Development of a recyclability index for photovoltaic products

3rd stakeholder meeting

16 May 2025, Pamplona (ES)
8:30-12:30

www.pv-recyclability-index.eu

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NATIONAL RENEWABLE ENERGY CENTRE
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Agenda

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1	Welcome – 8:30
2	Policy Background – European Commission 08:45 – 9:00
3	Recyclability Index Methodology 09:00 – 09:30
4	Testing – Selection of the sample 9:30 – 10:00
5	Testing protocols 10:00 – 10:45
	Coffee Break 10:45 – 11:00
6	Testing Results 11:00 – 12:00
7	Next steps of the study 12:00 – 12:15
8	General Questions and Answers 12:15 – 12:30
9	AOB, closure 12:30

Housekeeping rules & practical information for stakeholders

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More than registered for the meeting

1. Remain muted, unless speaking when invited by the chair
2. Only audio connection, no video
3. At each Q&A session, use chat when asking for the floor, stating name and organisation
4. Else please do not use chat - difficult to monitor during the meeting
5. Concise question or intervention when given the floor
6. Written comments and inputs after the meeting are welcomed, deadline 6th June 2025
7. Slides and brief minutes will be published at the study web site after the meeting, at https://www.pv-recyclability-index.eu/
8. The meeting is being recorded for the purpose of the minutes. You gave consent when registering.

The study team

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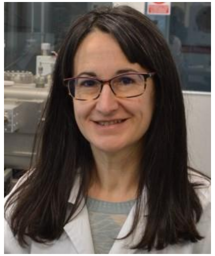

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ADItech

Objectives of the meeting

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1. Recap the previous steps of the study
2. Discuss the revised scoring methodology (including the weighting factors)
3. Present the results of the testing phase
4. Collect inputs from stakeholders
5. Describe next steps of the study

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Requirements/labelling under preparation

PV modules

- Durability(quantitative)
- Carbon footprint
- Repairability (information)
- Recyclability (information)
- energy yield (information)

PV inverters

- Efficiency (quantitative)
- Durability (quantitative)
- Smart readiness (compulsory feature)
- Repairability(compulsory feature)
- Recyclability (information)

Energy label

- PV modules

Initial product scope

- Modules
- Inverters
- ~~Systems~~

Market segments

- Residential
- Commercial
- Utility

European Commission

Research / policy question: can more be made, to regulate the recyclability of PV modules?

A recyclability index for photovoltaic modules!

How to proceed for a recyclability index?

A ‘CONCEPTUAL SWITCH’

FROM:

‘Disassembly’: means a process whereby a product is separated into its parts and/or components in such a way that it could subsequently be reassembled and made operational (→ REPARABILITY SCORE)

[Definition from EU Regulation 2023/1669]

TO

‘Dismantling’: means a process whereby a product is separated into its parts and/or components, in a way that could be irreversible, and with the aim to scavenge materials/components (→ RECYCLABILITY INDEX)

[Draft definition]

Potential policy implications for a recyclability index:

- displayed/made available by manufacturers for each PV module model placed on the EU market, as an effect of Ecodesign and/or energy labelling measures;
- public procurement: public procurers could use the index as awarding criteria;
- a recyclability index could also be used to modulate fees under collective collection schemes (waste legislation)

How to create synergy btw the PV Regulations with the study presented today?

Development of a recyclability index for photovoltaic products

Depending on timing, incorporation of the index, and related method, in the Regulation(s) as information, or feeding standardization work

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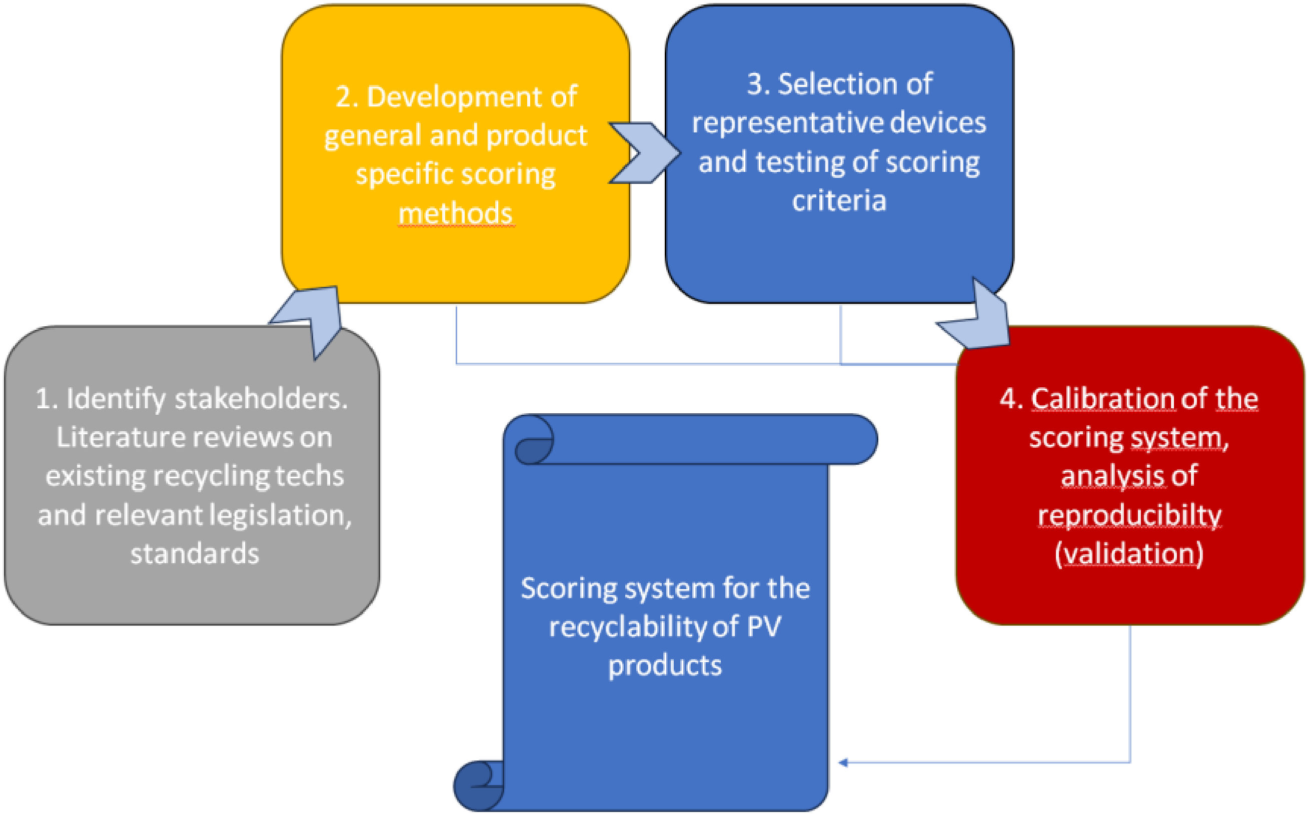
Recap of the previous steps of the study

1. Methodology process
2. Scope, parameters, scoring criteria
3. Weighting factors and score aggregation

Phases and Deliverables



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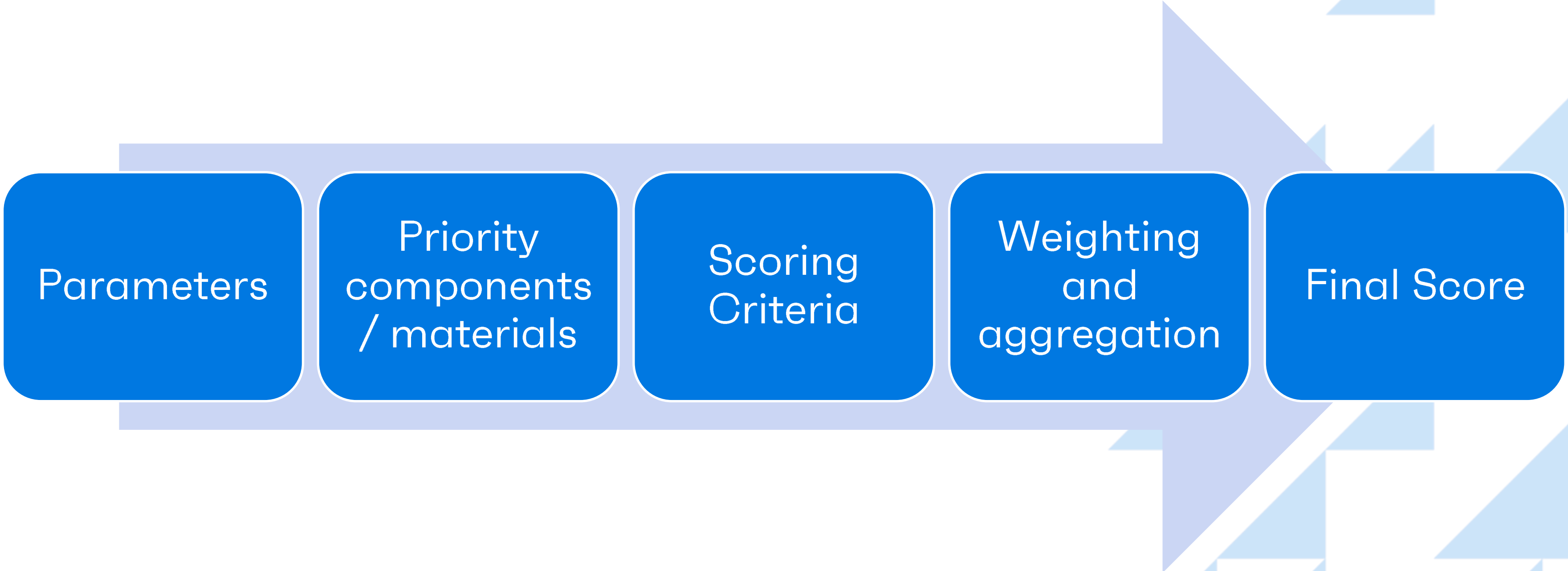
Development of the scoring method

Key steps for developing the recyclability scoring system:



Parameters: summary table – PV modules

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<table>
<tr><th>Type of parameters</th><th>N</th><th colspan="4">Parameter</th></tr>
<tr><td rowspan="5">Service related parameters</td><td>1</td><td colspan="4">Technology identification</td></tr>
<tr><td>2</td><td colspan="4">Information on the presence (or absence) of substances of concern</td></tr>
<tr><td>3</td><td colspan="4">Dismantling information and condition for access</td></tr>
<tr><td rowspan="2">4</td><td>4.1</td><td colspan="3">Disclosure of material composition</td></tr>
<tr><td>4.2</td><td colspan="3">Disclosure of presence and location of Critical, Strategic and Environmental Relevant materials</td></tr>
<tr><td rowspan="2">Dismantling related parameters</td><td rowspan="2">7</td><td>7.2</td><td>Removability of the encapsulant after heating process: peel of test</td><td>7.3</td><td>Removability of the encapsulant from the glass after heating process: metal cord test</td></tr>
<tr><td>7.4</td><td colspan="3">Removability of the frame</td></tr>
<tr><td rowspan="3">Material based parameters</td><td>8</td><td colspan="4">Level of concentration of hazardous substances and other substances affecting the recycling process</td></tr>
<tr><td>9</td><td colspan="4">Selection of materials based on recyclability complexity</td></tr>
<tr><td>10</td><td colspan="4">Combination of materials used / homogeneity</td></tr>
</table>

Parameters: summary table – PV inverters

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Type of parameters	N	Parameter
Service related parameters	2	Information on the presence (or absence) of substances of concern
	3	Dismantling information and condition for access
	4	Information on composition (including critical and strategic raw materials): #4.1 Disclosure of material composition
		Information on composition (including critical and strategic raw materials): # 4.2 Disclosure of presence and location of Critical, Strategic and Environmental Relevant materials
Dismantling related Parameters	5	Number of steps for the dismantling of priority parts (dismantling depth)
	6	Types of tools to dismantle priority parts
	7	Type of fasteners to dismantle priority parts
Material based parameters	8	Level of concentration of hazardous substances and other substances affecting the recycling process
	9	Selection of materials based on recyclability complexity
	10	Combination of materials used / homogeneity

Scoring Criteria: PV Inverters

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Nº	Parameters	Product specific parameters (if applicable)	Applicability	Scoring Criteria	Points
5	Number of steps for the dismantling of priority part (X)		PV inverters	DDi > A steps	1
				A steps ≥ DDi > B steps	2
				B steps ≥ DDi > C steps	3
				C steps ≥ DDi > D steps	4
				DD ≤ D steps	5
6	Type of tools to dismantle priority part (X)		PV inverters	Proprietary tools	1
				Commercially available tools	2
				Basic tools	4
				No tools	5
7	Removability of fasteners, reversible sealants and encapsulant layers	7.1 Type of fasteners to dismantle priority part (X)	PV Inverters	Not-removable fasteners	1
				Removable or reusable fasteners	5

Scoring Criteria: PV modules

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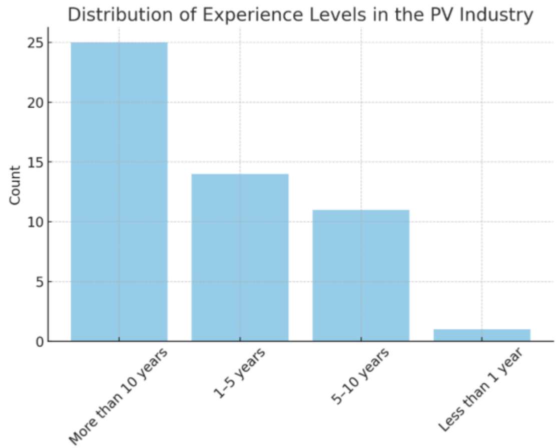
Nº	Parameters	Product specific parameters (if applicable)	Applicability	Scoring Criteria	Points
7	Removability of fasteners, reversible sealants and encapsulant layers	7.2 Removability of the encapsulant after heating process: Delamination test	Mono-facial PV modules	"Non-reversible encapsulant": the product/components are damaged during the testing delamination process (the delamination test is not passed).	1
				Difficult to remove encapsulant: based on the measurement of the drop of the adhesion force between 70 and 150 °C.	3
				Easy to remove encapsulant: based on the measurement of the drop of the adhesion force between 70 and 150 °C.	5
		7.3 Removability of the encapsulant from the glass after heating process: metal cord test	Bifacial PV modules	"Non-removable encapsulant": the product / components are damaged during the dismantling process.	1
				Difficult to remove encapsulant: the dismantling with the cord is feasible but only at a temperature equal or higher than 150 °C.	3
				Easy to remove encapsulant: the dismantling with the cord is feasible at a temperature lower than 150 °C.	5
		7.4 Removability of the frame	PV modules with frame	Presence of adhesive on the glass / frame interface.	1
				Use of edge sealing techniques (e.g. O-ring or U-profile design).	5

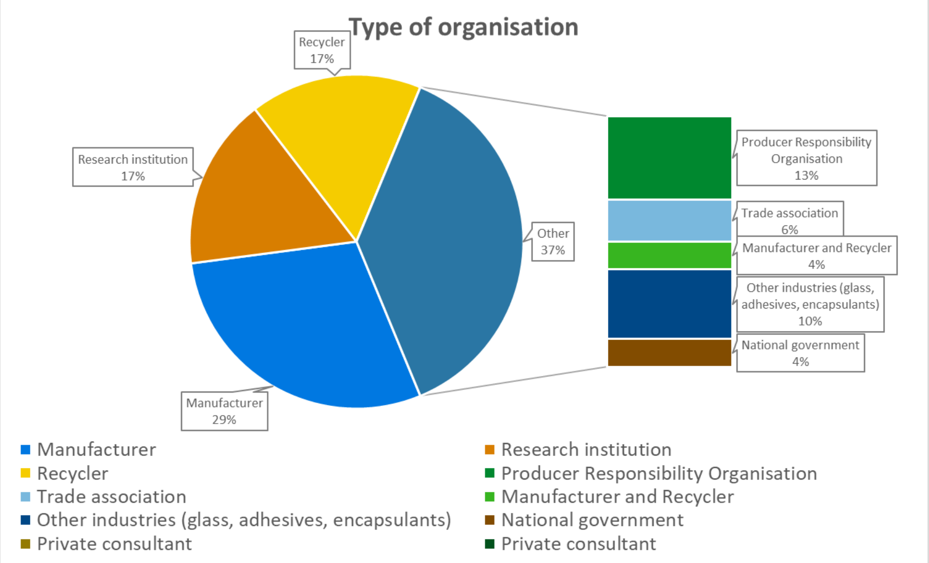
Proposed to be replaced by a hot knife process

Proposed to be replaced by a more "technology neutral" approach (test approach described by CENER later today)

Results of the weighting survey and proposal of weighting factors

- Consultation open: Dec 2024 – Jan 2025
- Two tailored surveys: PV Modules & PV Inverters
- Targeted experts in manufacturing, recycling, circular economy, policy
- Define the relative importance (weight) of parameters and confirm the priority parts importance components.
- Respondents asked to score parameter importance (1 = Not Important, 5 = Very Important)

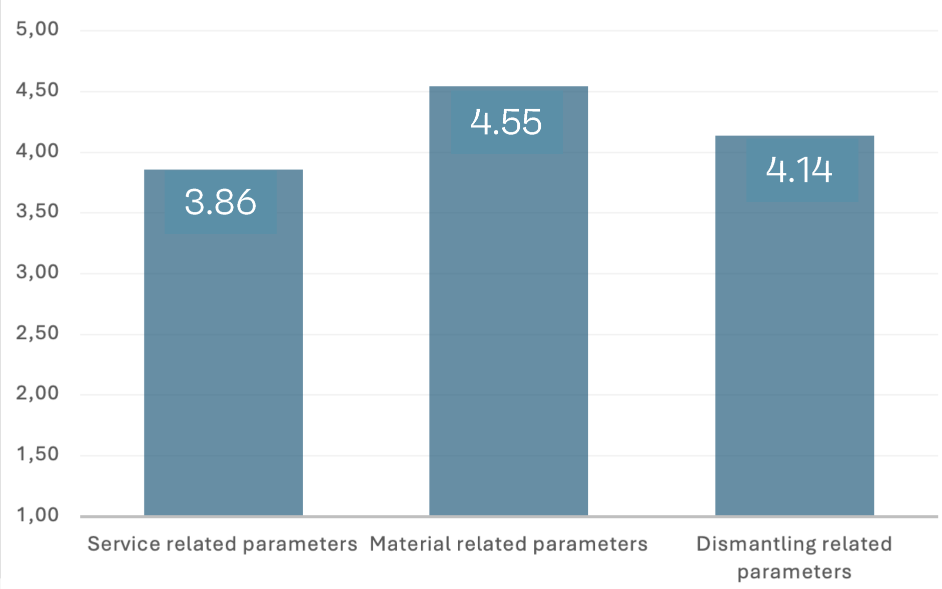




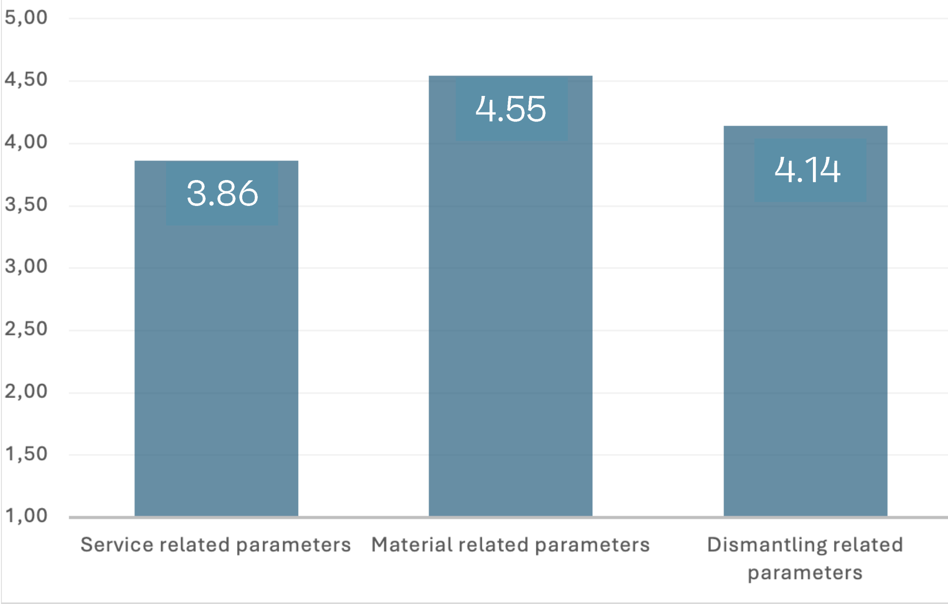
Results of the weighting survey and proposal of weighting factors

General Importance of Parameter Categories

PV modules



PV inverters



Weighting factors

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	PV Modules	
#1	Technology identification	5 %
#2	Information on substances of concern	10 %
#3	Availability of dismantling instructions	10 %
#4	Disclosure of material composition (5%)	5 %
#7	Removability of encapsulant after heating (OITOKS; 15:12)	15 %
#8	Substances of concern Antimany/ditos: BPR.Cables BFR/function.box_Fluorins/Bacheet	15 %
#9	Selection of materials based on complexity	10 %
#10	Combination of materials / homogenity	10 %

	PV Inverters	
#2	Information on substances of concern	15 %
#3	Availability of dismantling instructions	10 %
#4	Disclosure of material composition	5 %
#5	Dismantling depth	10 %
#6	Tools (type)	15 %
#7	Fasteners (type)	10 %
#9	Selection of materials based complexity	10 %
#10	Combination of materials/homogeneity	10 %

$$S_j = \sum_{i=1}^{N} S_{j,i} \cdot \omega_i$$

Where:

S is the score (per part/material or parameter)
j is a specific parameter
ω is the priority part weighting factor
i is a specific priority part/material,
N is the number of priority parts/materials

$$R = \sum_{j=1}^{10} \mathbf{S_j} \cdot \mathbf{W_j}$$

Where
R is the recyclability index
W is the parameter weighting factor

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From the 2nd stakeholder meeting…

Selection of the samples

PV modules (8 different types)

PV technology	PERC	TopCon	HJT	IBC
Modules	2	3	1	2

PV configuration	Monofacial	Bifacial
Modules	4	4

PV recycling	Conventional	Easy-to-disassemble
Modules	8	2?

