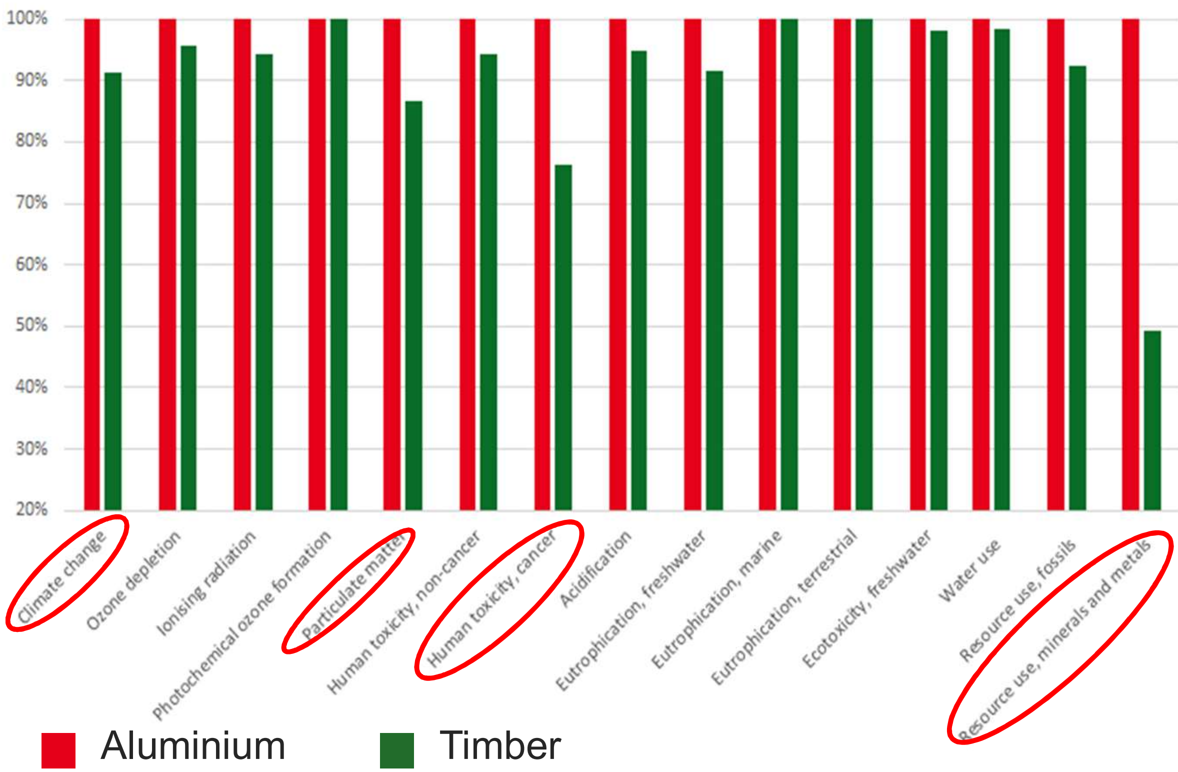
- Solar glass: module in GBs configuration
  - To reduce environmental impact we chose 1,8mm thick glass instead of standard 3,2mm glasses
- Encapsulant and backsheet
  - They have strong impact on health and environmental aspects
  - **TPO** encapsulant was chose for **design for recycling**
  - To maximise power output we used UV through transparent encapsulant in front and white one in back position from same supplier
  - Fluor-free multilayer backsheet was chose from European manufacturer
  - Preliminary tests to verify adhesion between layers at initial and after 1000h of DH
- Frame: aluminium has a large impact on CO_2 balance
  - Case study: wood frame

Aluminium frame share in LCA balance





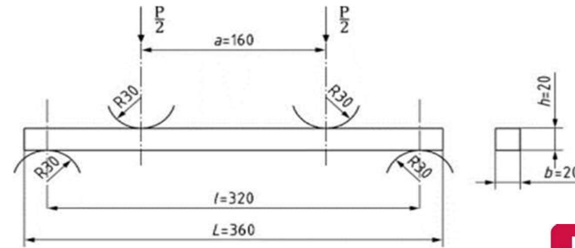
Environmental comparison of Al and Wood frames



- 10% decrease in climate change
- 13% decrease of particulate matter emissions
- 22% decrease in human toxicity
- 50% decrease raw material depletion

Experimental study: 4 points bending

(NF B51 008)



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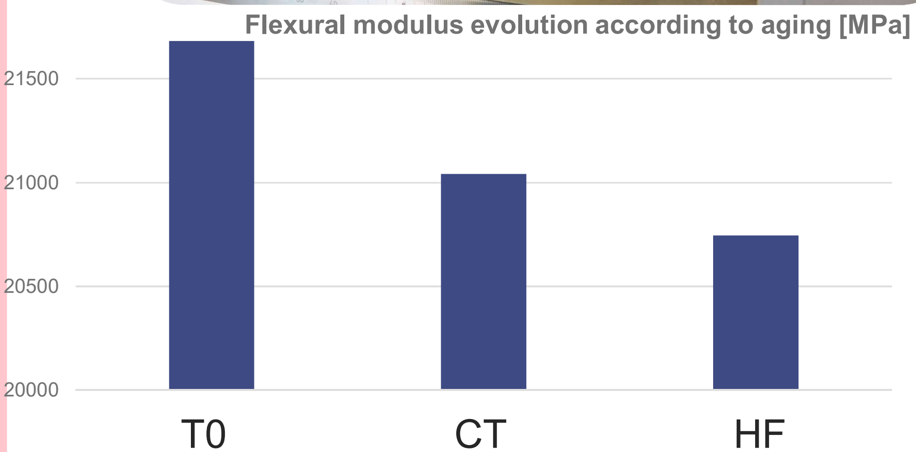
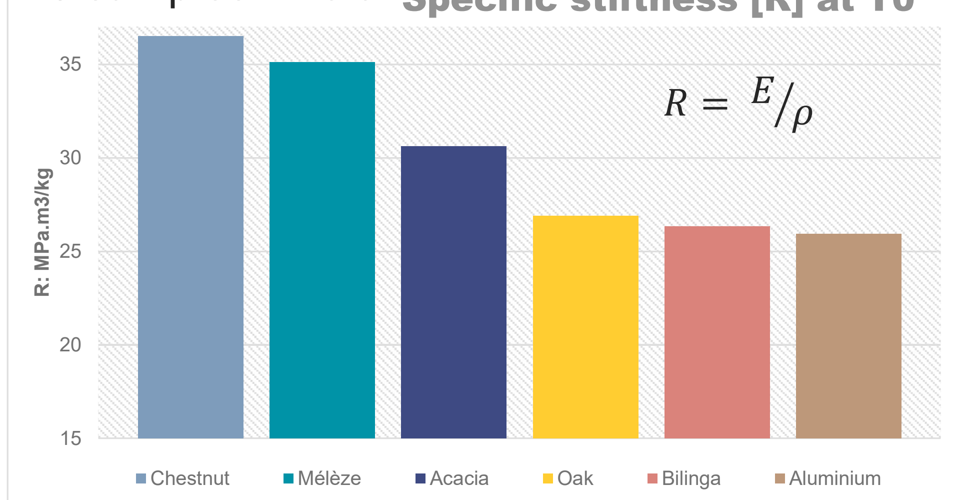
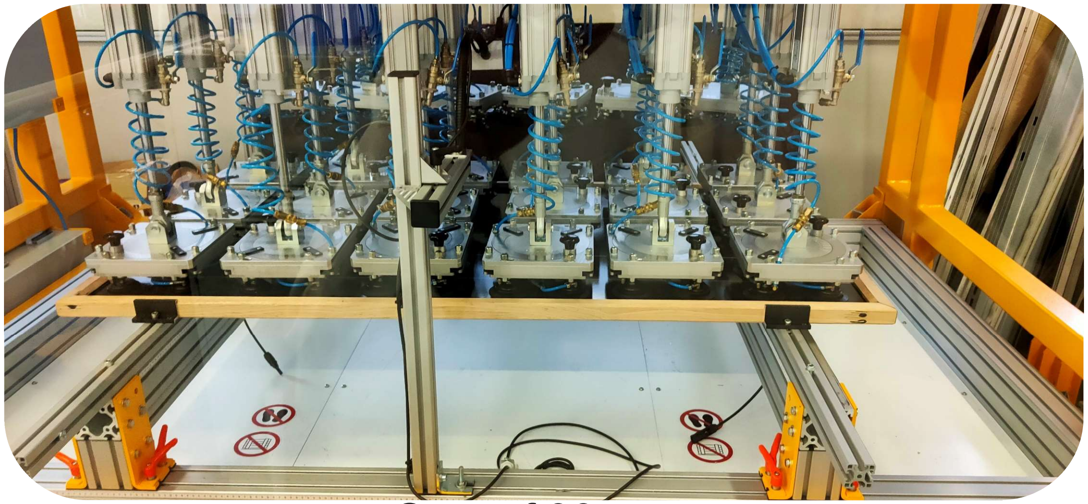