PV inverters (8 different types)

Inverter power	0-1 kW	1-10 kW	10-30 kW
Inverters	1	5	2

Inverter phase	Single-phase	Three-phase
Inverters	4	4

	Micro-inverter	With battery charger
Inverters	1	3

Excluded:

- Central PV packed with transformers
- DC-to- DC converters
- DC optimisers

Out of the scope of Ecodesign measures on PV products

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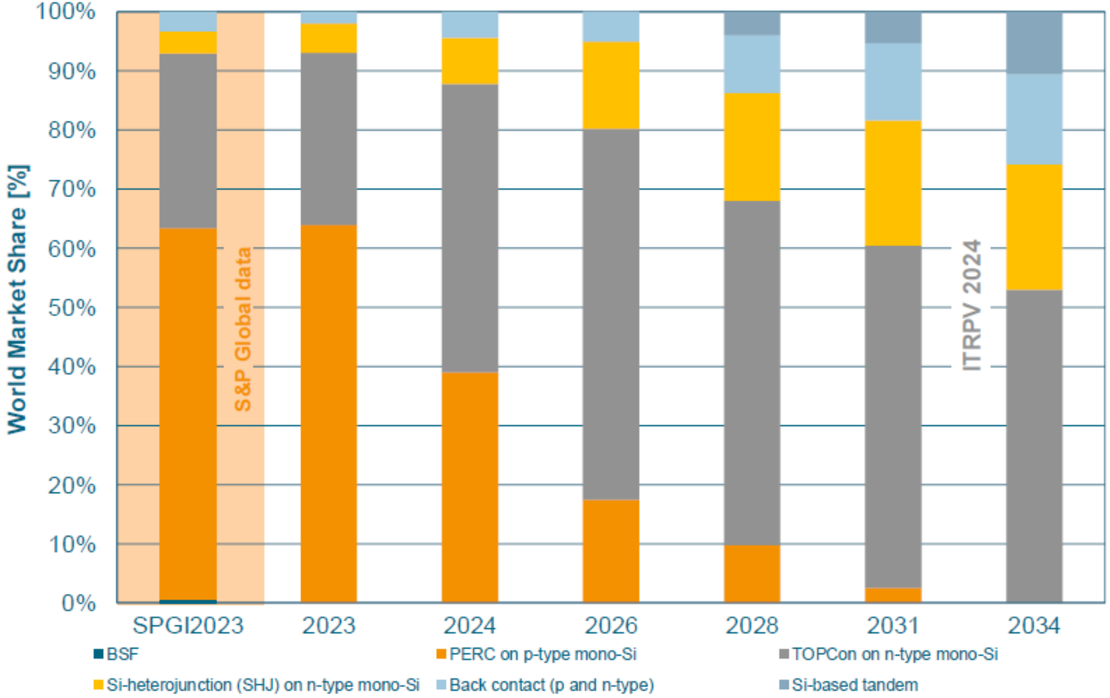
PV module list

PV module technology trends:

- *PERC ⇒ TOPCon*
- *IBC ⇒ Pb-free interconnection*
- *Silicon Heterojunction (HJT)*
- *Thin-film technology ⇒ 5-7% market share*
- *Interest in more recyclable PV module*

International Technology Roadmap for PV



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PV module list

9 models of PV modules:

PV technology	PERC	TopCon	HJT	IBC	Thin-film
Nº Modules	2	3	1	2	1

PV configuration	Monofacial	Bifacial
Nº Modules	5	4

PV recycling	Conventional	Recyclable design
Nº Modules	8	1

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PV module list

9 models of PV modules, 2 modules per type:

Product type identification	Technology	Power (W)	Module type - Bifaciality
Module type 1	mc-Si, n-BC	420	Monofacial
Module type 2	mc-Si, non-encapsulant	550	Bifacial
Module type 3	Si-heterojunction	450	Monofacial
Module type 4	mc-Si, PERC Shingled	430	Monofacial
Module type 5	mc-Si, TOPCon	525	Bifacial
Module type 6	mc-Si, p-BC	610	Monofacial
Module type 7	mc-Si, n-TOPCon, half cut	600	Bifacial
Module type 8	mc-Si, i-TOPCon	605	Bifacial
Module type 9	Thin-film	400	Monofacial

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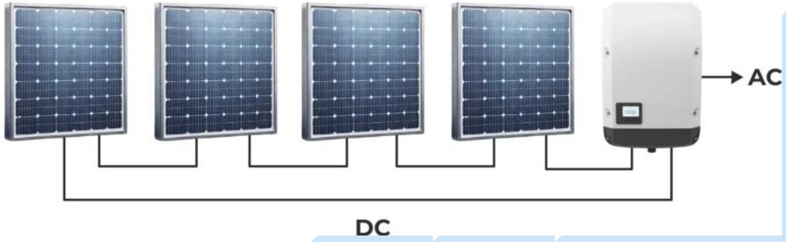
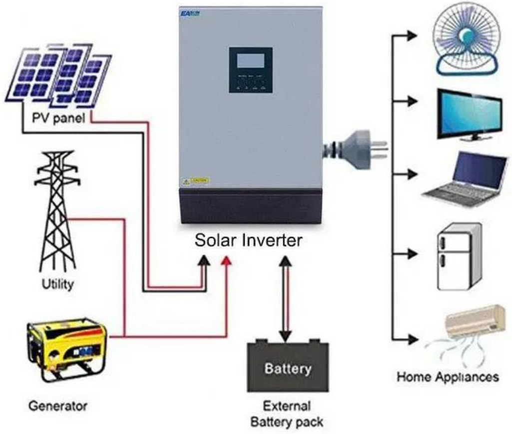
PV inverter list

List of PV inverters, which includes different models from companies around the globe, covering a wide range of powers:

- String inverters
- Hybrid inverters: possibility to connect to batteries and regulate them
- Microinverters





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PV inverter list

8 PV inverter models, 2 of each types:

Product identification	Characteristics	P out (W)	Phase	Cooling
Inverter type 1	Microinverter	295	Monophase	-
Inverter type 2	Inverter-Charger 2 MPPT	2 200	Monophase	Natural cooling
Inverter type 3	High Power	66 600	Three-phase	Active cooling
Inverter type 4	Medium Power	20 000	Three-phase	Active cooling
Inverter type 5	Inverter-Charger	3 000	Three-phase	Not provided
Inverter type 6	Inverter-Charger 2 MPPT	6 000	Three-phase	Natural cooling
Inverter type 7	1 MPPT Inverter	3 700	Three-phase	Active cooling
Inverter type 8	Hybrid	3 000	Monophase	Active cooling

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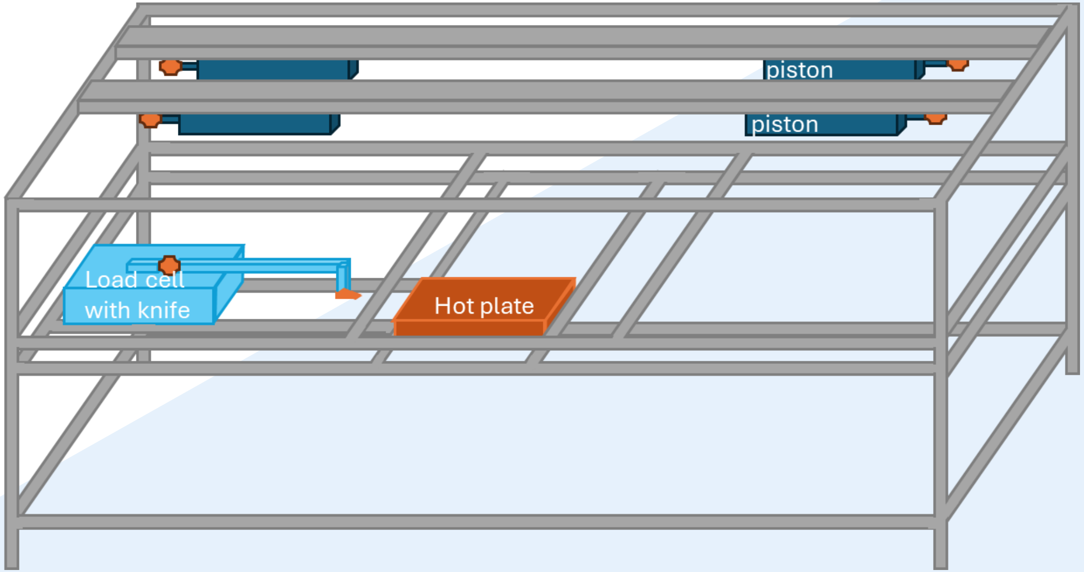
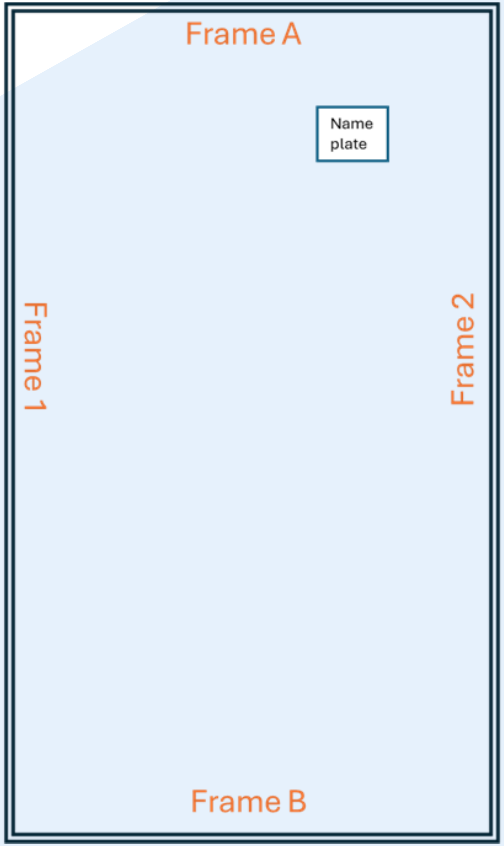
PV MODULES DISMANTLING PROTOCOLS

1. PV frame removal
2. Delamination of monofacial PV modules
3. Delamination of bifacial PV modules





1. PV Frame removal equipment

Quantify the mechanical resistance of the frame detachment

Study the structural characteristics of the frame

Potential failure modes during dismantling

Module glass should remain intact. Maintaining the integrity of the glass is critical, as breakage would compromise subsequent recycling processes.

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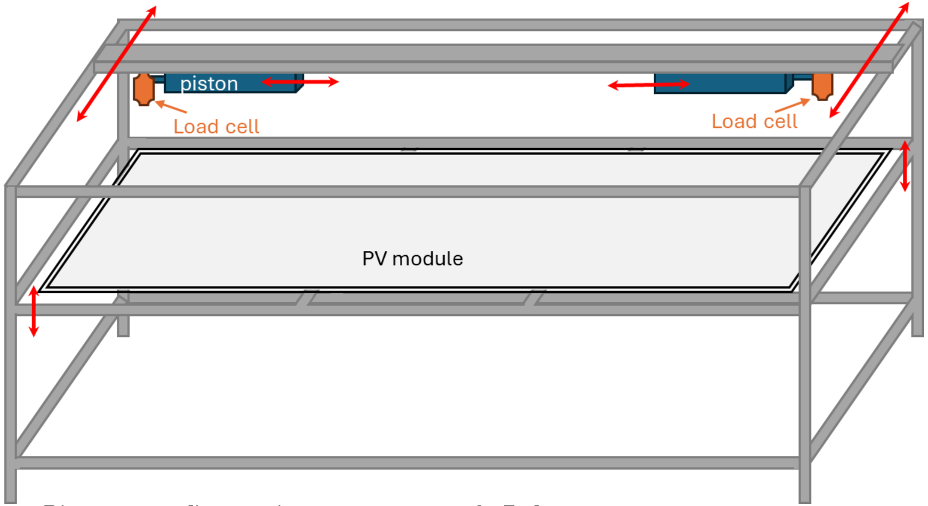
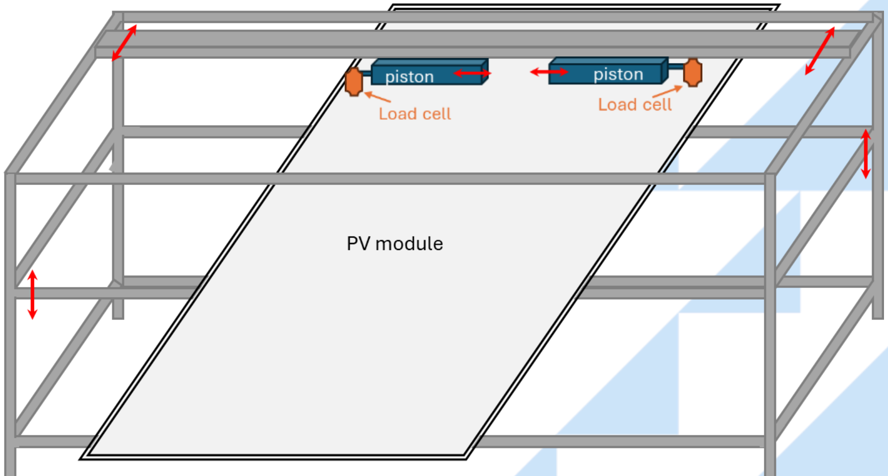
1. PV Frame removal equipment

Pressure unit equipped with load cells to obtain the maximum force.



Piston configuration to remove A-B frames



Piston configuration to remove 1-2 frames

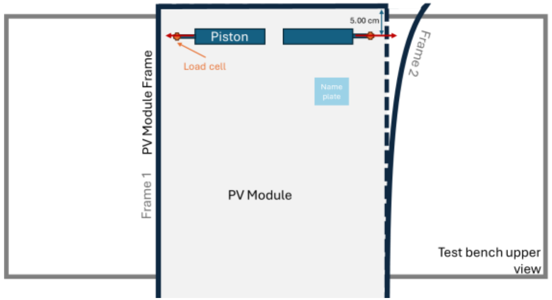
1. PV Frame removal equipment

Test sequence:

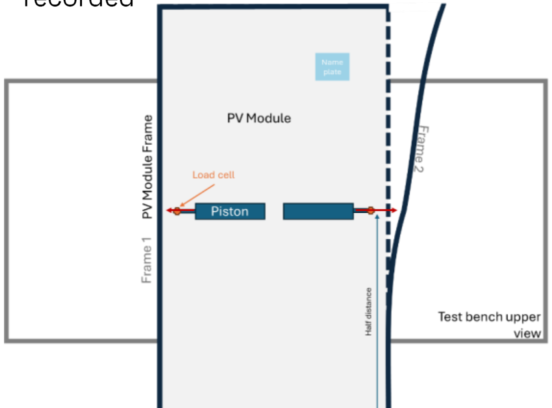
1. **Initial positioning:** The PV module is placed face-down on the bench. The pistons are then adjusted to align with the module's frame and brought into contact with the aluminium edges.

2. Long frame removal (1-2):

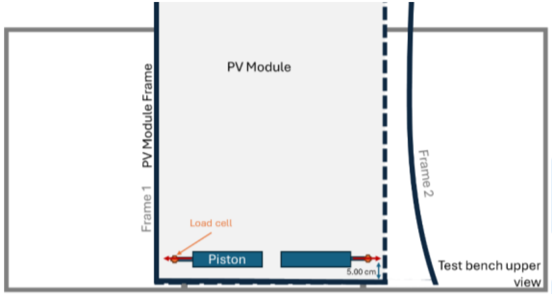
Pistons at 5.00 cm from the corner. Pressure is applied until the frame detaches or breaks, and the peak force is recorded.



Central Pressure Test: The module is repositioned so that pressure is applied at the midpoint of the long frame side. The process is repeated, and the force is recorded



Opposite Corner Test: The module is rotated 180º or shifted to apply pressure at the remaining attached corner, at 5.00 cm from the inner corner. At this point, the long side frames (Frame 1–2) are typically fully detached.



1. PV Frame removal equipment

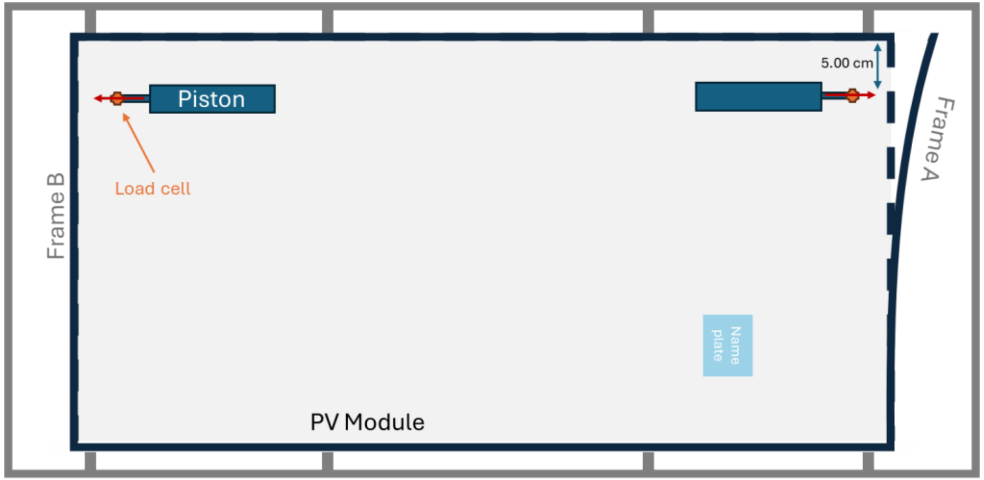
3. Short frame removal (A-B):

   The module is rotated 90º to allow access to the short frames.

   Pistons are realigned accordingly.

   The pressure is first applied near one corner, then at the opposite corner, following the same methodology as with the long sides.

   Maximum removal forces for each attempt are recorded.



Test bench upper view

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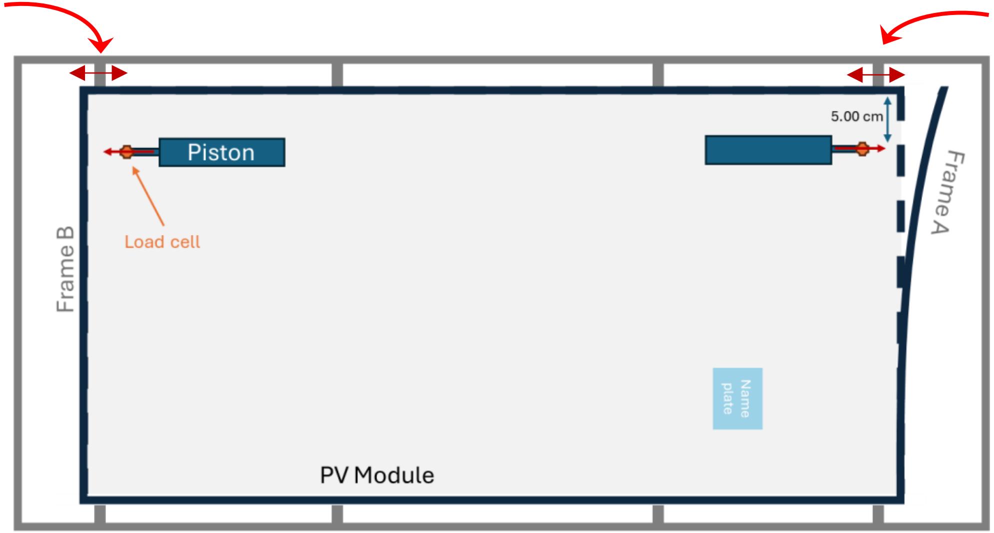
1. PV Frame removal equipment

3. Short frame removal (A-B):

   To ensure the integrity of the glass, two structural supports are installed in the bench table to stabilise the module during the test and avoid its bending. This feature significantly reduces the risk of glass fracture

Structural support profiles



Test bench upper view

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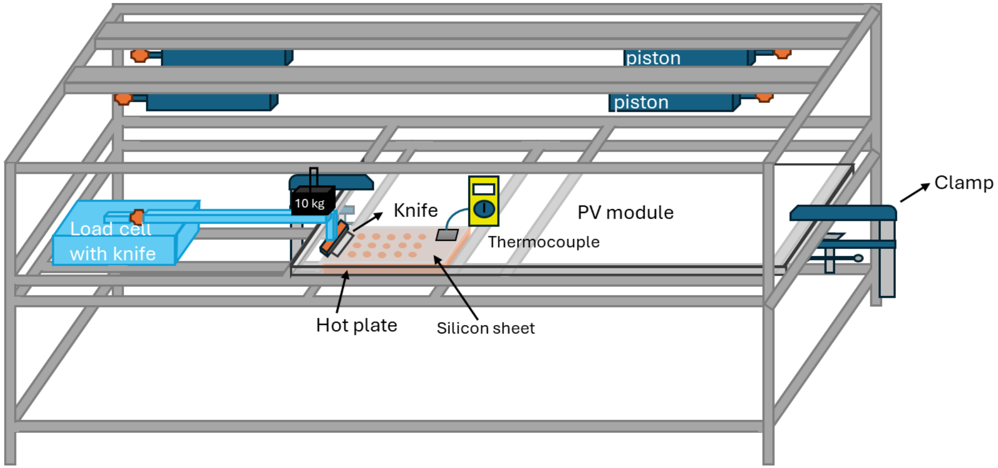
2. Delamination of monofacial modules

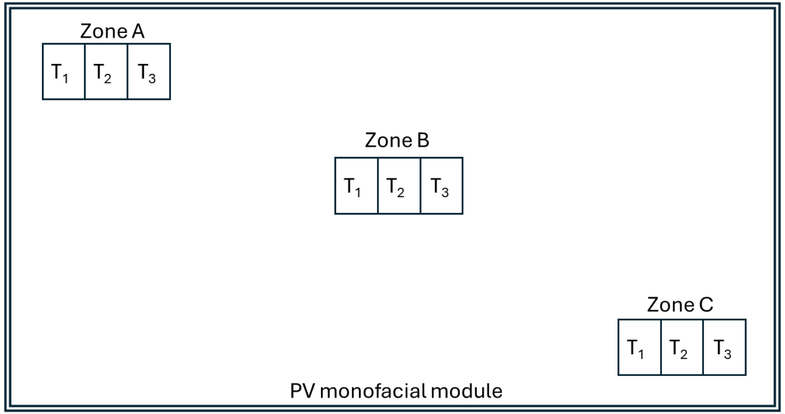
Measures the adhesion force at different temperatures between the PV laminate and the glass.

Made at 3 different temperatures: 70ºC, 150ºC and 200ºC in 3 different locations*

Cut the perimeter of the test zones with a blade.

Test zone, 10 cm wide and a minimum of 11 cm long



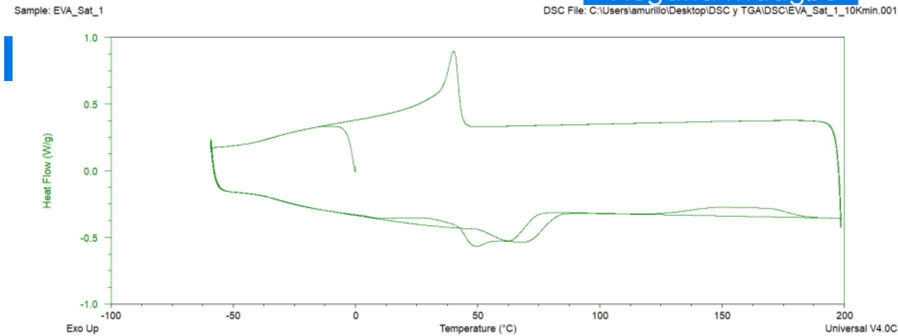


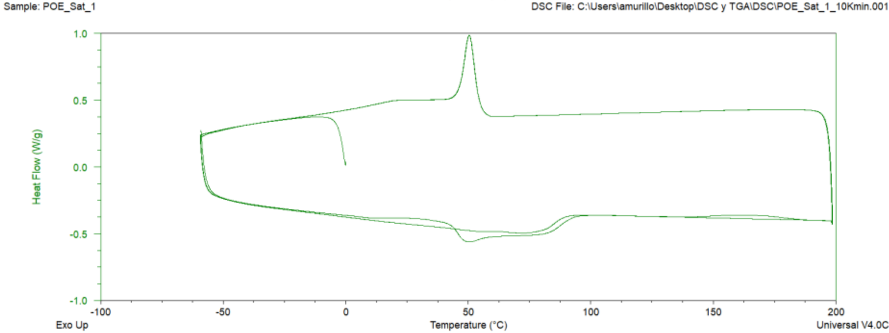
*For the evaluation of the index, only test at 70ºC and 150ºC

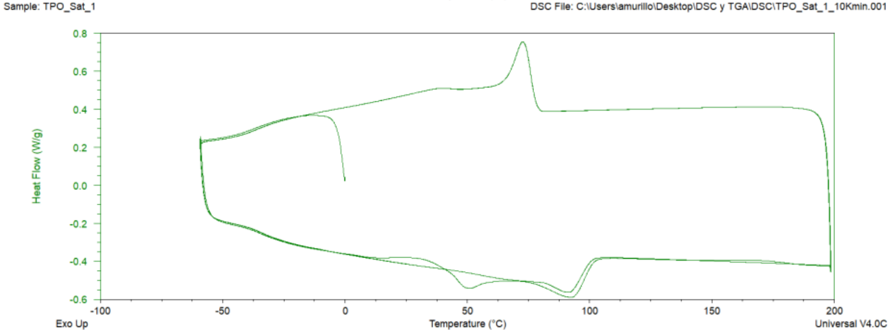
2. Delamination of monofacial modules

Temperature justification:

According to calorimetric analyses, the melting point of the most common encapsulants—EVA, POE, and TPO—lies within the range of 70–90 °C (although this may vary depending on the specific composition of the encapsulant). Therefore, a temperature of 70 °C was selected to remain below the melting point while still representing a temperature that can realistically be reached by a PV module in normal working conditions. The second temperature chosen was 150 °C, as it is well above the melting point and far beyond the working temperatures that PV modules would normally experience. This approach allows for the analysis of the reduction in the force required to delaminate between the two temperature conditions.



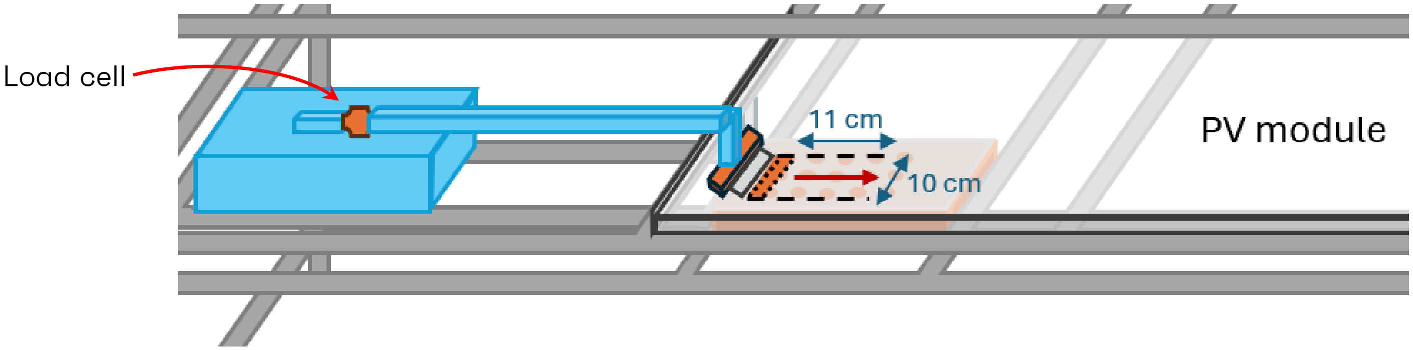




2. Delamination of monofacial modules

The delamination test is made in 2 steps:

1. Entrance of the blade: at 50 mm/min until the blade has entered the laminate
2. Zero the load cell measurement
3. Test: at 150 mm/min blade speed for 11 cm long

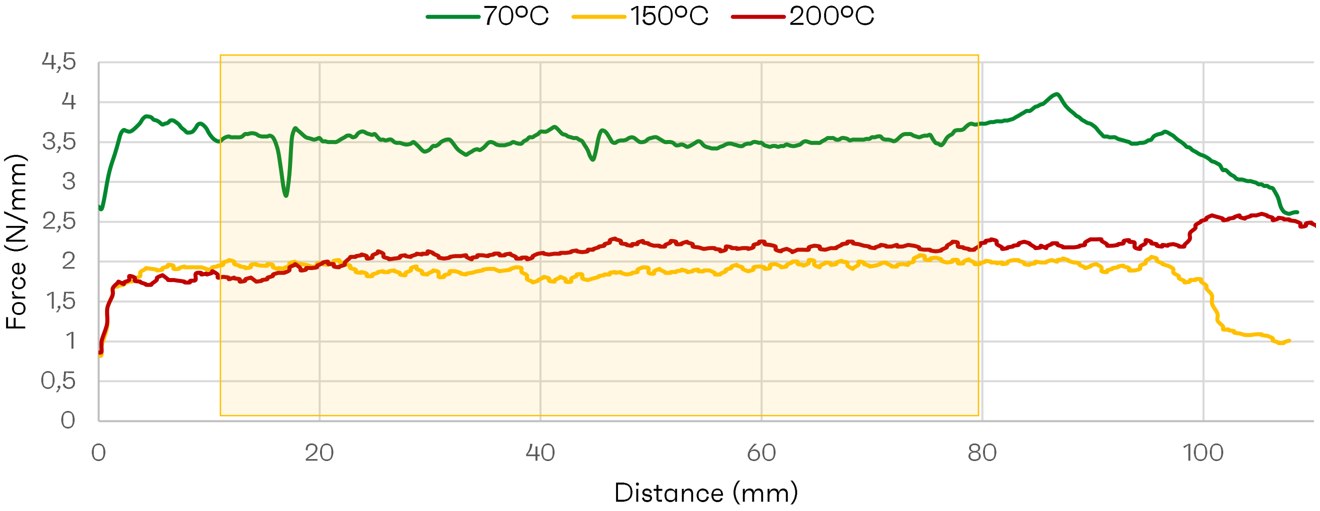


2. Delamination of monofacial modules

Results and evaluation:

From the 11 cm long test, select 7 cm of constant force to obtain the mean value in N/mm

The average delamination force decrease between different temperatures will be the criterion for assessing the recyclability of modules across different technologies.



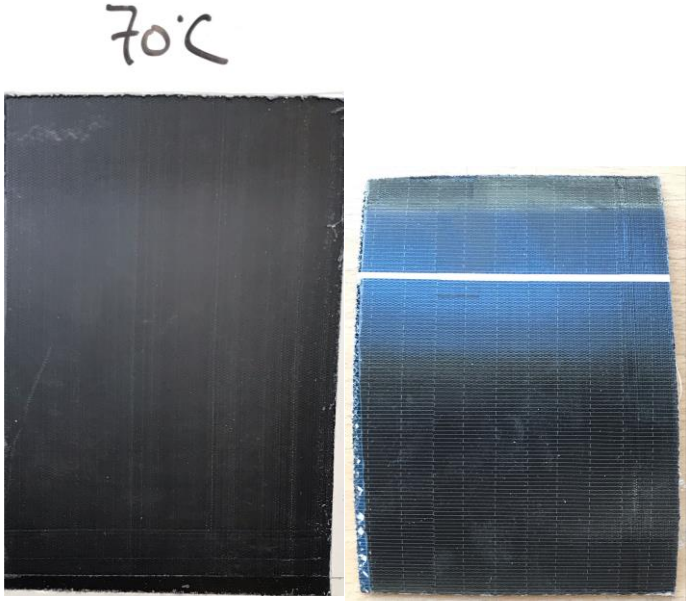
T	Force (N/mm)	Decrease
70ºC	3.52	-
150ºC	1.91	-46%
200ºC	2.15	-39%

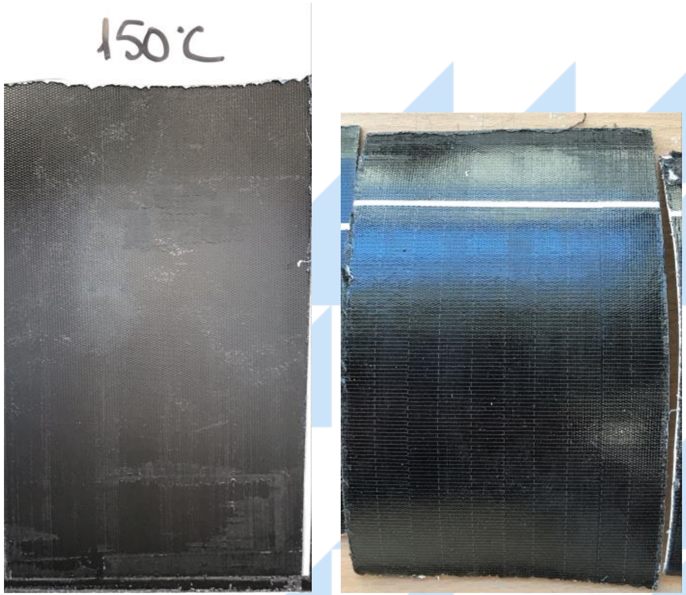
* The increase in the force between 150ºC and 200ºC is unclear

2. Delamination of monofacial modules

Results and evaluation:

The evaluation of the glass after the delamination test to analyse the transmittance of the glass.

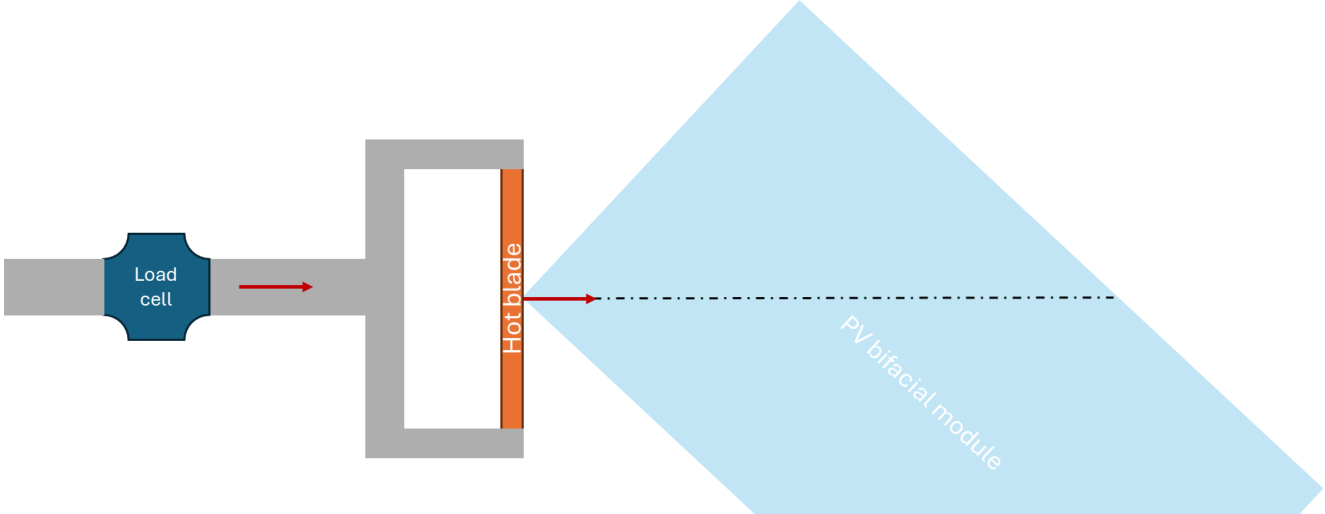




3. Delamination of bifacial modules

Process:

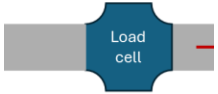
1. Heating the PV module at 150 °C
2. Blade inserted between two glasses manually: velocity 50 mm/min
3. Test: increase the velocity to 150 mm/min and record the force

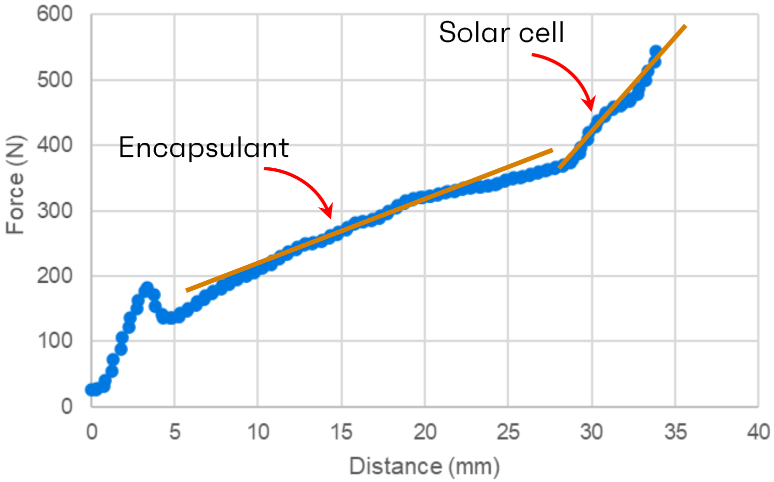


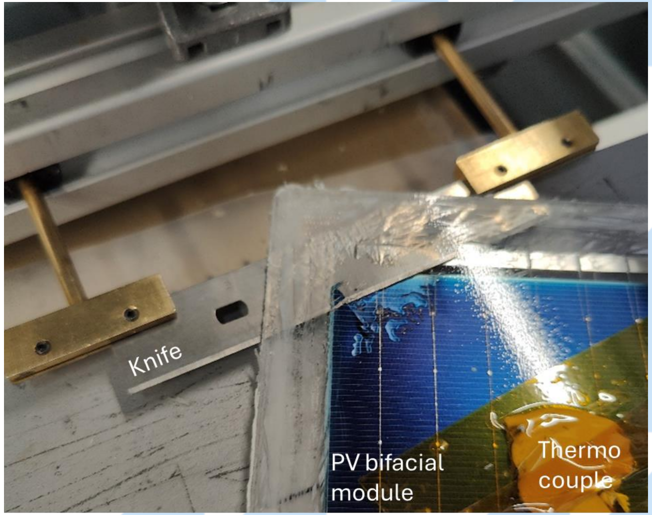
3. Delamination of bifacial modules

Measures and Evaluation:

1. The slope of the force is evaluated: As the blade advances diagonally from the corner, the resistance gradually increases due to the enlarging interface area, resulting in a linear upward trend in the force profile
2. Ensure the position of the module. Always the same







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PV MODULES DISMANTLING PROTOCOL

Template

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Photovoltaic module dismantling template

This template is designed to systematically document the dismantling process of photovoltaic (PV) modules as part of the recyclability assessment. It provides a structured approach to record key parameters such as the force required to remove the aluminium frame, the evaluation of the frame profile, the condition of the glass after dismantling, the force for the delamination process by means of hot knife or hot cord, and the condition of the glass after the process. By collecting standardized data across different module types, this template facilitates the comparison of recyclability performance and helps identify design features that influence the ease of disassembly and material recovery. The results obtained will contribute to optimizing recycling processes and promoting circular economy principles in PV module design.

1. General Information

This section records the basic information about the tested PV module, including manufacturer details, model, and testing date.

Parameter	Description / Value
Module ID	
Manufacturer	
Model	
Technology (Monofacial/Bifacial)	

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PV INVERTER DISSASEMBLE PROTOCOL

Priority components:

- Chasing
- Cables
- Heat sink
- DC capacitors
- PCB: printed circuit board
- LCD display
- Transformers and Solenoids

Evaluated parameters:

- Number of steps
- Type of tools used:
    - Proprietary tools
    - Commercially available tools
    - Basic tools
    - No tools
- Removability of the fasteners, reversible sealants and encapsulated layers

PV INVERTER DISSASEMBLE PROTOCOL

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Definitions:

- **Steps:** A step consists of an operation that finishes with the removal of either a priority part and/or with the change of a tool. Hands are not considered a tool, but if the use of the hand leads to the removal of a part of the device, then this action must be considered as a step without the use of tools, “no tools”.
- **Fasteners:** Any hardware that mechanically or magnetically connects or fixes two or more objects, parts or pieces. Some fasteners are generally non-permanent, i. e. they can be easily removed or disassembled without damaging the objects, parts or pieces connected or fixed together (screws, clips). However, welds and some glues are, in contrast, permanent fixing techniques. In this context, two types of fasteners are defined: removable and non-removable.



PV INVERTER DISSASEMBLE PROTOCOL

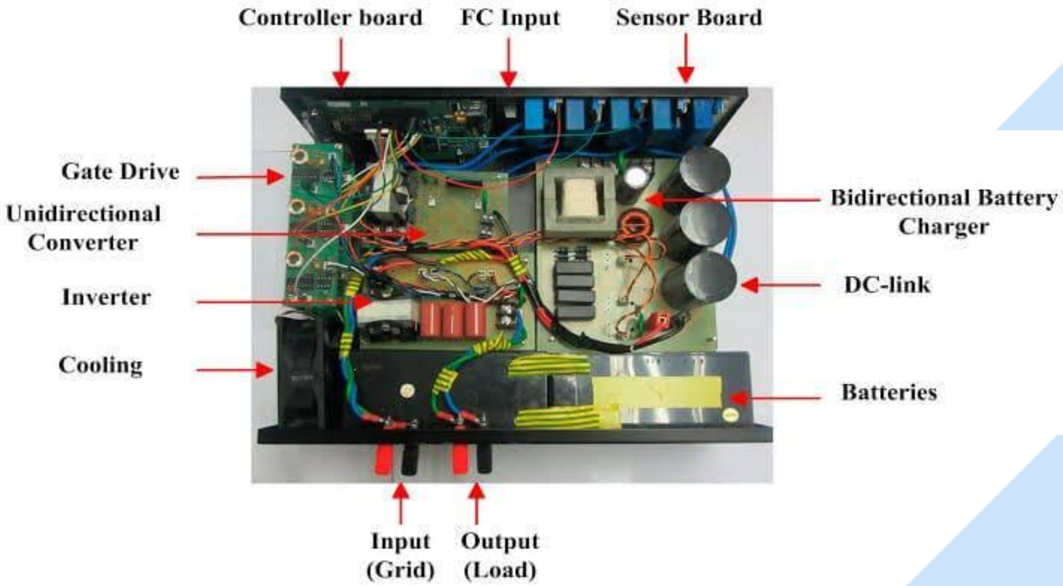
Definitions:

- **Tools:** defined in the EN4554:2020 for the parameter "tools".
  - No tools: the dismantling is feasible by only using hands.
  - Basic tools: listed in Table A.3 of the standard EN45554:2020.
  - Commercially available tools: the dismantling of a specific priority part is feasible with the use of tools available in the open market
  - Proprietary tools: These are tools that are not available for general public purchase or for which any applicable partners are not available to license under fair, reasonable and non-discriminatory terms.

PV INVERTER DISSASEMBLE PROTOCOL

Dismantling process:

1. Recording of the process
2. Removal of the chasing
3. Remove any existing connectors on the casing
4. Disassembly of LCD screen
5. Removal of cables
6. PCB board removal
7. Removal of the heatsinks
8. Desoldering of the DC bus capacitors
9. Weighing of disassembled components



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PV INVERTER DISSASEMBLE PROTOCOL

Template:

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Photovoltaic Inverter Disassembly Report

This disassembly protocol aims to assess the level of difficulty involved in recovering the following priority components of PV inverters:

1. General Information

Parameter	Description/Value
PV Inverter ID	
Manufacturer	
Model	
Test date	
Disassembly video	

Coffee Break 10:45 – 11:00

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We will be back in 15 minutes

Agenda

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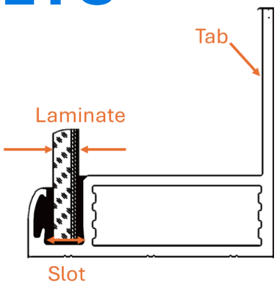
1	Welcome – 8:30
2	Policy Background – European Commission 08:45 – 9:00
3	Recyclability Index Methodology 09:00 – 09:30
4	Testing – Selection of the sample 9:30 – 10:00
5	Testing protocols 10:00 – 11:00
6	Testing Results 11:00 – 12:00
7	Next steps of the study 12:00 – 12:15
8	General Questions and Answers 12:15 – 12:30
9	AOB, closure 12:30

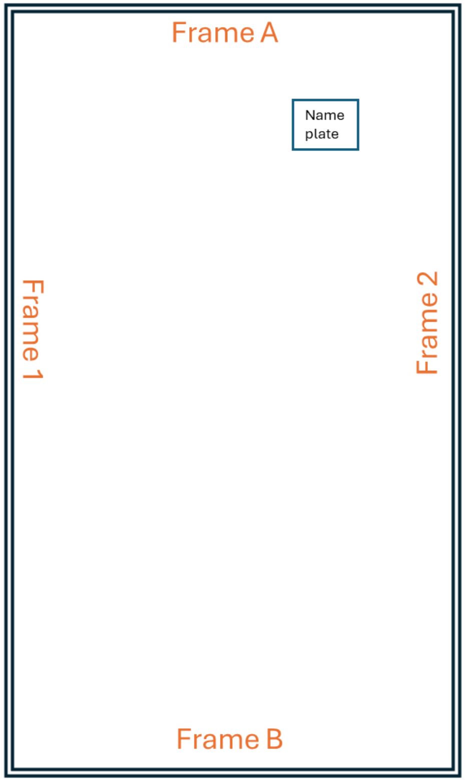
PV MODULE DISMANTLING RESULTS

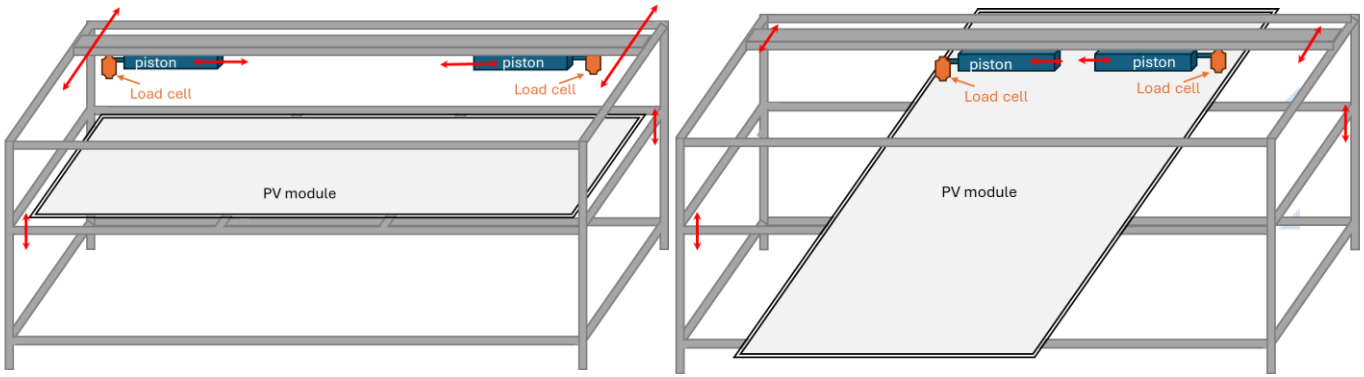
Frame removal test

Determine the mechanical force needed to remove the aluminium frames (without breaking other components).

The force is applied near the corner reinforcement until the frame is detached or broken, and the maximum force is recorded







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PV MODULE DISMANTLING RESULTS

Frame removal test - RESULTS

	Force (kgf)						Comments			
Module	Frame 1-2		mean	Frame A-B		mean	comments Frame 1-2	comments Frame 2-1	comments frame A-B	comments frame B-A
1a	1180	1264	1222	747	760	754	Frame 1 partially detached	Frame 2 partially detached	Frame B partially detached	Frame B totally detached
1b	688	628	658				Frame 1 broken	Frame 2 broken in a hole	The module got broken while changing the test bench configuration between frame removals	
2a	1140	1065	1103				The glass break	The whole module break, both glasses and the solar cells		
2b	No tested because module 2a explode into pieces during frame removal test									
3a	1228	1114	1171	1182		1182	Frame 2 partially detached	Frame 2 completely detached	Frame A completely detached	
3b	1337	1159	1248	1356		1356	Frame 1 partially detached	Frame 1 completely detached	Frame A completely detached	
4a	951	1344	1148	927	921	924	3 attempts to break part of the frame 2	Frame 1 partially detached	Frame A partially detached	Frame A totally detached
4b	1380	1419	1400	1342	921	1132	Frame 1 partially broken in hole	Frame 2 partially detached	Frame B partially detached	Frame B totally detached
5a	643	594	619				Frame 2 broken in a hole	Frame 1 partially detached	No force enough to detach frames A and B	
5b	1179	1127	1153	1440	973	1207	Frame 2 partially broken in hole	Frame 1 partially broken	Frame B partially detached	Frame B totally detached but the glass got broken
6a	1531	1540	1536	1650	1637	1644	Frame 2 broken in a hole	Frame 1 broken in a hole	Frame A partially detached	Frame B partially detached
6b	1540	1529	1535	1430	1656	1543	Frame 2 broken in a hole	Frame 2 broken in a hole	Frame B partially detached	Frame B totally detached
7a	1325	1796	1561	1617		1617	Frame 1 broken in a hole	Frame 2, partially detached	Frame B partially detached and then completly detached by hand	
7b	1771	1664	1718	1566	1118	1342	Frame 1 broken in a hole	Frame 2, partially detached	Frame B, partially detached	Frame A totally detached
8a	1138	1151	1145	1313	1539	1426	Frame 1 broken in the hole	Frame 1 broken from a hole	Frame B partially detached	Frame B totally detached
8b	1086	1119	1103	982	582	782	Frame 2 partially detached	Frame 2 partially broken in a hole	Frame B partially detached	Frame B totally detached
9a	1645	1564	1605	647		647	Frame 2 broken in the middle	Frame 1 broken in the middle	Frame B partially detached	
9b	1199	1423	1311	497		497	Frame 2 partially detached	Frame 1 partially detached	Frame B partially detached	

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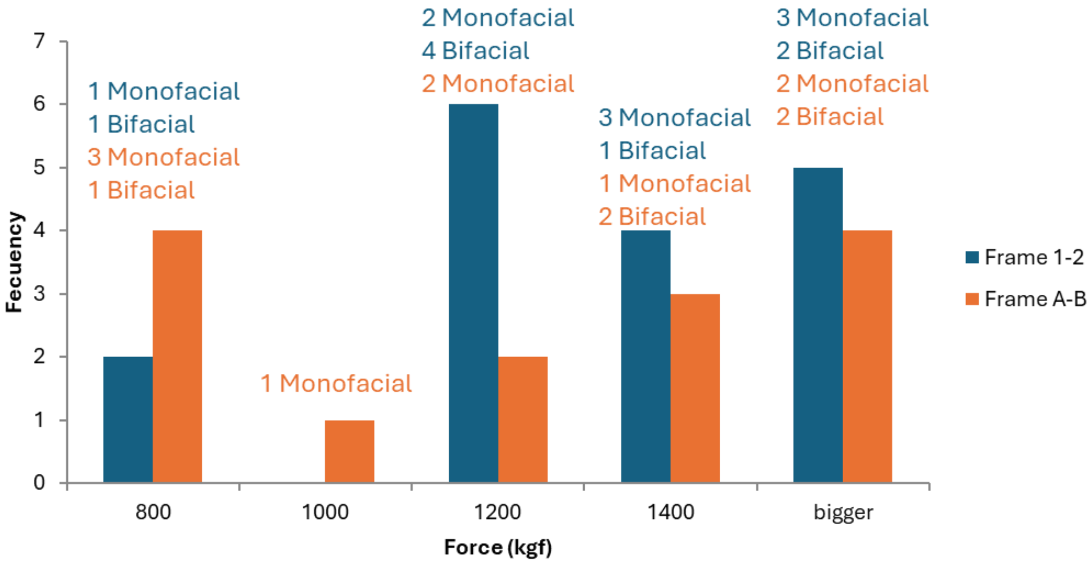
PV MODULE DISMANTLING RESULTS
Frame removal test - RESULTS

Process Video – Monofacial and Bifacial

- The force required to detach the frames varied significantly across brands and frame types:
    - Short sides (A–B) required less force to be removed than the long sides (1–2).