75 samples in total

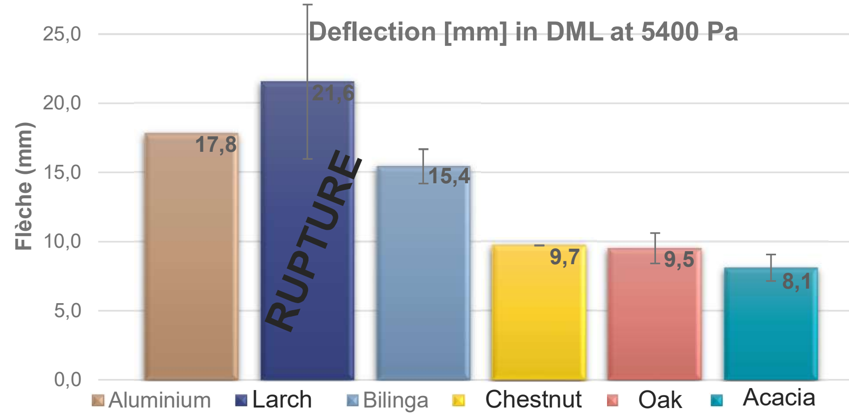


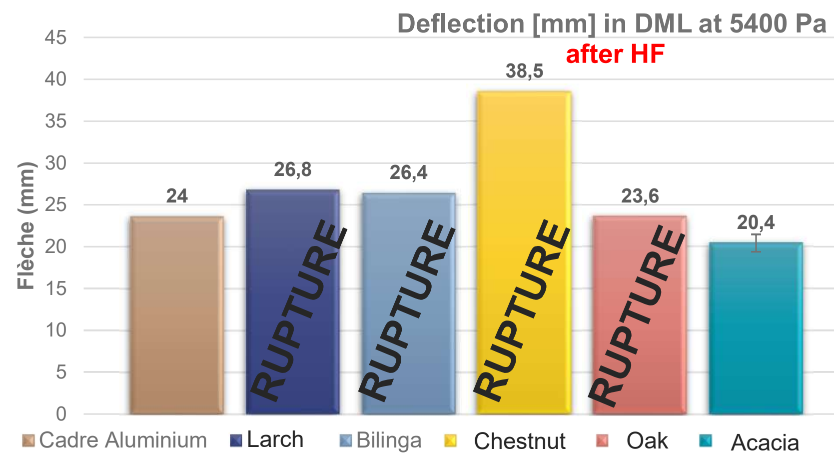
Experimental study: Dynamic Mechanical Load (DML)

(IEC 61 215)



Sum of 30 tests





After HF only acacia had not break during DML test, we kept it for further investigation

Conclusions on alternative frame qualification - case study of wood

- Advantages:
  - European acacia (timber) is a possible low carbon impact material for PV framing
  - It is available and low cost
  - Passes first qualifications (mechanical and CT/HF)