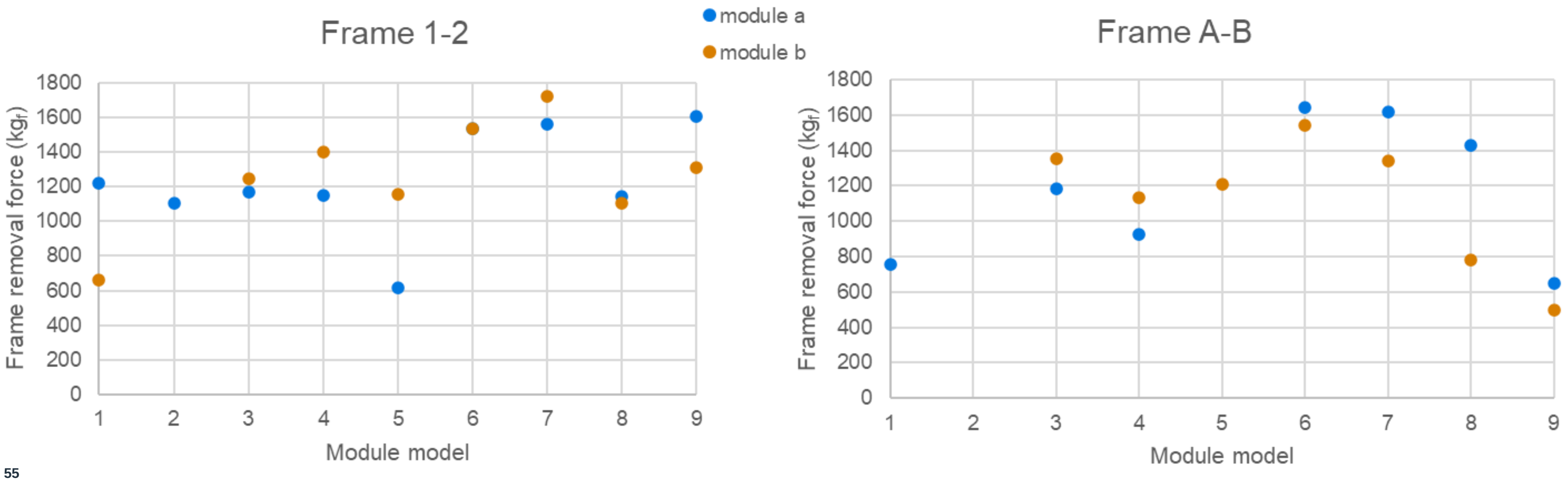


Two tests were conducted per module, and the average of the two measurements was considered

PV MODULE DISMANTLING RESULTS

Frame removal test - RESULTS

- Broad variety of forces: from 800 kg to more than 1400 kg
- Despite being the same model from the same manufacturer, some intra-model variation is evident -> module-to-module variability must be accounted for when evaluating the recyclability of PV modules via mechanical disassembly methods.

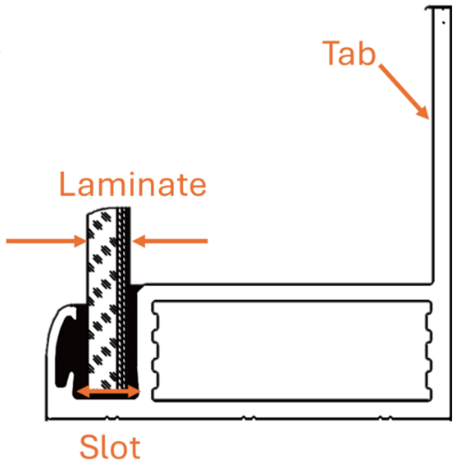


PV MODULE DISMANTLING RESULTS

Frame removal test

Substantial variability in the frame removal forces -> detailed evaluation of the aluminium profile design to identify potential structural factors that may influence the mechanical effort required for disassembly.

- Profile Uniformity: same profile for long and short frames
- Slot Geometry
- Residual Gap: The remaining clearance between the internal edge of the profile and the laminate edge (Slot – Laminate).
- Presence of Additional Features



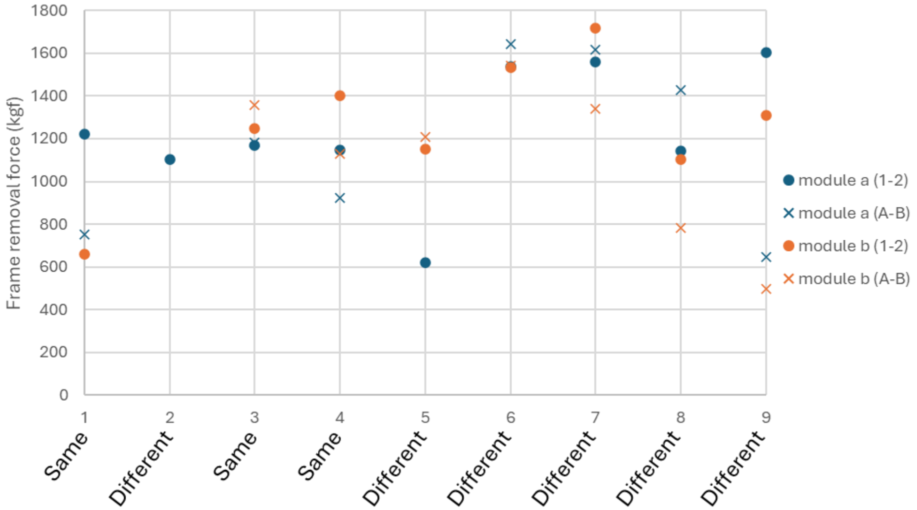
PV MODULE DISMANTLING RESULTS

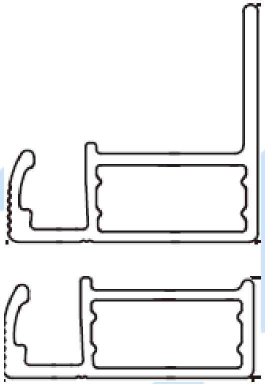
Frame removal test - RESULTS

Monofacial modules have the same frame profile for frames 1-2 and A-B, except for the module type 6

Bifacial modules have different frame profiles

- Same profiles: more consistent force values across all frame sides
- Different profiles: displayed greater variability between long and short frame sides





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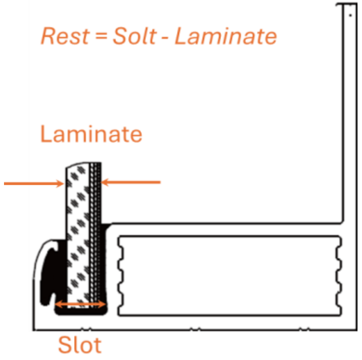
PV MODULE DISMANTLING RESULTS

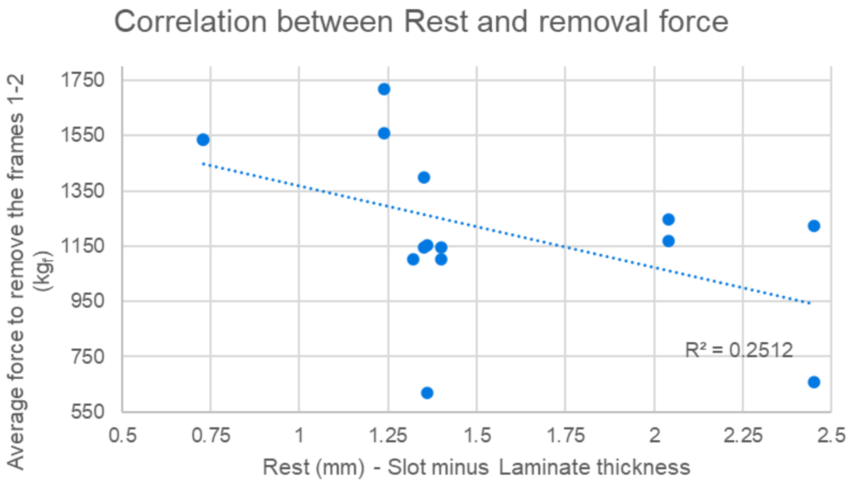
Frame removal test - RESULTS

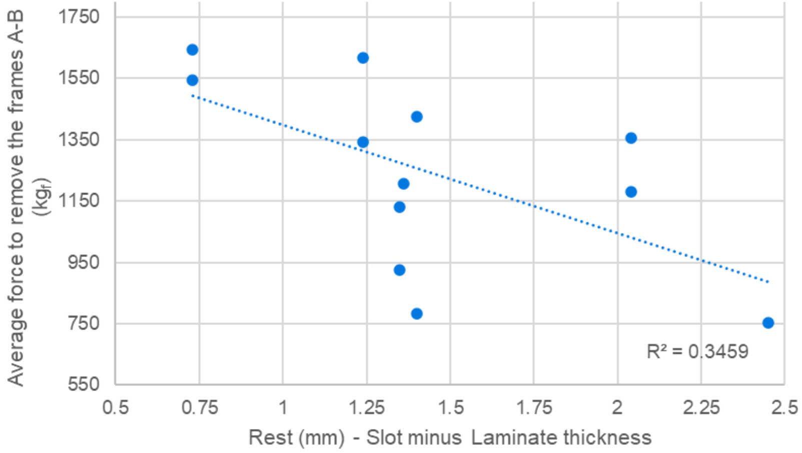
Average slot dimension:

- Bifacial: ~6.48 mm
- Monofacial: ~5.89 mm

Modules with lower tolerance or “rest” tended to require higher removal forces.







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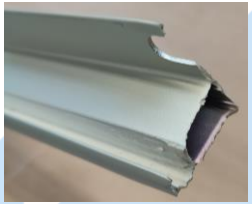
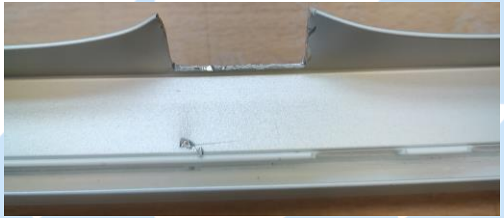
PV MODULE DISMANTLING RESULTS

Frame removal test - RESULTS

- Bifacial modules did not consistently require more force
- Mounting holes emerged as critical weak points—several models (5, 6, 8) exhibited breaks specifically at these locations
- Use large profiles to homogenise the force of the pistons to avoid the tab breakage
- Model 2 modules, tested without encapsulant, shattered completely during frame removal indicating incompatibility with this method.
- This analysis is preliminary in nature due to the small sample size (18 modules)





PV MODULE DISMANTLING RESULTS

Frame removal test - CONCLUSIONS

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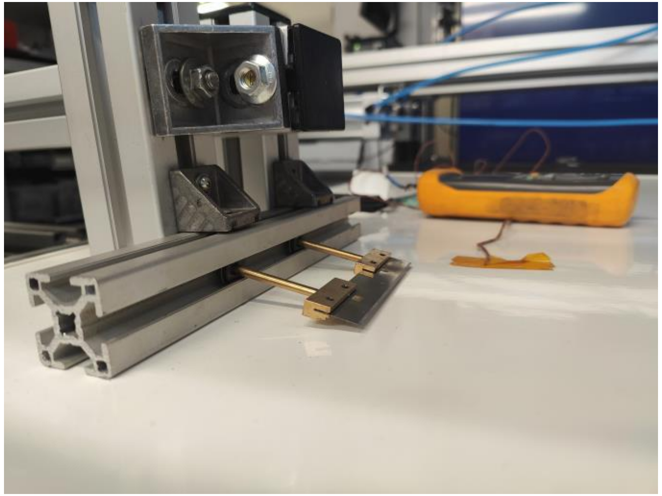
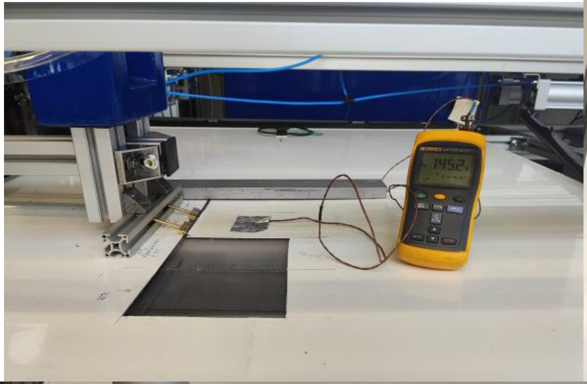
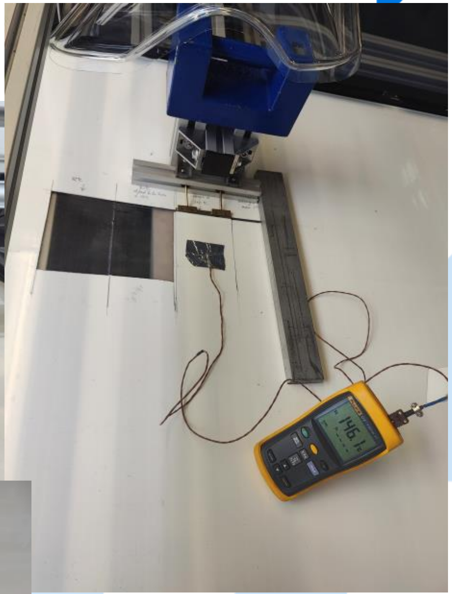
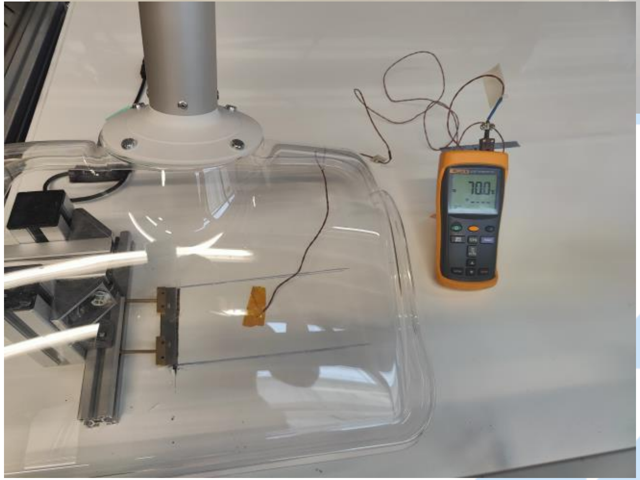
- Mechanical Resistance vs. Slot Fit: lower “rest” values are associated with higher removal forces.
- Encapsulation Status: model 2 modules were outliers, as they lacked encapsulant, and both glass layers (back and front) broke during frame removal. This strongly influenced the failure mode and disqualifies them from statistical comparisons.
- Frame Profiles: some brands using uniform profiles in both sides exhibited more consistent behaviour during removal. Brands with varied profiles showed inconsistent resistance depending on the side tested.
- Bifacial modules: tend to have larger slot dimensions, this does not directly translate to higher detachment forces.
- No single factor determines the detachment force. Rather, it is the result of a combination of slot dimension, laminate thickness, frame profile design, and manufacturing quality.

PV MODULE DISMANTLING RESULTS
Monofacial delamination test









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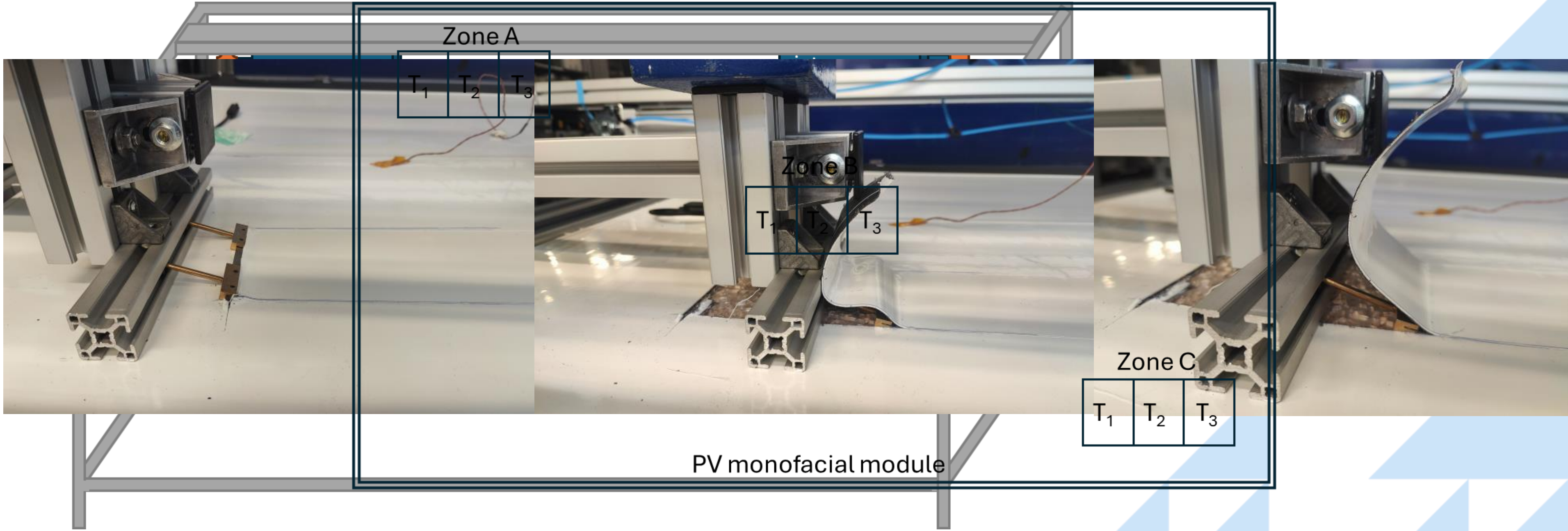
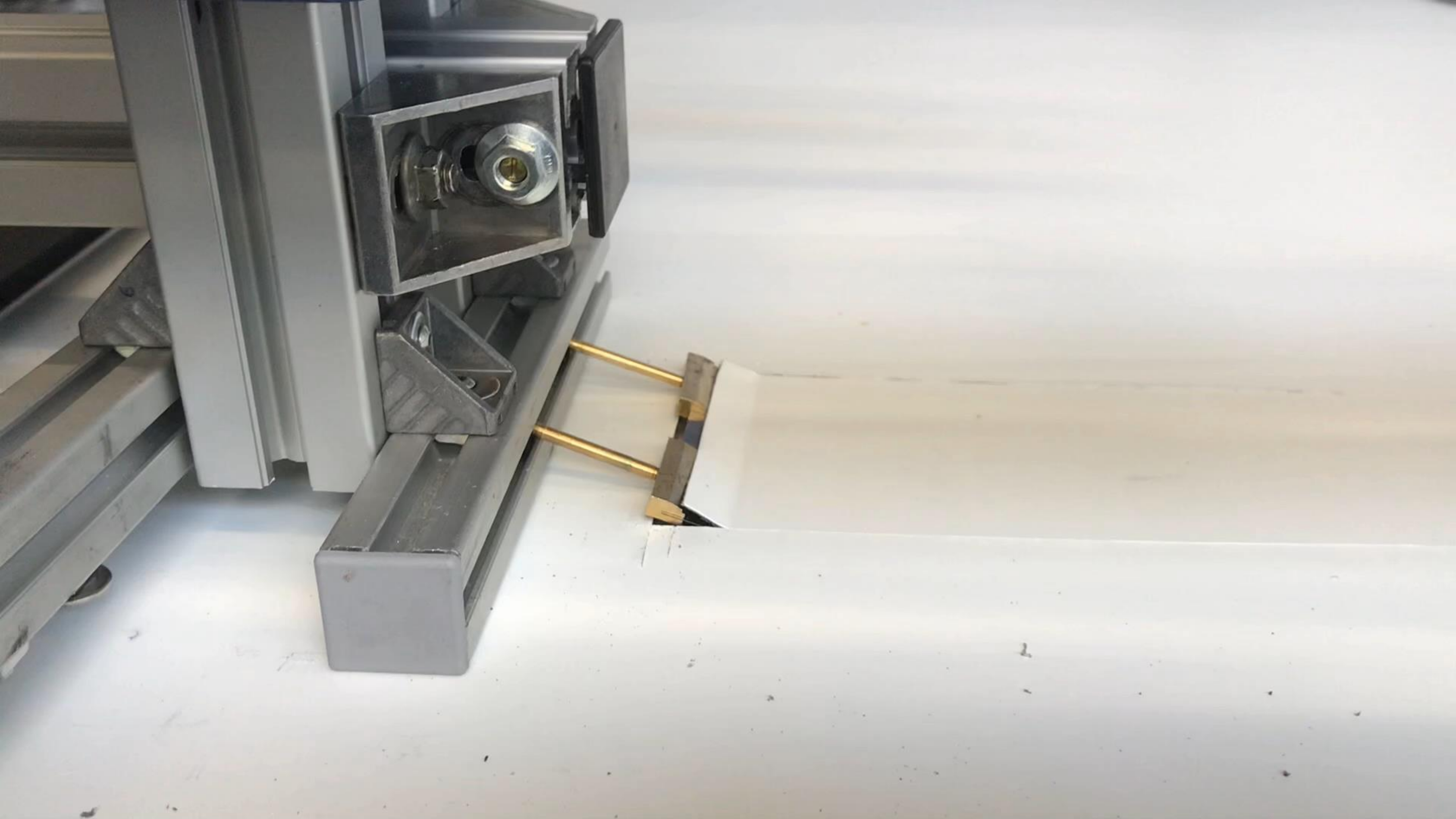
PV MODULE DISMANTLING RESULTS
Monofacial delamination test





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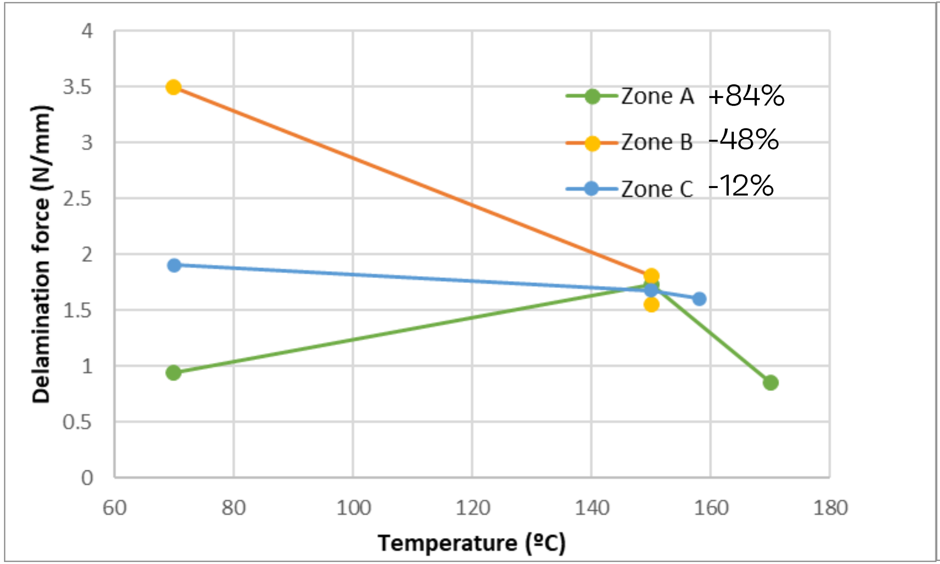
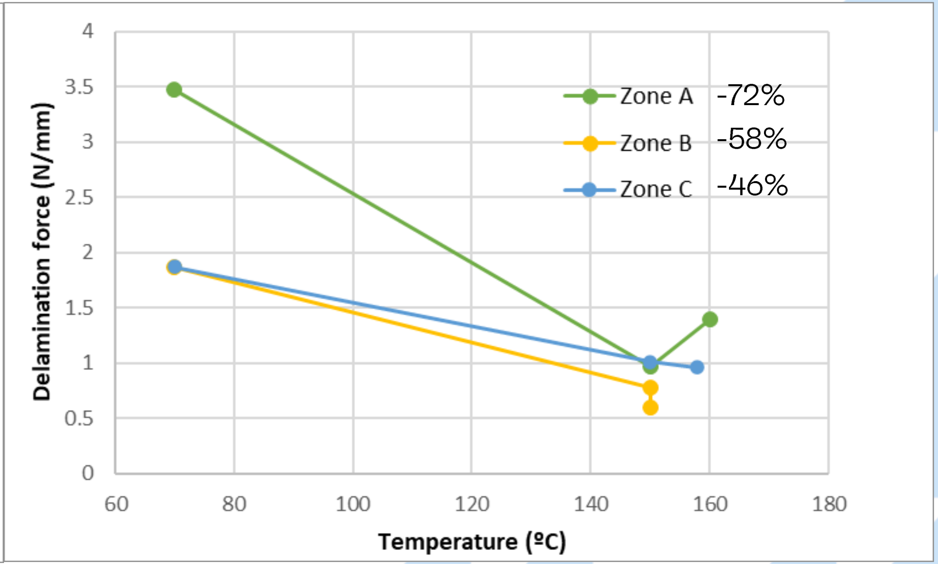
PV MODULE DISMANTLING RESULTS
Monofacial delamination test - RESULTS

- Model 3: Heterojunction multi-busbar

Module a: Mean force drop of -23%



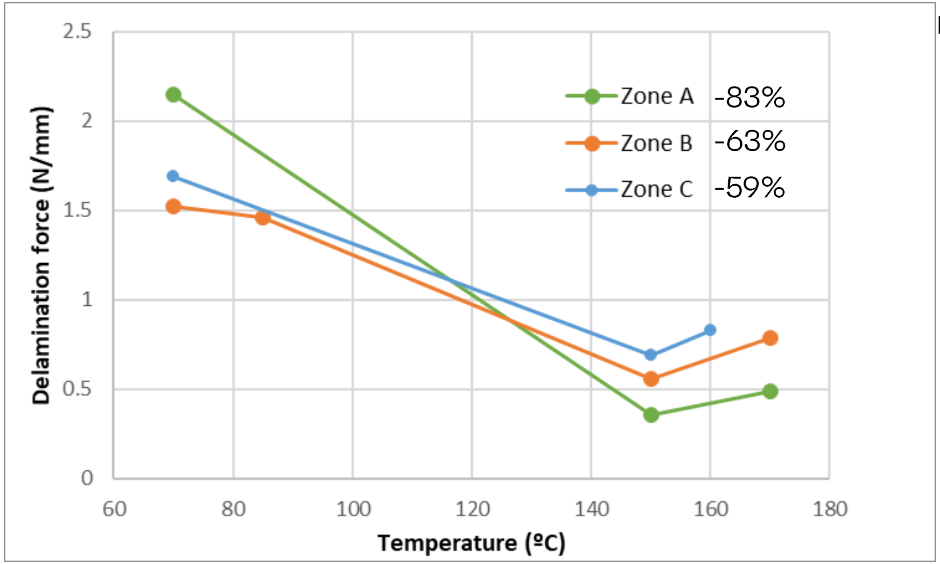
Module b: Mean force drop of -59%



PV MODULE DISMANTLING RESULTS
Monofacial delamination test - RESULTS

- Model 4: Shingled and encapsulated with EVA

Module a: Mean force drop of -69%



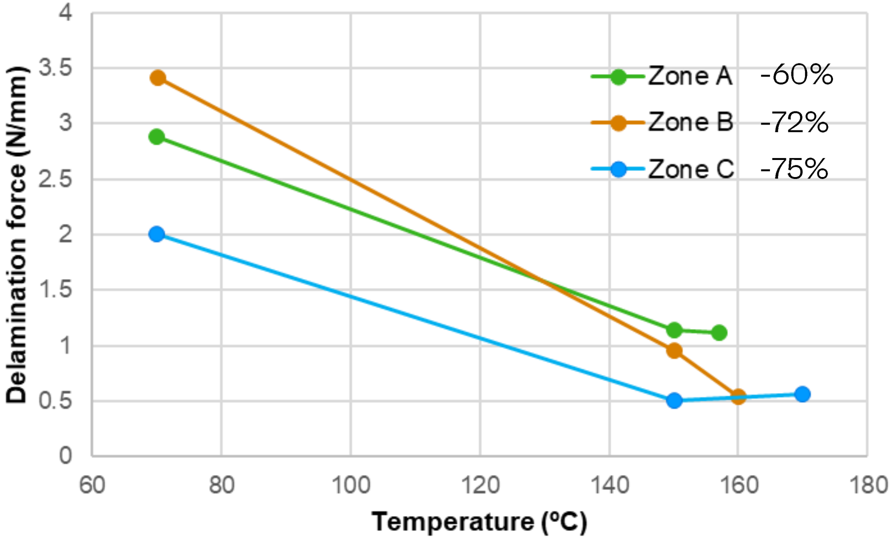
Module b: only one test as it get broken during the manipulation

Zona A	
T (ºC)	F (N/mm)
70	1.37

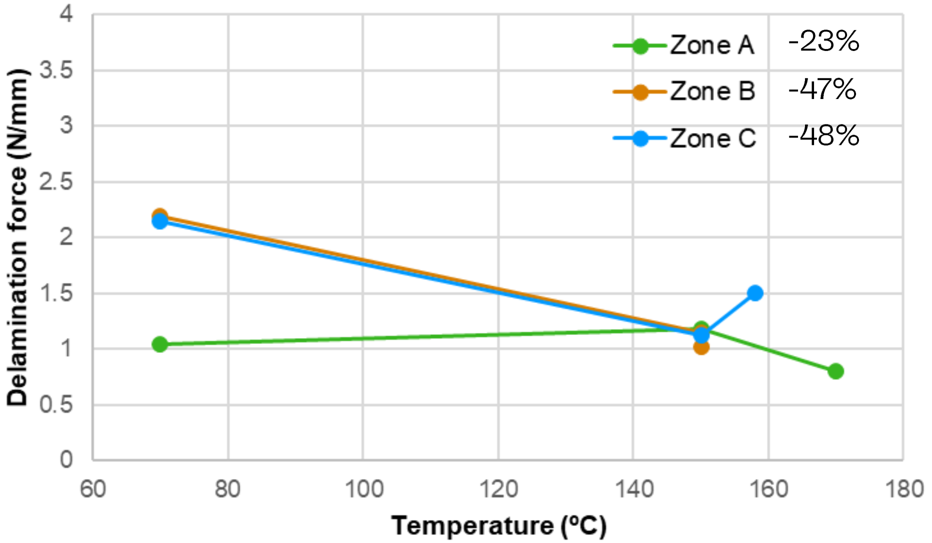
PV MODULE DISMANTLING RESULTS
Monofacial delamination test - RESULTS

- Model 6: Back-Contact Cells

Module a: Mean force drop of -69%



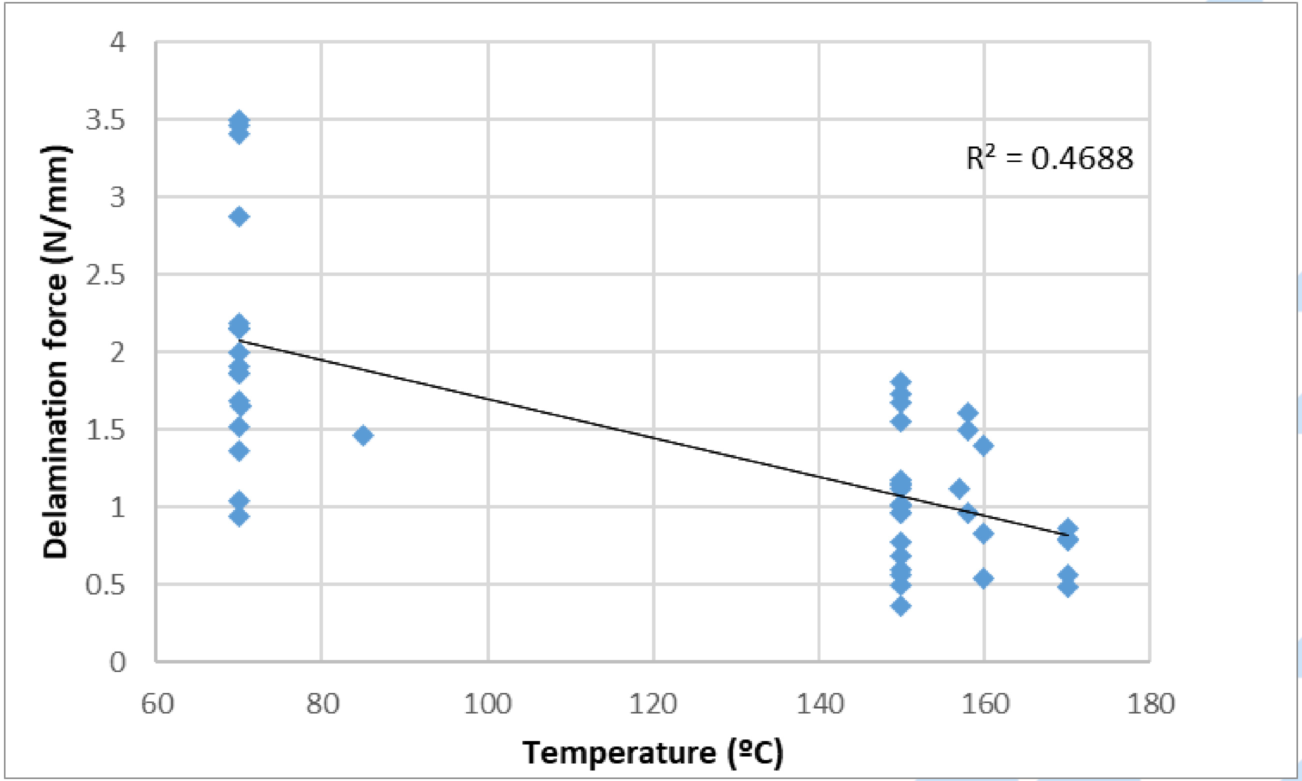
Module b: Mean force drop of -39%



PV MODULE DISMANTLING RESULTS

Monofacial delamination test - RESULTS

All results



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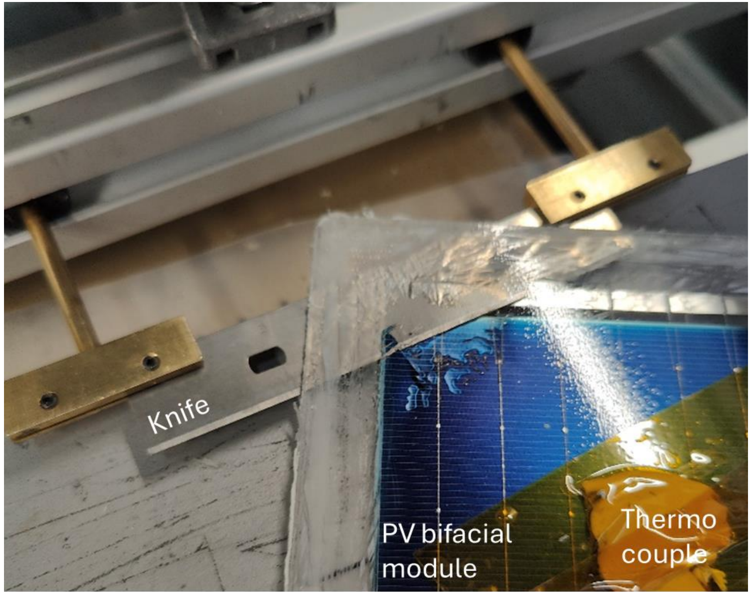
PV MODULE DISMANTLING RESULTS

Bifacial delamination test - RESULTS



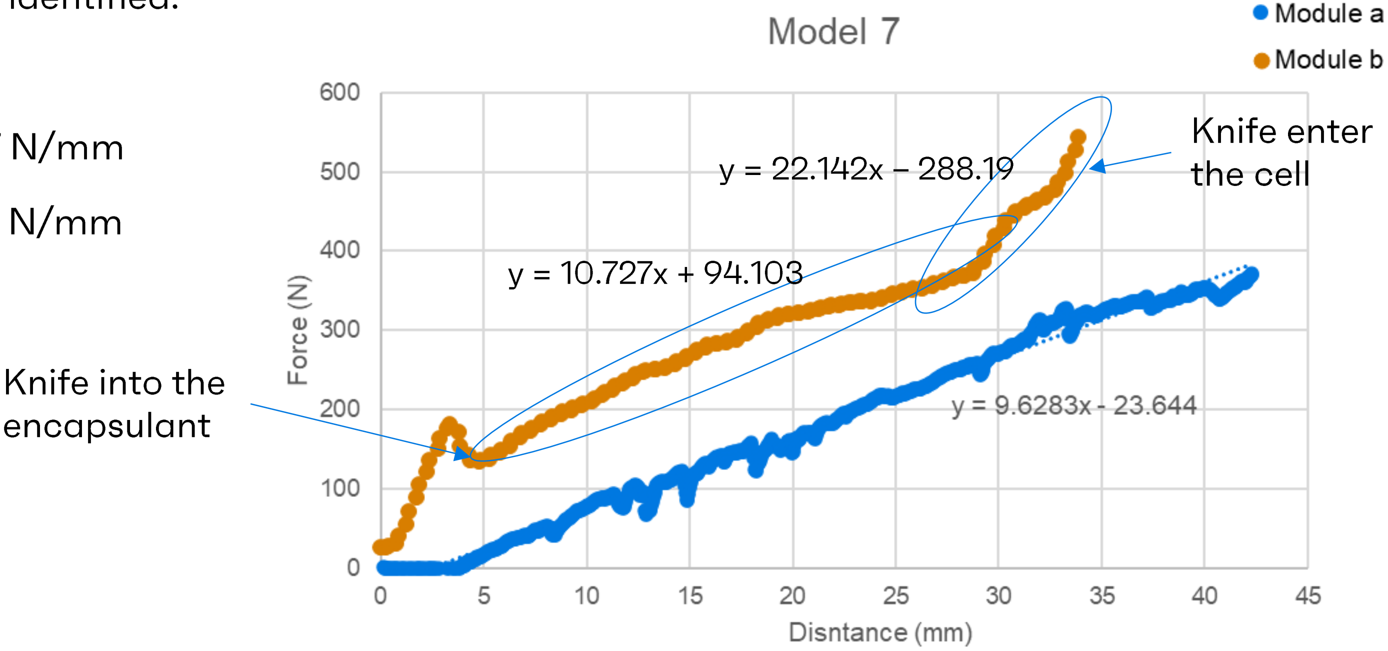
PV MODULE DISMANTLING RESULTS
Bifacial delamination test - RESULTS

The slope of the curve is measured.

Two slopes could be identified.

<u>Model 7</u>

- Module a: 10.727 N/mm
- Module b: 11.307 N/mm



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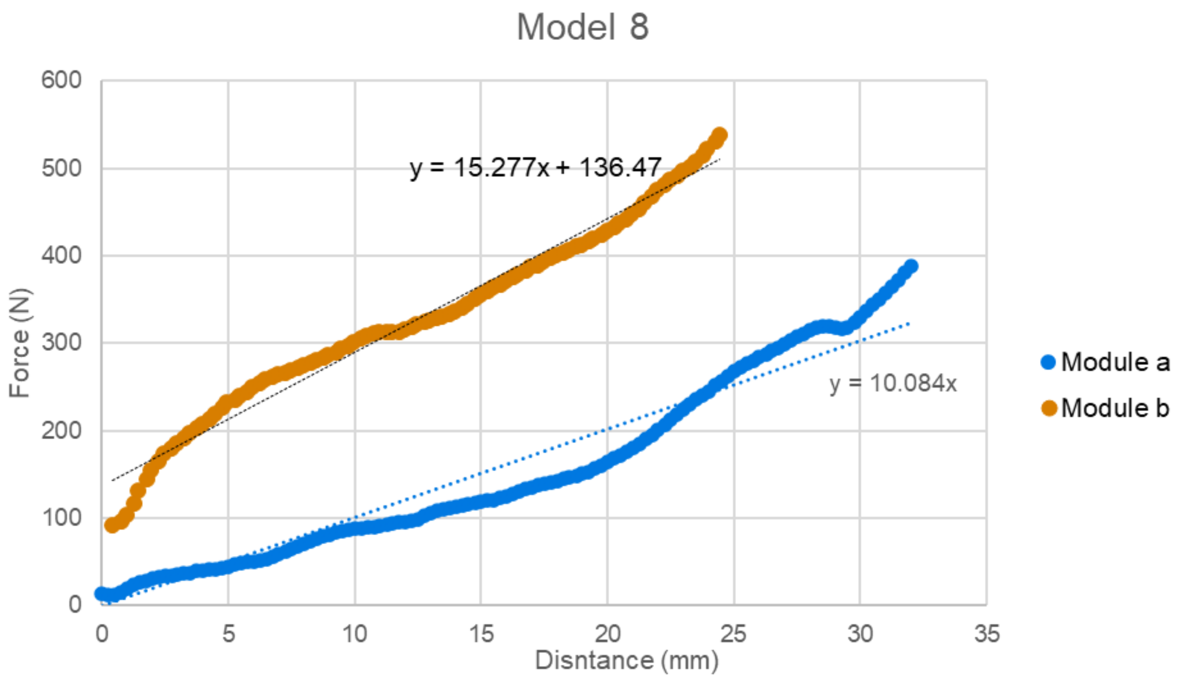
PV MODULE DISMANTLING RESULTS
Bifacial delamination test - RESULTS

Model 8

- Module a: 10.084 N/mm
- Module b: 15.277 N/mm



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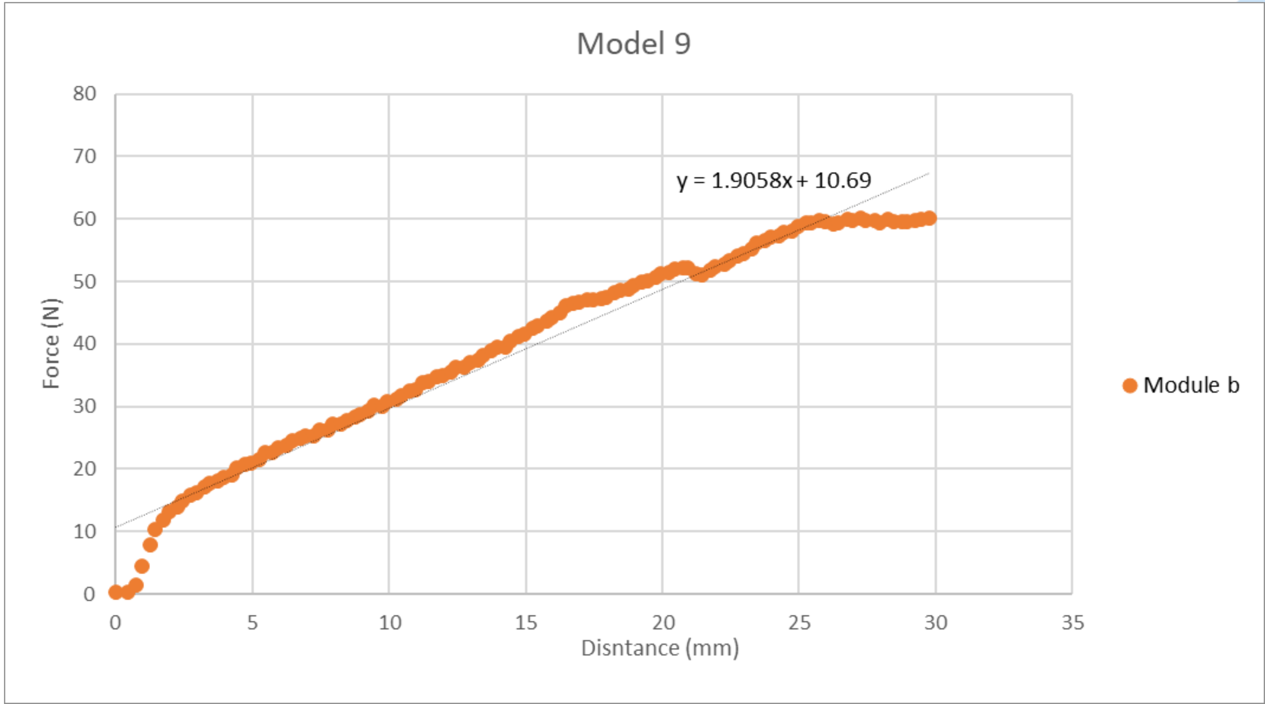
PV MODULE DISMANTLING RESULTS
Bifacial delamination test - RESULTS

Model 9: thin film

- Module b: 1.9058 N/mm



PV MODULE DISMANTLING RESULTS

Bifacial delamination test - RESULTS

Conclusions:

- Differences between modules of the same model
- The test should be performed on the 4 corners and obtain the mean value
- Need of longer blades to be able to enter more into the module and evaluate effect of different c-Si technologies
- Thin-film modules need less force than c-Si modules.
- Modules from model 5 couldn't be tested as one got broken in the frame removal text, and other was impossible to release one module corner

PV INVERTER RESULTS

8 inverter models were disassembled

The process has been completed by two technicians, where each one has disassembled each model type of inverters.