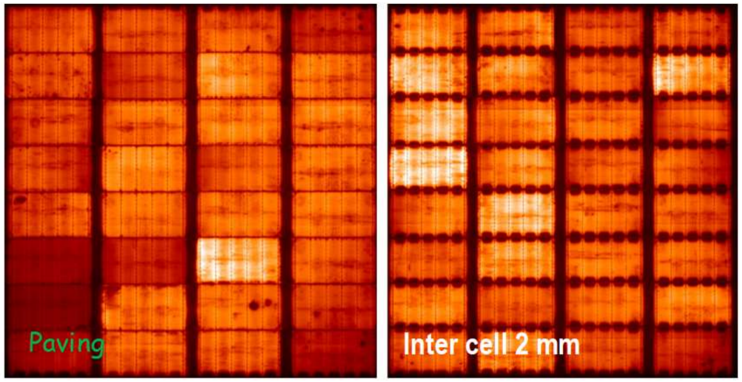
- Disadvantages:
  - Aesthetical aspects (tannin marks)
  - Stiff material rather difficult to transform
  - Robust geometry generate shading, more optimisation is necessary
- Perspectives: wood composites could be considered for certain PV applications

BOM validation

- MOMO modules: 32 half cells for aging
  - Initial characterization by EL and Flash test
  - Paving lamination needed special attention (overlapping very thin cells)
  - Module size was 700mm*674mm with 3,2 mm glass

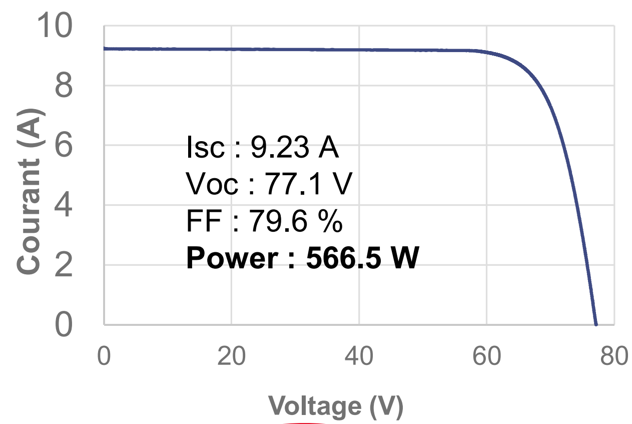
- First 1000h DH and UV/CT/HF :
  - Backsheets seems to less functioning as barrier => replacement with new material
  - Paving seems to slow down humidity ingress from rear side

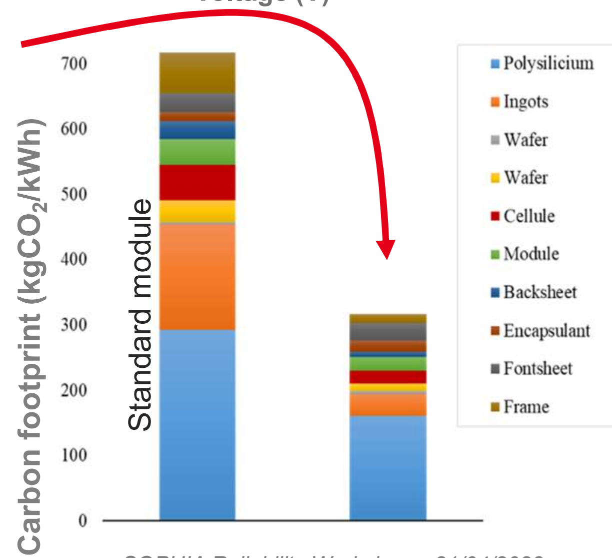
- Final module with M2 cells in large size
  - Final dimensions: 2166 x 1297 mm^2



Low environmental impact module demonstrator

- Cell performance of **22.8% on 130 µm thin wafers**
- Module performance of 566 Wp combining:
  - **Paving** ECA based gluing inter-connection
  - **Thermoplastic encapsulant** for ease of recycling
  - **Fluorine-free backsheet**
  - **Timber frame**
- Resulting in environmental footprint of **317 $kgCO_2eq/kWp$**
- Perspectives:
  - BOM improvement to resist to humidity ingress
  - Continue to reduce In and Ag quantity/Wp at same performance





Thank you

SPECIAL thanks to all the heterojunction solar cells and the module teams at CEA-INES!