Note that microinverters have been tested, but the substantial differences in design, components and disassembly process in comparison to other PV inverters make them out of the scope of this disassembly study

Product identification	Characteristics	P out (W)	Phase	Cooling
Inverter type 1	Microinverter	295	Monophase	-
Inverter type 2	Inverter-Charger 2 MPPT	2 200	Monophase	Natural cooling
Inverter type 3	High Power	66 600	Three-phase	Active cooling
Inverter type 4	Medium Power	20 000	Three-phase	Active cooling
Inverter type 5	Inverter-Charger	3 000	Three-phase	Not provided
Inverter type 6	Inverter-Charger 2 MPPT	6 000	Three-phase	Natural cooling
Inverter type 7	1 MPPT Inverter	3 700	Three-phase	Active cooling
Inverter type 8	Hybrid	3 000	Monophase	Active cooling

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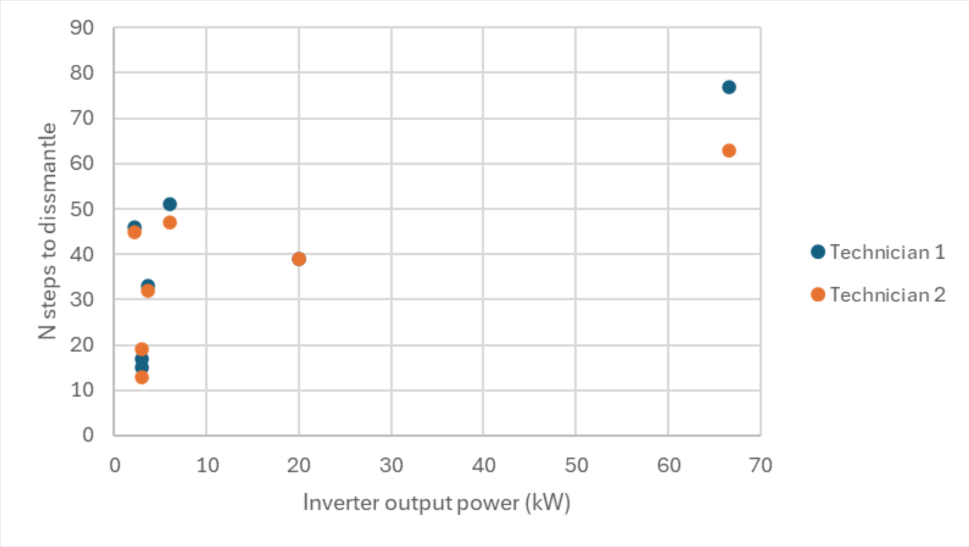
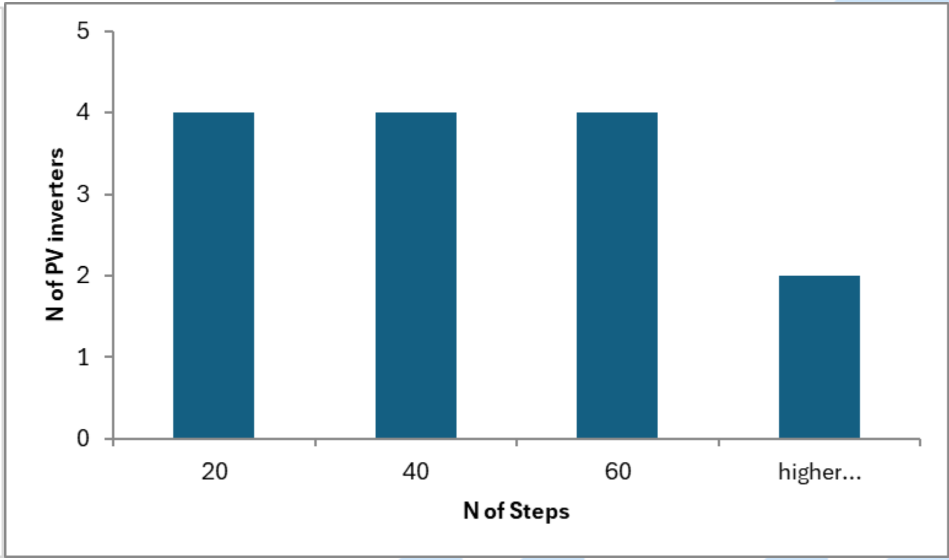
PV INVERTER RESULTS

Number of steps needed to disassemble the PV inverters as a function of the inverter power as performed by each technician:

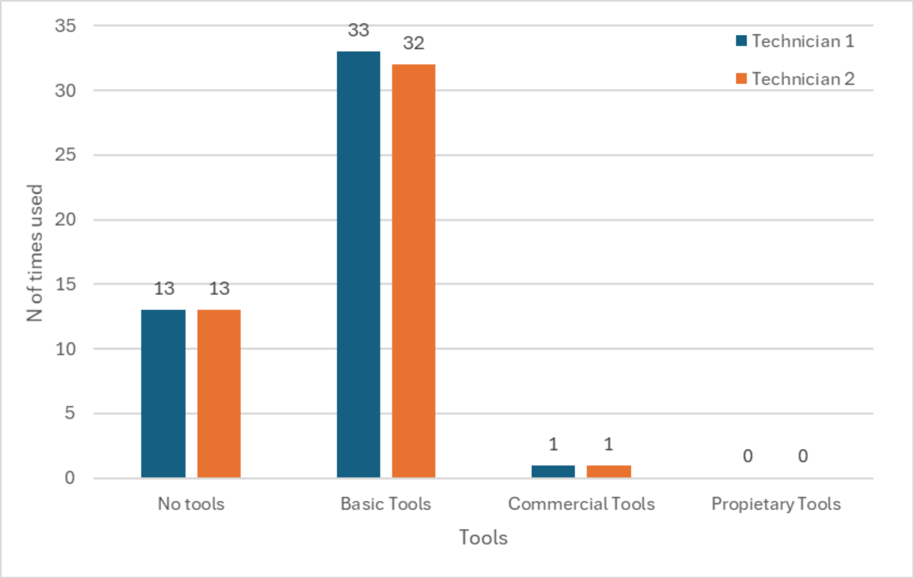


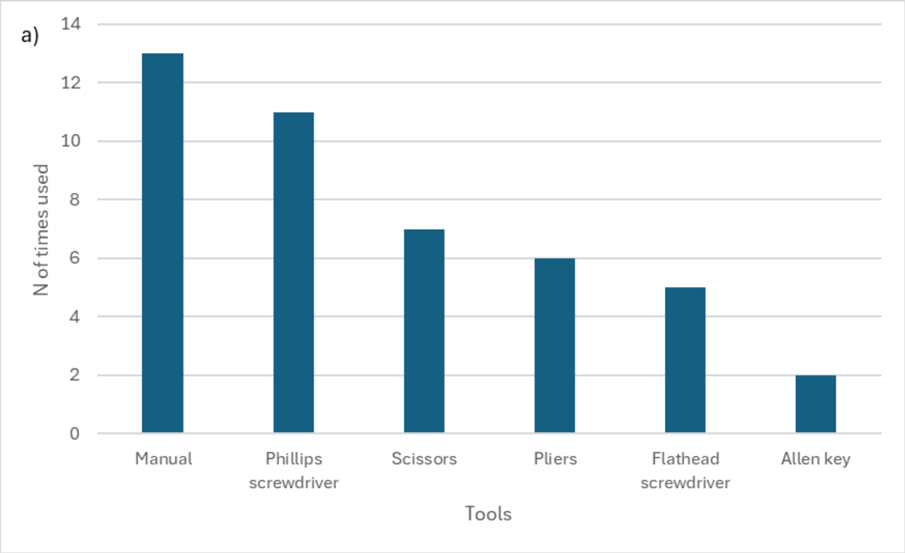


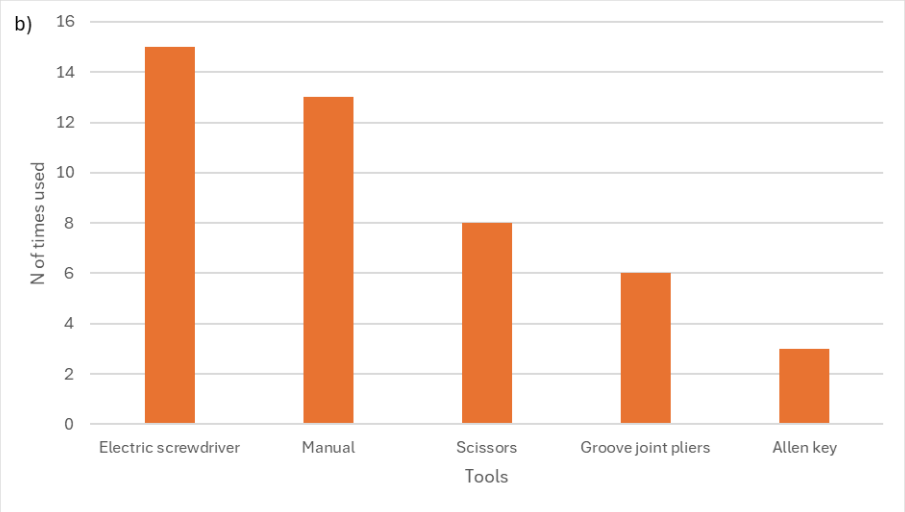
PV INVERTER RESULTS

Inverter model 2 (2.2 kW):

46 and 32 steps



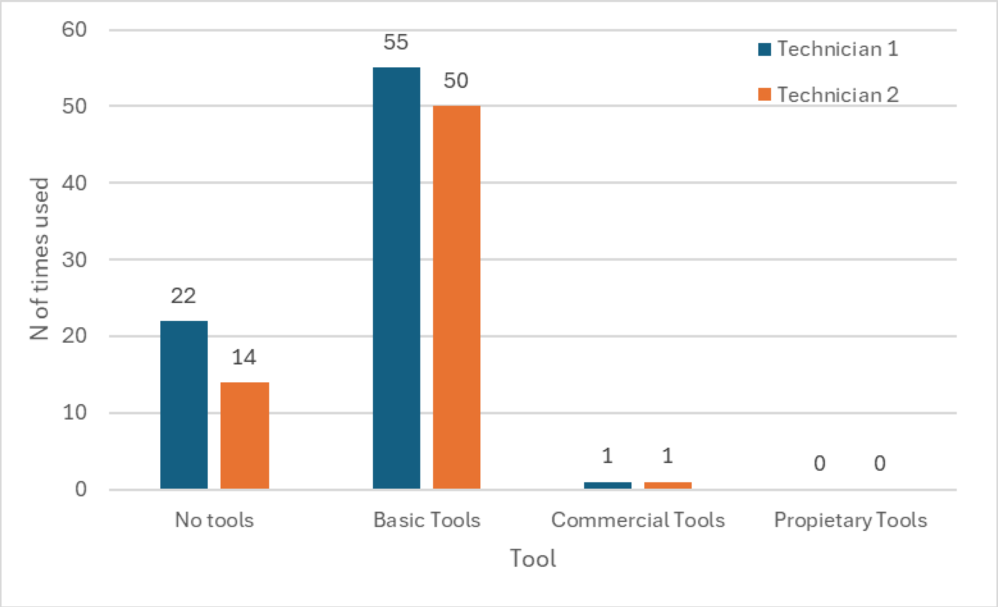


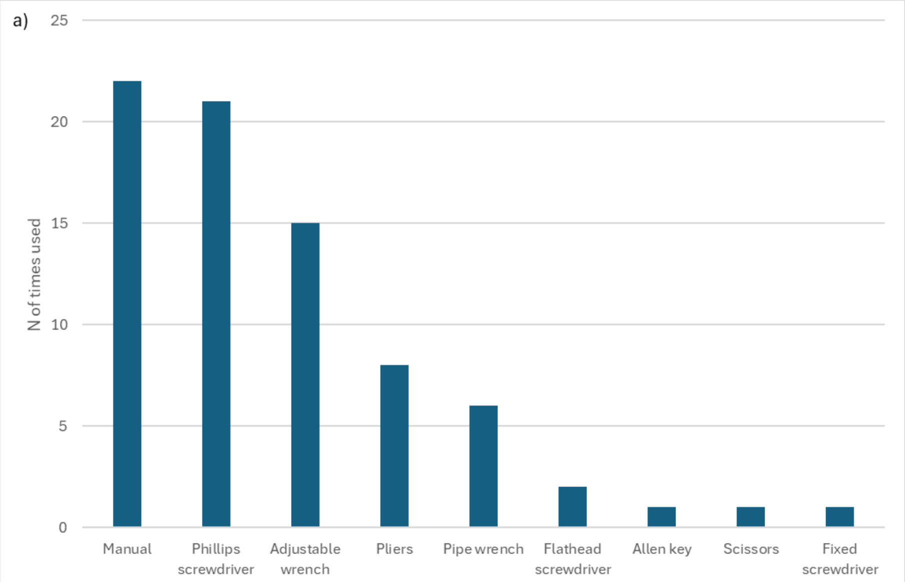


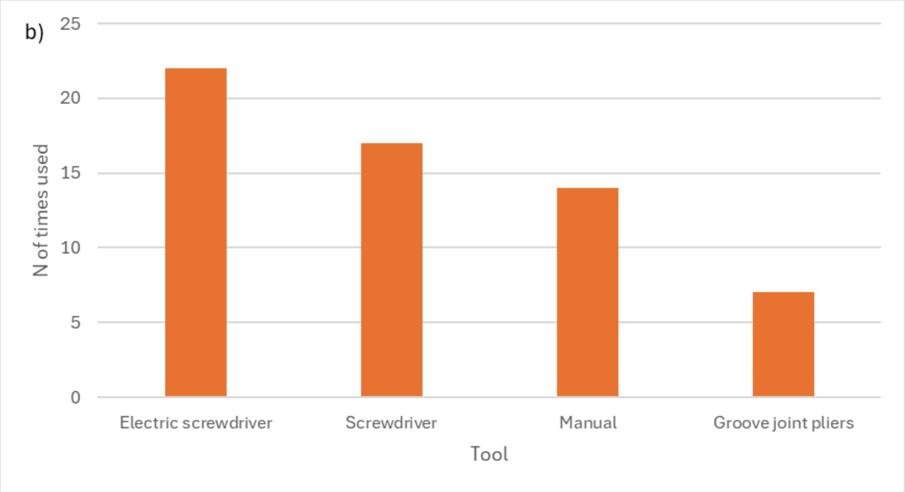
PV INVERTER RESULTS

Inverter model 3 (66.6 kW):

77 and 52 steps



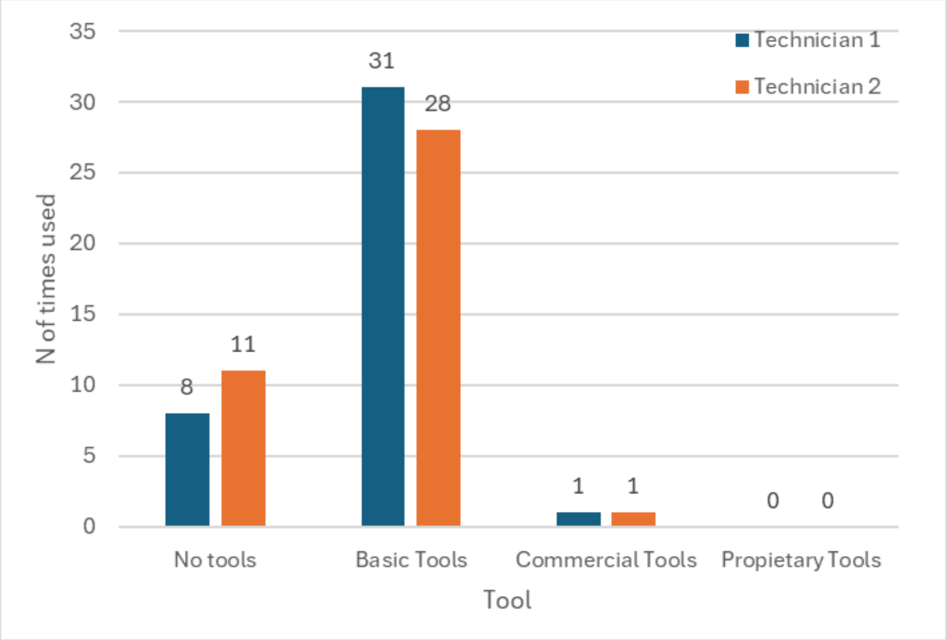


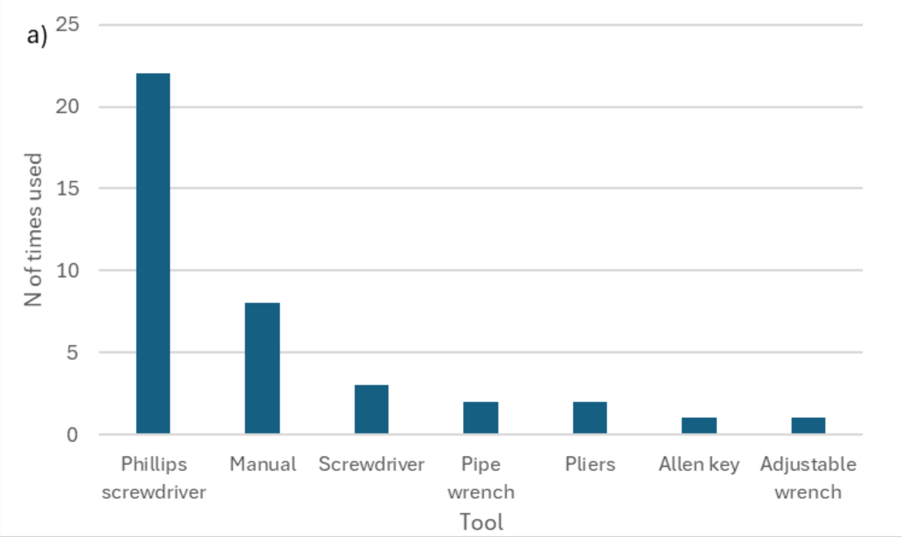


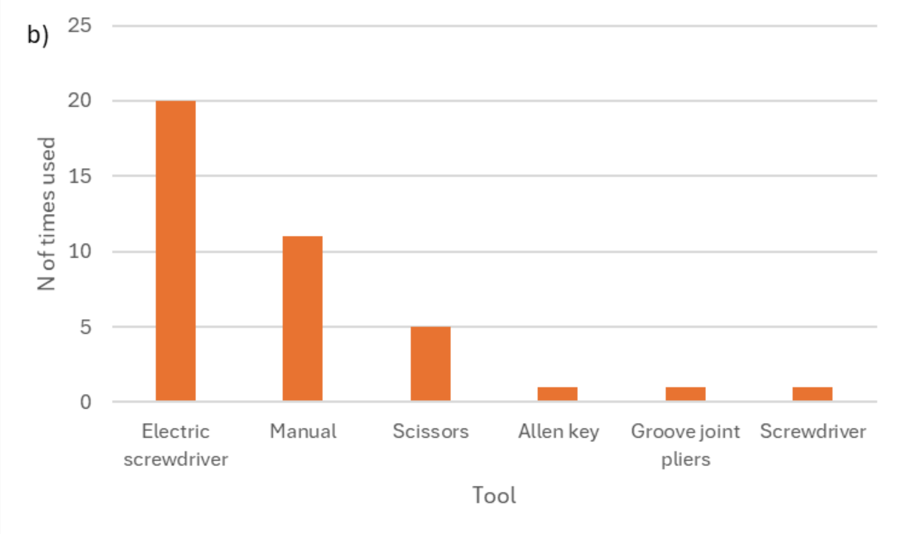
PV INVERTER RESULTS

Inverter model 4 (20 kW):

39 and 39 steps



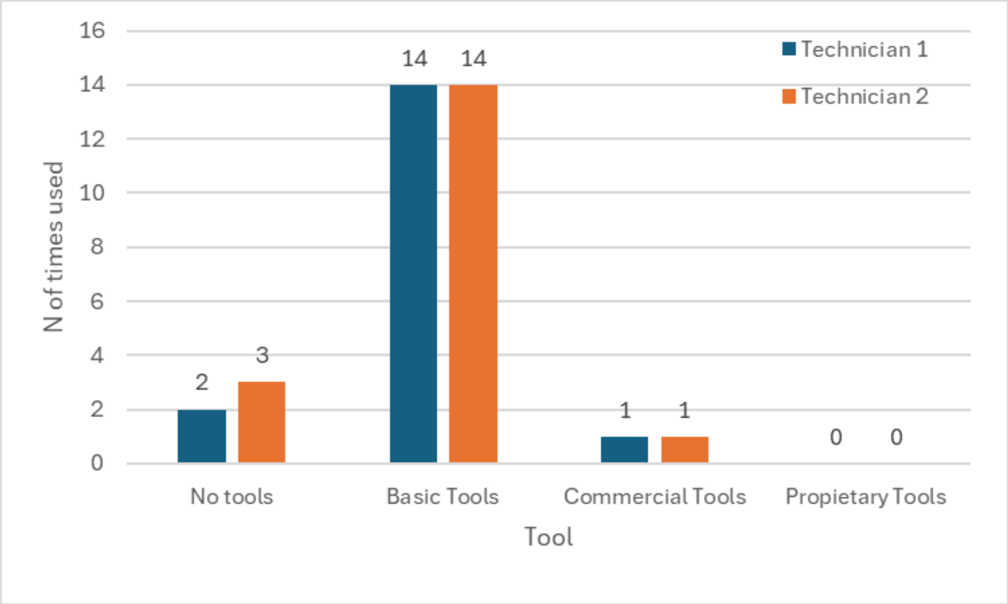


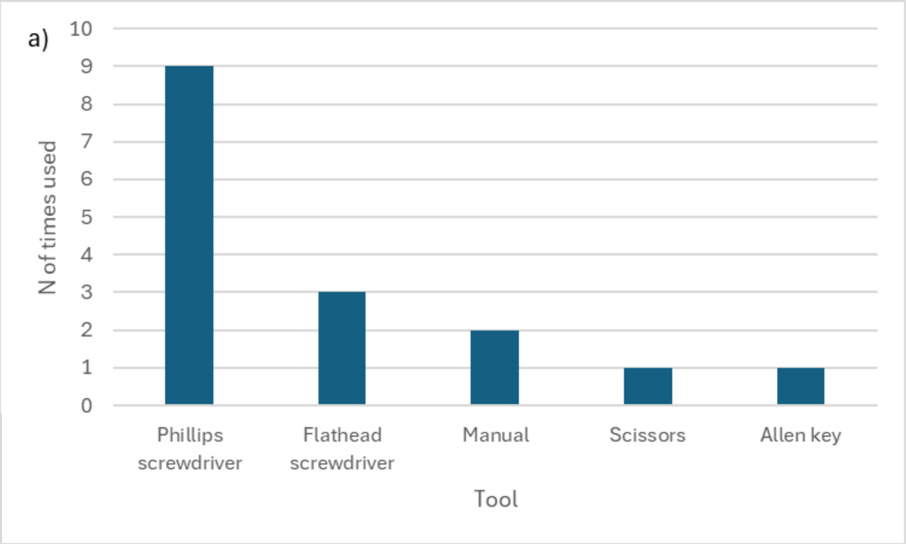


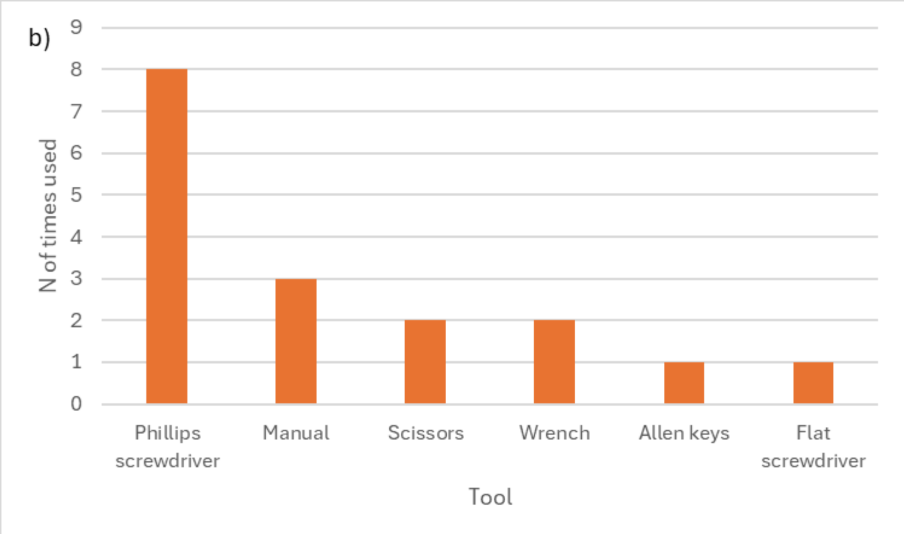
PV INVERTER RESULTS

Inverter model 5 (3 kW):

18 and 17 steps



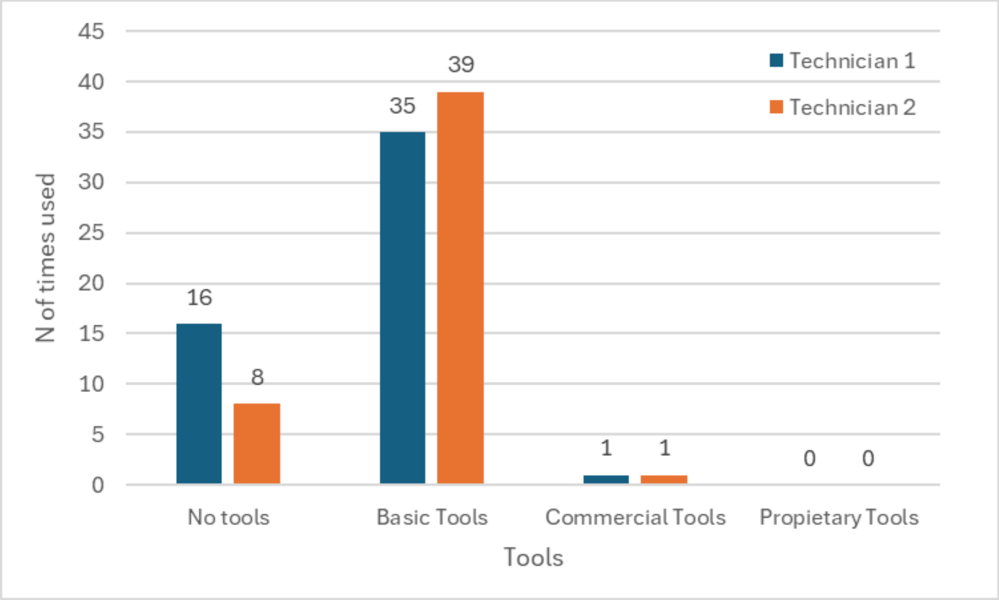


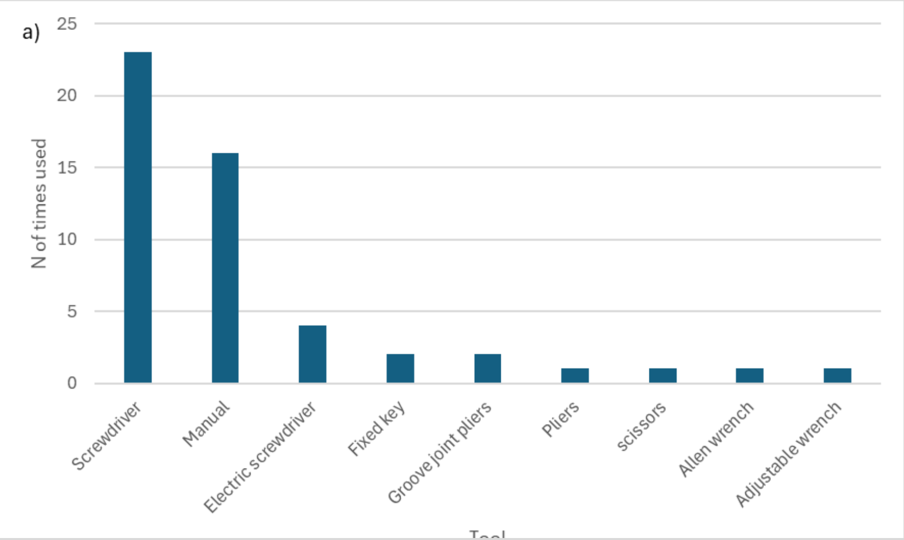


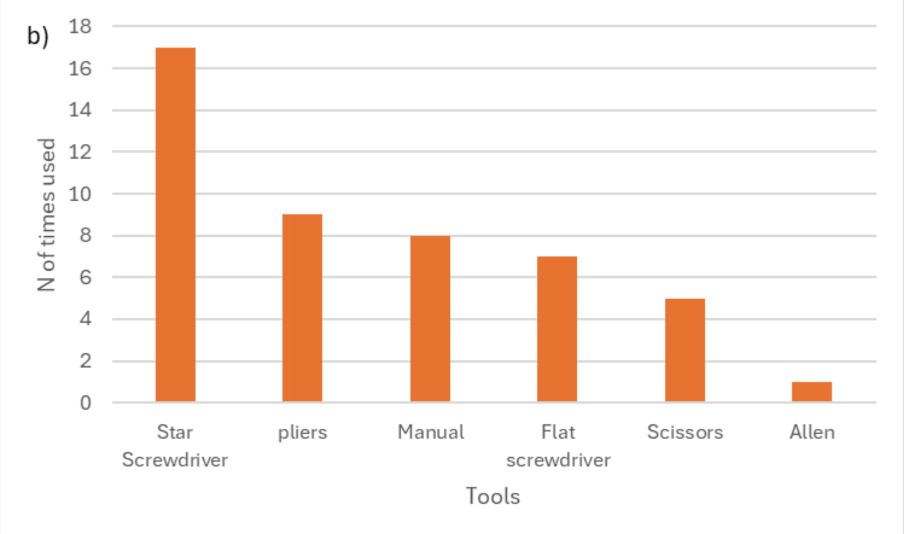
PV INVERTER RESULTS

Inverter model 6 (6 kW):

52 and 47 steps



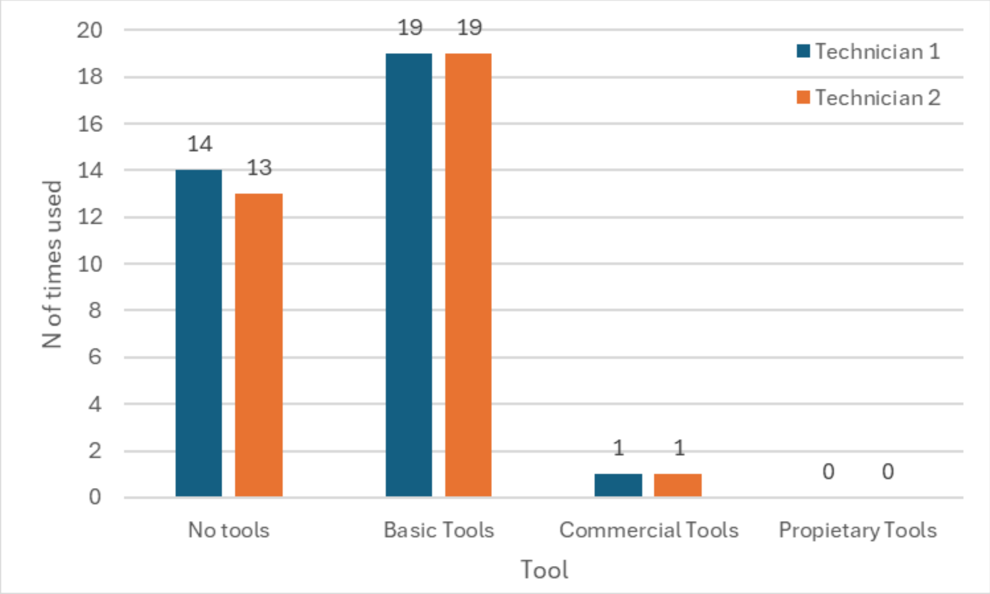


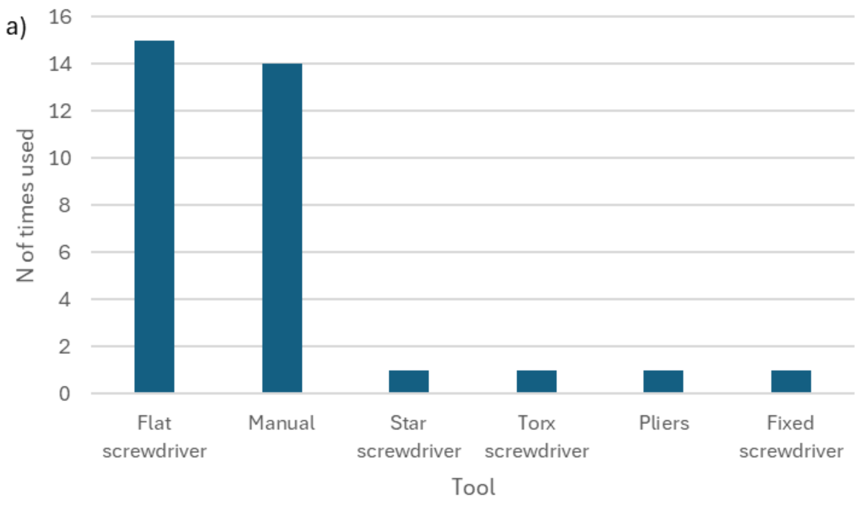


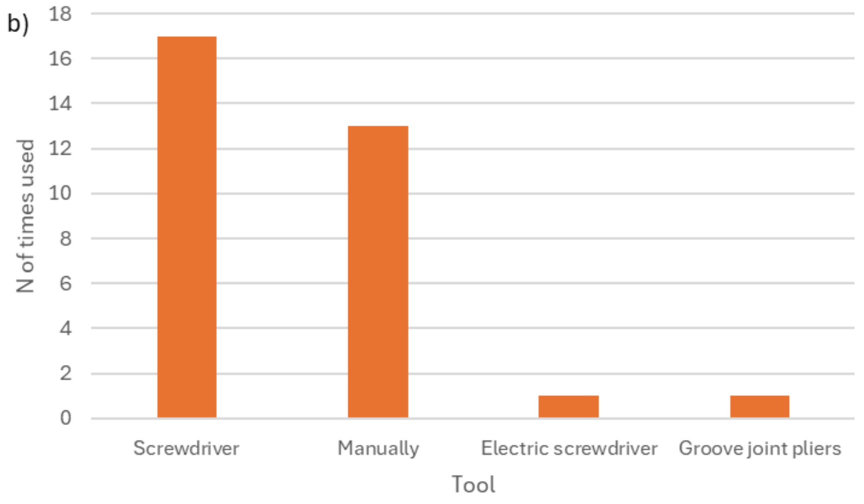
PV INVERTER RESULTS

Inverter model 7 (3.7 kW):

34 and 33 steps



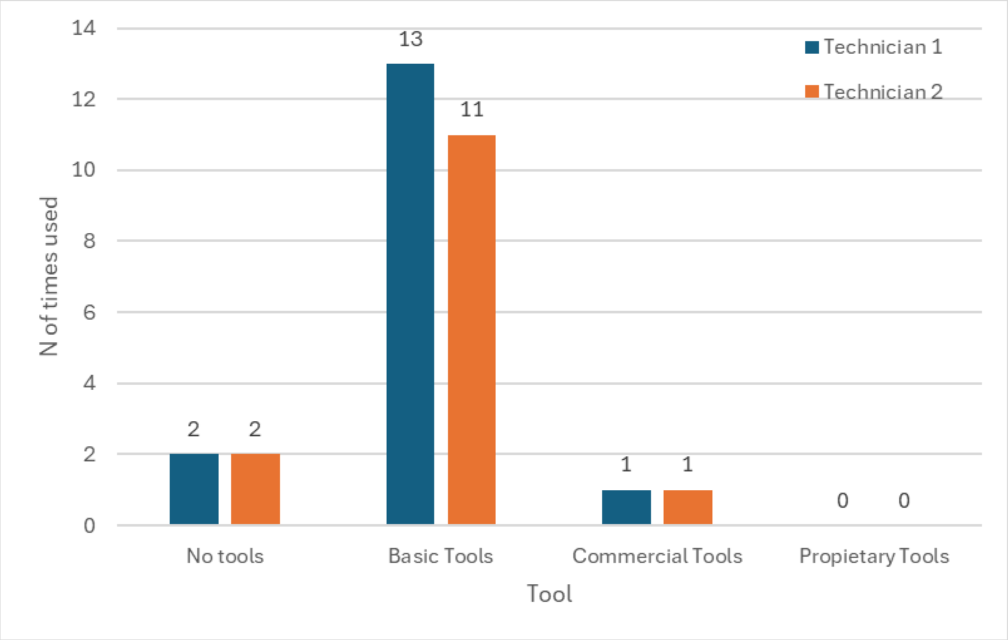


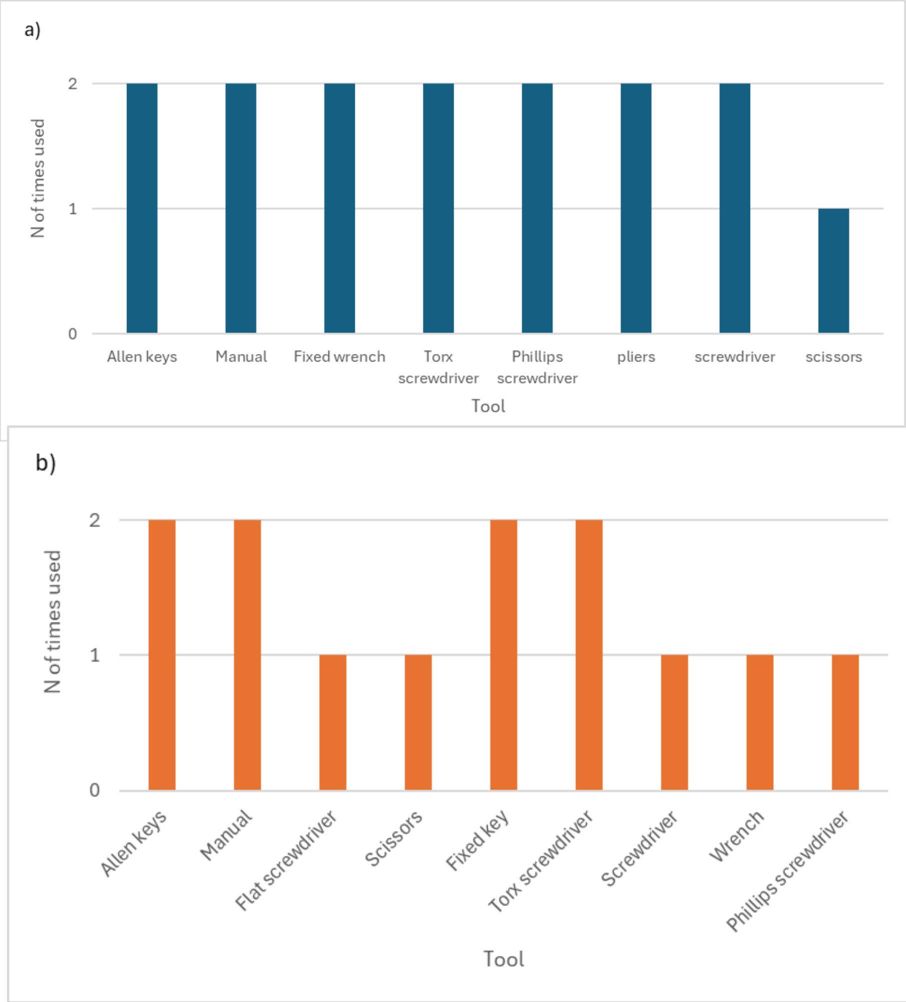


PV INVERTER RESULTS

Inverter model 8 (3 kW):

16 and 14 steps





PV INVERTER RESULTS

- Almost all the priority parts could be removed using basic tools and bare hands. However, to remove specific parts from the PCB, such as capacitors, solenoids and transformers, (de)soldering tools are required, which will be categorised as commercial tools.

- In some inverters (models 4 and 8), the coils were immersed in a silicone solution, which made it impossible to separate them from the chassis of the inverter.

- The number of steps varies significantly depending on the complexity of the inverter, which is not directly related to the power of the inverter itself.

Agenda

Viegand Maagøe

1	Welcome – 8:30
2	Policy Background – European Commission 08:45 – 9:00
3	Recyclability Index Methodology 09:00 – 09:30
4	Testing – Selection of the sample 9:30 – 10:00
5	Testing protocols 10:00 – 11:00
6	Testing Results 11:00 – 12:00
7	Next steps of the study 12:00 – 12:15
8	General Questions and Answers 12:15 – 12:30
9	AOB, closure 12:30

Next steps

- Written comments and inputs after the meeting are welcomed, **deadline 6th June 2025**, send comments to **info@pv-recyclability-index.eu**
- Slides and minutes of the meeting will be uploaded to: https://www.pv-recyclability-index.eu/documents/
- **End of June 2025:** Written consultation on the final validated and calibrated scoring system
- **August 2025:** Publication of final report of the study

Agenda

Viegand Maagøe

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Viegand Maagøe

Thank you for attending this meeting!

info@pv-recyclability-index.eu

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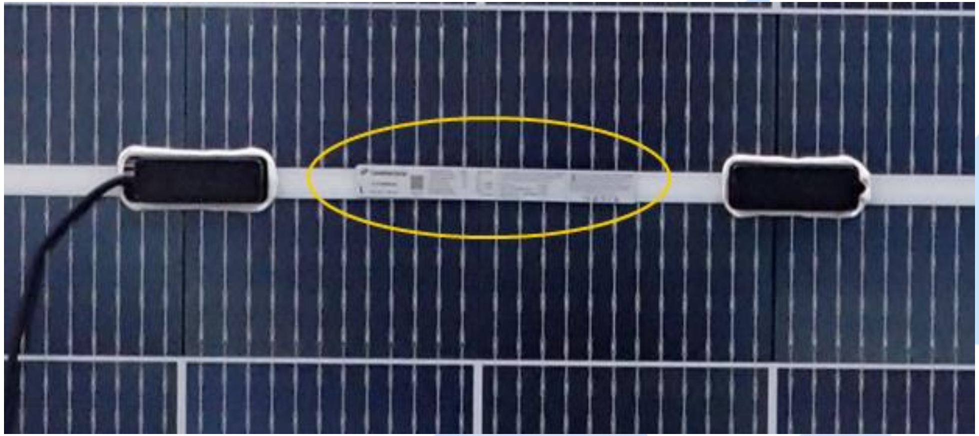
Back up slides

1. Technology Identification

Viegand Maagøe

- Distinction of PV technologies is not always possible by optical inspection, especially in the case of thin film PV modules (as indicated in the EN 50625-2-4:2017 – Annex AA)

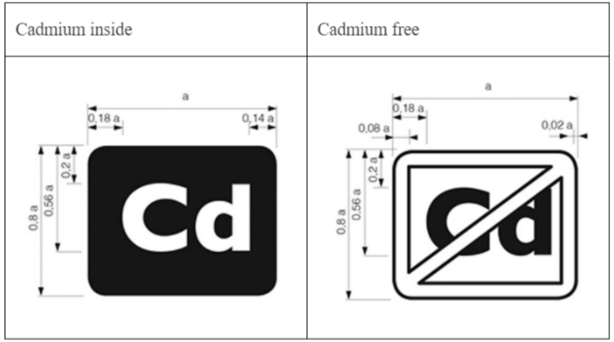
- Identifying composition and construction may permit sorting and higher tolerance at the recycling plants



2. Information on the presence of SoC

- Information can be added to the product data plate, embossed or engraved on the product itself or accessible from the product by electronic means in the form of bar codes, radio-frequency identification (RFID) or product passport based on blockchain technologies (in the future)

- Example in current Ecodesing on Electronic Displays (Regulation on ecodesign for electronic displays (EU) 2019/2021)



3. Dismantling information / access

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The dismantling instructions freely available on third party database / website. This would ensure that this information will be available for future use. The instruction should also include:

- the unequivocal **product identification;**
- the **dismantling map** or exploded view;
- the detailed **step-by-step instructions on the dismantling** of priority parts, including information on the unfastening operations, type of tools needed;
- diagnostic fault and error information (including manufacturer-specific codes, where applicable) component and diagnosis information (such as minimum and maximum theoretical values for measurements);
- **type of recycling technology needed** to carry our specific recycling steps.

4. Information on composition

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4.1 Disclosure of composition

- Different levels of ambitions could be awarded based on the percentage of product mass disclosed (e.g. 70% - 90% - 95% - 99%).
- A similar scoring criterion is provided by the NSF/ANSI 457 standard where the manufacturer shall demonstrate to have in place a system for recording information, calculating percentages of data acquired.

4.2 Disclosure of presence and location of Critical, Strategic and Environmental Relevant materials

PV Modules	PV Inverters
Cadmium, Silicon metal, Silver, Aluminium, Copper, Indium, Gallium, Germanium, Tellurium, Lead, Antimony Tin	Aluminium, Gold, Lead, Copper, Silicon carbide, Silver, Indium, Gallium, Tantalum, Nickel, Palladium Tin, Cobalt, Zinc

5. Dismantling Depth

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This scoring criterion award points based on the **number of dismantling steps (N)** to reach and remove specific priority parts. For the calculation of dismantling steps, the following rules are proposed:

- the dismantling depth count is completed when the **target part is separated** and individually accessible.
- where multiple tools need to be used simultaneously, **the use of each tool counts as a separate step**.
- operations like applying **thermal or chemical treatments to the product** in order to facilitate the dismantling **are also counted as steps**.
- The Dismantling Depth score (DDi) for each priority part shall be calculated based on the number of steps required to remove that part from the product. **The counting of the steps for each part starts from the fully assembled product.**

6. Types of tools to dismantle priority parts

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This scoring criterion award points based on the **complexity of tools needed** to reach and remove specific priority parts.

In this context

- **'basic tools'** means list of tools specifically defined for the product groups under assessment, considering the preliminary list in Table A.3 of the standard EN45554:2020;

- **'commercially available tool'** means a tool that is available for purchase by the general public and is neither a basic tool nor a proprietary tool;

- **'proprietary tool'** means a tool that is not available for purchase by the general public or for which any applicable patents are not available to license under fair, reasonable and non-discriminatory terms.

7. Removability of fasteners, reversibility of sealants and encapsulants

7.1 Type of fasteners to dismantle priority part (X) (inverters)

Taking apart components for recycling can have different levels of complexity and circularity based on the type of fastening (or joining) technique applied:

- **“reusable fasteners”** An original fastening system that can be completely re-used, or any elements of the fastening system that cannot be reused are supplied with the new part for a repair, re-use or upgrade process.

- **“removable fastener”** means a fastener that is not a reusable fastener, but whose removal does not damage the product, or leave residue, which precludes reassembly (e.g. a screw is typically designed in a way that allows fastening and unfastening);

- **“non-removable fasteners”** means a permanent fastening (joining) techniques that makes the separation of the target part from the rest of the product not feasible or only feasible by damaging the part itself or the entire product.

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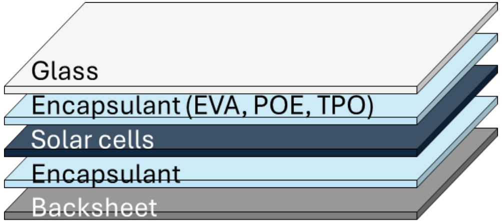
7. Removability of fasteners, reversibility of sealants and encapsulants

#7.2 Removability of the encapsulant after heating process (mono-facial PV modules)

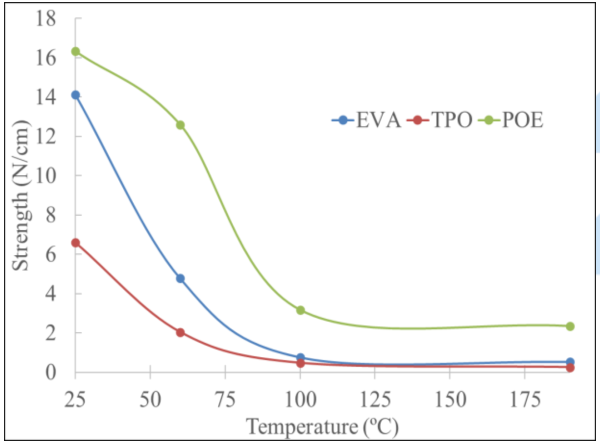
Measure the reversibility of the encapsulant bond at conditions simulating a thermal-based recycling process (hot-knife) by a peel-off test applied to the interface encapsulant-glass.

Peel-off test at different temperatures (25ºC, 60ºC, 100ºC, 190ºC)

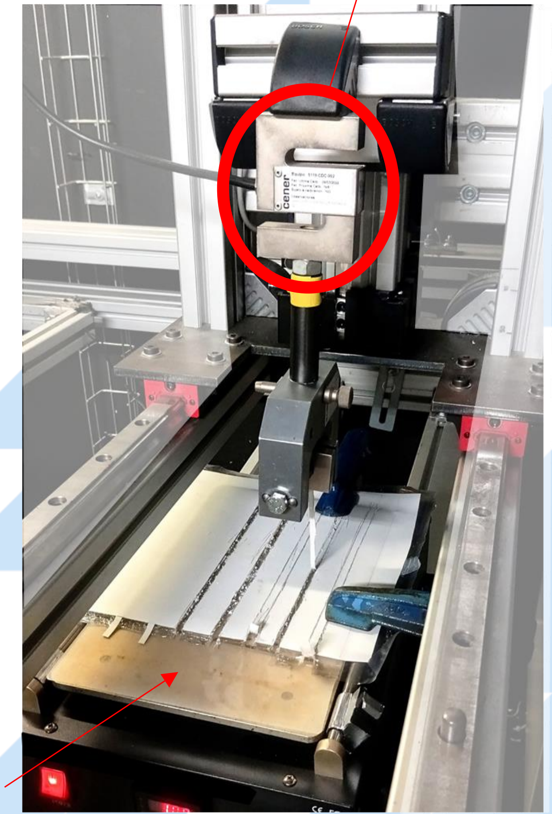


Preliminary test:
The **adhesion difference decreases as test T increases**, especially above 60°C.

Parameter: force decrease from T_{amb} to $T_{dissamble}$



Load cell



Heater

7. Removability of fasteners, reversibility of sealants and encapsulants

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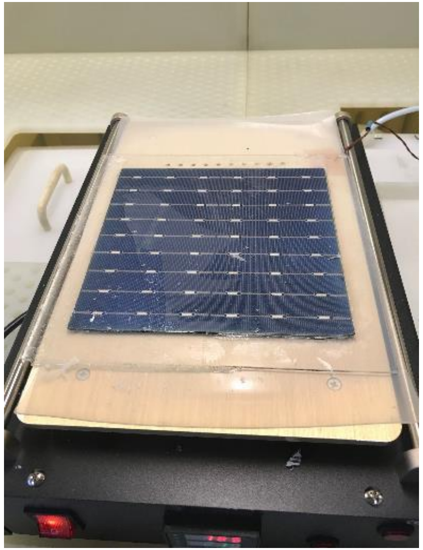
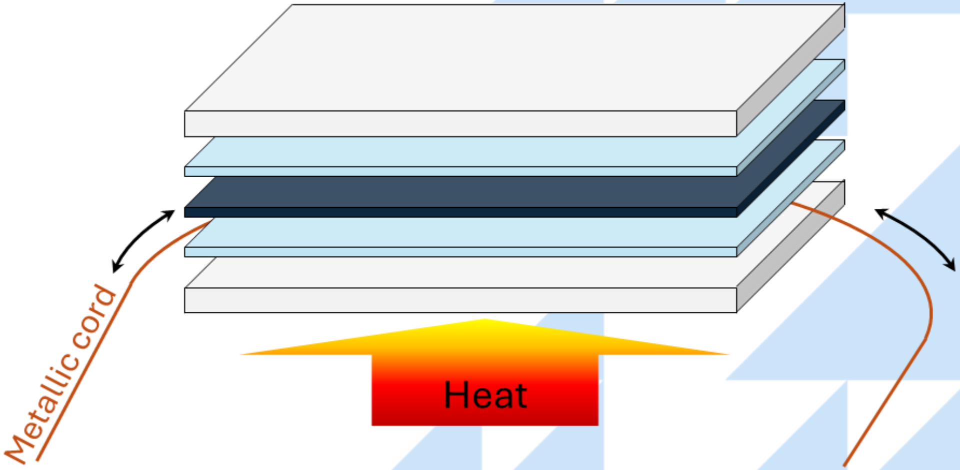
#7.3 Removability of the encapsulant after heating process (bi-facial PV modules)

We propose a hot-wire technique (Peel-off test cannot be applied in glass-glass modules)

Heat up the panel and measure at which temperature and force the module can be dismantled by means of a metallic cord in standardised conditions / force measured by a load cell





7. Removability of fasteners, reversibility of sealants and encapsulants

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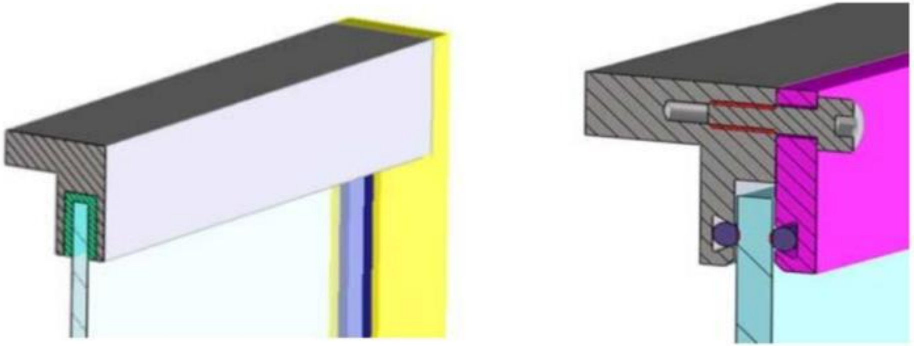
#7.4 Removability of the frame (only applicable to PV modules with frame)

According to Bilbao et a. (2021) O-ring and U-profile techniques are alternative, easy-to-remove edge-sealing solutions that are suitable for PV modules. This sub-criterion aims to **penalise the use of adhesives for fixing the frame on the surface of the module and award the presence of alternative edge sealing techniques, as the use of O-ring or U-profile**



U-profile rubber

O-ring

8. Concentration of hazardous substances and other substances affecting the recycling process

This parameter aims to assess the concentration of **substances of concern, including specific substances affecting the recycling process**, in specific homogenous parts of the product.

Reducing the presence of these substances is likely to enhance the possibilities and economic profitability of recycling of PV products and decrease the negative impacts on the health of workers in recycling plants.

The identifed substances for this parameter include:

- **Fluorine in backsheets**
- **Antimony in glass**
- **Brominated flame retardants in plastic components**

9. Selection of materials based on recyclability complexity

- **green list:** substances that are the easiest to be recycled (metals and metal alloys such as copper, aluminium, steel, silver).
- **orange list:** substances that are easy to be recycled but for which the fulfilment of specific design conditions should be verified (e.g. plastics as ABS, PE and PP not filled with BFR; glass without intentionally added antimony).
- **red list:** substances that are more complex to recycle: thermoset and composites, rubbers, silicones, elastomers, foams, BFR-filled plastics, magnets).

10. Combination of materials used

This scoring criterion award points based on the way different materials are combined in single parts and aims to award design based on homogeneous or separable materials versus the use of **“disruptive” linkages** (non-separable material combinations). The assessment has to be carried out at priority part level.

Identified disruptive linkages include:

- **Moulding different material types together by multiple-K processes** (different plastic materials injected into the same mould, over-moulding, or in-mould decoration).
- **Connections that enclose a material permanently.** Avoid methods such as moulding-in inserts into plastics, rivets, staples, press-fits, bolts, bolt and nuts, brazing, welding, and clinching.
- Use of **coatings on plastics.**
- **Plating, galvanizing, and vacuum-metallization** as a coating on plastics.
- **Fixing ferrous metals to non-ferrous metals** in either parts or fasteners.
- **Multi-material injection moulding** is the process of moulding two or more different materials into one plastic part, at the same time.

Agenda

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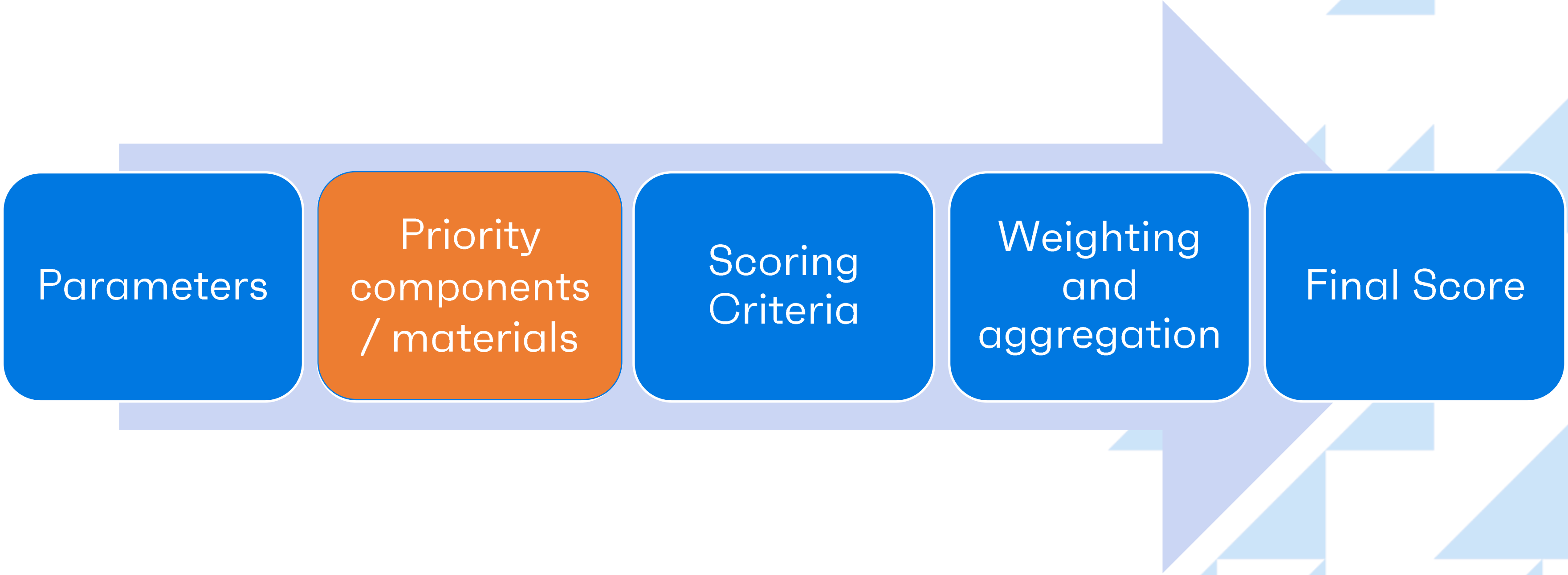
1	Welcome – 10:30
2	Policy Background – European Commission 10:40 – 11:00
3	Scientific Background of the study 11:00 – 11:30
4	Scoring System Method – Parameters 11:30 – 12:30
5	Scoring System Method – Priority Materials / Components 14:00 – 14:30
6	Scoring System Method – Scoring, Weight and Aggregation 14:30 – 15:00
7	Next steps of the study 15:00 – 15:30
8	General Questions and Answers 15:30 – 15:55
9	AOB, closure 16:00

Development of the scoring method

Key steps for developing the recyclability scoring system:



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Key criteria for prioritization

1. **Mass Content Relevance**
    - Higher relevance assigned to abundant materials in PV modules and PV inverters.
2. **Environmental Relevance**
    - Using Life Cycle Assessment (LCA) and the Environmental Footprint 3.0 method.
    - Ecoinvent database for background data.
    - Materials' impacts normalized with established factors.
3. **Criticality and Strategic Relevance**
    - Based on EU CRM list (2023).
    - Scale of 1 to 4 (1 = not critical, 4 = critical raw material).
4. **Economic / Demand Relevance**
    - Prioritizes high-value materials with strong market demand.
    - Data from Trading Economics and Price Metal websites.

Typical Si PV module Break-down

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Material/parts		Concentration (%)
Glass		73,19
		10,17
Polymers	EVA (ethylvinylacetate)	3,55
	Tedlar (polyvinylfluoride)	
Solar cell		3,43
Adhesive		1,14
Copper		0,56
Junction box		1,31

SOLAR CELL

Material	Concentration (%)
Silver	0,69
Aluminium	9,00
Lead	0,04
Tin	0,06
Silicon	90,00
Copper	0,01

Environmental Aspect & Material Prioritization in PV Modules

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MASS CONTENT
Glass is the most relevant material

ENVIRONMENTAL IMPACT CALCULATION

1. **Impact Calculation**:
   - Normalized impacts were calculated using Simapro and the Environmental Footprint method.
   - Ag shows the highest cumulative environmental impacts in PV modules.
2. **Impact Categories**:
   - **Resource Use (minerals and metals)** is the most significant category.
   - Followed by **Freshwater eutrophication** and **Ecotoxicity in freshwater**.

CRITICALITY INSIGHTS

- **Si**: Critical and strategic; EU only produces 0.6% of global crystalline silicon cells.
- **Al**: Critical, but not strategic.
- **Ag**: Not classified, but heavily used in PV module production.
- **Ge**: Marginal impact on energy markets.

ECONOMIC VALUE

- **Ag** is the most valuable material in solar cells, with a price over **€953/kg**, more than 1500 times higher than other materials.

Material	Mass-content	Env. impacts	Criticality / EU strategy	Economic / demand	Weighted Relevance score
Silver	3,28E-04	1,00	0,75	1,00	2,75
Glass (material)*	1,00	9,19E-06	0,50	6,50E-04	1,50
Silicon*	0,04	7,40E-05	1,00	0,02	1,06
Aluminium	0,14	8,55E-05	0,75	2,64E-03	0,90
Copper	0,01	9,19E-03	0,75	0,01	0,78
Tin	2,73E-05	3,41E-02	0,50	0,03	0,57
Lead	1,37E-05	1,67E-03	0,50	2,30E-03	0,50
Ethyl vinyl acetate (EVA)	0,09	3,28E-05	0,25	1,94E-03	0,34
Tedlar (PVF)/Polydivinyl fluoride (PVDF)	0,05	2,17E-04	0,25	0,01	0,31

Environmental Aspect & Material Prioritization in PV Modules

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Priority parts for PV modules
Solar Cell (silver, silicon, tin, lead)
Glass
Frame (aluminium)
Cables (copper)
Junction box (copper)

Typical inverter Break-down

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Material	Concentration (%)
Aluminium (CRM)	19%
Copper (SRM)	28%
Nickel (SRM)	0,4%
Silicon	9%
Tin	0,4%
Gold	0,4%
Silver	1%
Lead	0,2%
Palladium	0,002%
Steel	21%
Cobalt	0,002%
Zinc	0,002%
Specific plastic polymers:	11%
FR-4, Glass-reinforced epoxy laminate material	1%
Ferrite	2%

Environmental Aspect & Material Prioritization in PV Inverters

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MASS CONTENT

Al, **Cu** and **steel** are the most relevant materials

ENVIRONMENTAL IMPACT CALCULATION

1. **Impact Calculation**:
   - Normalized impacts were calculated using Simapro and the Environmental Footprint method.
2. **Impact Categories**:
   - **Resource Use (minerals and metals)** is the most significant category.
   - Followed by **Climate change** and **Resource use (fossils)**.

CRITICALITY INSIGHTS

- **Si, Pd** Critical and strategic; EU only produces 0.6% of global crystalline silicon cells.
- **Al**: Critical, but not strategic.
- **Cu, Ni,** : Not classified, but heavily used in PV inverters.

ECONOMIC VALUE

- **Au** and **Pd** are the most valuable material in solar cells, with a price ca **€70k** and **€30k/kg** respectively; more than 70000 times higher than other materials.

Metal/Material	Mass-content	Env. impacts	Criticality / EU strategy	Economic / demand	Weighted score
Gold	2,82E-03	2,50E-01	0,13	2,50E-01	0,63
Copper (SRM)	0,25	2,77E-05	0,19	3,51E-05	0,44
Aluminium (CRM)	0,17	2,60E-07	0,25	9,05E-06	0,42
Palladium	0,00	3,22E-03	0,25	1,10E-01	0,36
Silicon	0,08	6,11E-07	0,19	6,04E-06	0,27
Steel	0,19	7,82E-09	0,06	1,22E-05	0,25
Silver	0,01	3,04E-03	0,19	3,43E-03	0,20
Nickel (SRM)	0,00	8,40E-06	0,19	6,21E-05	0,19
Tin	0,00	1,04E-04	0,13	1,17E-04	0,13
Ferrite	0,02	2,85E-08	0,06	8,61E-08	0,08
Glass-reinforced epoxy (FR4)	0,01	3,47E-03	0,06	1,1E-05	0,07
Lead	0,00	5,09E-06	0,06	7,88E-06	0,06
Cobalt	0,00	6,11E-05	0,06	9,76E-05	0,06
Zinc	0,00	5,84E-06	0,06	1,03E-05	0,06

Environmental Aspect & Material Prioritization in PV Inverters

Viegand Maagøe

Priority parts for PV inverters
Printed Circuit Board (PCB) (gold, silver, copper, tin, lead)
Heat sink (copper, aluminium)
Casing (aluminium)
Cables (copper)
DC link Capacitors (palladium, tantalum)

Agenda

Viegand Maagøe

1	Welcome – 10:30
2	Policy Background – European Commission 10:40 – 11:00
3	Scientific Background of the study 11:00 – 11:30
4	Scoring System Method – Parameters 11:30 – 12:30
5	Scoring System Method – Priority Materials / Components 14:00 – 14:30
6	Scoring System Method – Scoring, Weight and Aggregation 14:30 – 15:00
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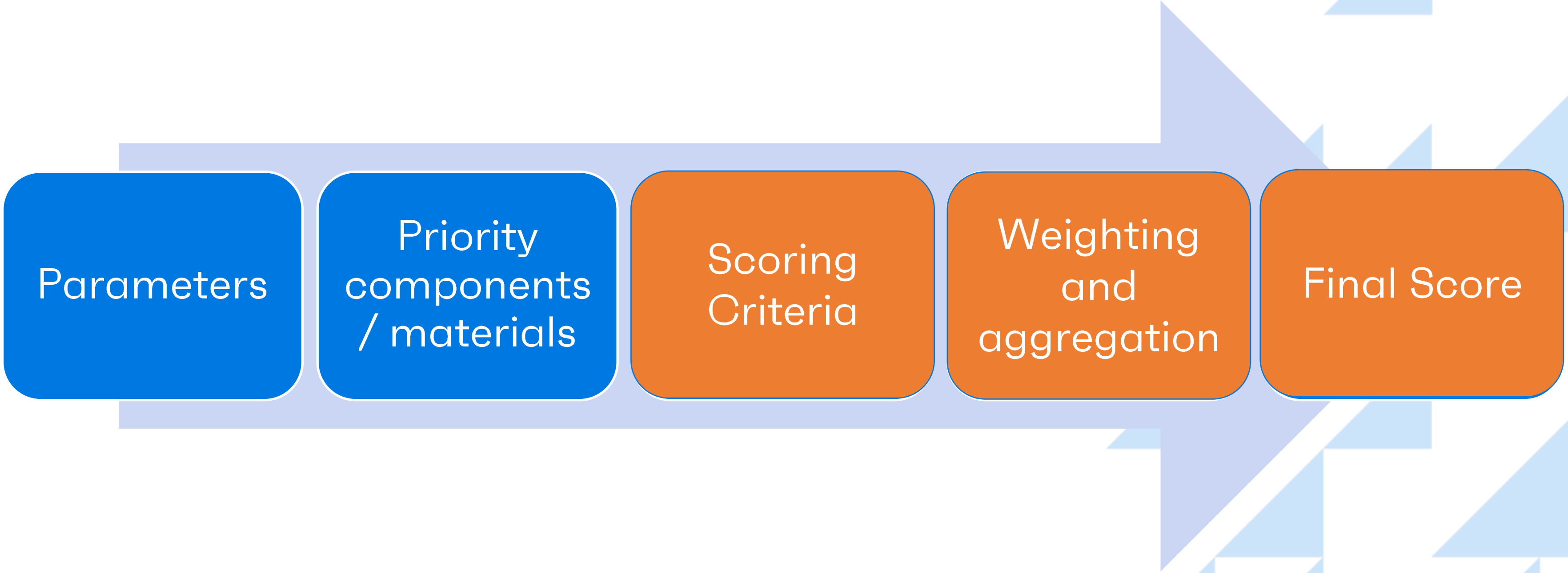
8	General Questions and Answers 15:30 – 15:55
9	AOB, closure 16:00

Development of the scoring method

Key steps for developing the recyclability scoring system:



Scoring Criteria

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	Numerical score (1 to 5) Less recyclable ⟷ More recyclable				
5 scoring options	1	2	3	4	5
4 scoring options	1	2	--	4	5
3 scoring options	1	--	3	--	5
2 scoring options	1	--	--	--	5

Viegand Maagøe

Scoring Criteria: service-related parameters

N◦	Parameters	Product specific parameters	Applicability	Scoring Criteria	Points
1	Technology identification		PV modules	No technology identification available/accessible on the product itself.	1
				Technology identification available/accessible on the product itself.	5
2	Information on the presence (or absence) of substance of concern		PV modules and PV inverters	No information specifying the presence/absence of substances of concern on the product itself.	1
				Information specifying the presence/absence of substances of concern on the product itself.	5
3	Availability of dismantling instructions		PV modules and PV inverters	Dismantling instructions not freely available on a third-party database / website.	1
				Dismantling instructions freely available on a third-party database / website.	5

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Scoring Criteria: service-related parameters

N◦	Parameters	Product specific parameters	Applicability	Scoring Criteria	Points
4	Information on composition	4.1 Disclosure of material composition	PV modules and PV inverters	Disclosure of material composition (≤70% of product mass) freely available on a third-party database / website.	1
				Disclosure of material composition (> 70% of product mass) freely available on a third-party database freely available on a third-party database / website.	2
				Disclosure of material composition (> 90% of product mass) freely available on a third-party database / website.	3
				Disclosure of material composition (> 95% of product mass) freely available on a third-party database / website.	4
				Disclosure of material composition (> 99% of product mass) freely available on a third-party database / website.	5

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Scoring Criteria: service-related parameters

N◦	Parameters	Product specific parameters	Applicability	Scoring Criteria	Points
4	Information on composition	4.2 Disclosure of presence and location of Critical, Strategic and Environmenta l Relevant materials	PV modules and PV inverters	Presence and location of CRM, Strategic and Environmental Relevant materials not disclosed	1
				Presence and location of CRM, Strategic and Environmental Relevant materials only partially disclosed	3
				Presence and location of CRM, Strategic and Environmental Relevant materials fully disclosed and available on a third-party database / website.	5

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Scoring Criteria: dismantling-related parameters

N◦	Parameters	Product specific parameters	Applicability	Scoring Criteria	Points
5	Number of steps for the dismantling of priority part (X)		PV modules and PV inverters	DDi > A steps	1
				A steps ≥ DDi > B steps	2
				B steps ≥ DDi > C steps	3
				C steps ≥ DDi > D steps	4
				DD ≤ D steps	5
6	Type of tools to dismantle priority part (X)		PV modules and PV PV inverters	Proprietary tools	1
				Commercially available tools	2
				Basic tools	4
				No tools	5

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Scoring Criteria: dismantling-related parameters

N◦	Parameters	Product specific parameters	Applicability	Scoring Criteria	Points
7	Removability of fasteners, reversible sealants and encapsulant layers	7.1 Type of fasteners to dismantle priority part (X)	PV Inverters	Not-removable fasteners	1
				Reusable or Removable fasteners	5
		7.2 Removability of the encapsulant after heating process: peel-off test	Mono-facial PV modules	"Non-reversible encapsulant": the product / components are damaged during the testing peel-off process (the peel-off test is not passed)	1
				Difficult to remove encapsulant: based on the measurement of the drop of the adhesion force between 100 at 140 °C	3
				Easy to remove encapsulant[22]: based on the measurement of the drop of the adhesion force between 100 at 140 °C	5
		7.3 Removability of the encapsulant from the glass after heating process: metal cord test	Bifacial PV modules	"Non-removable encapsulant": the product / components are damaged during the dismantling process	1
				Difficult to remove encapsulant: the dismantling with the cord is feasible but only at a temperature equal or higher than 140 °C	3
				Easy to remove encapsulant: the dismantling with the cord is feasible but only at a temperature higher than 150 °C	5
		7.4 Removability of the frame	PV modules with frame	Presence of adhesive on the glass / frame interface	1
				Use of edge sealing techniques (e.g. O-ring or U-profile design)	5

Scoring Criteria: material-based parameters

N∘	Parameters	Product specific parameters	Applicability	Scoring Criteria	Points
8	Concentration of substances of concern, including substances affecting the recycling process in Priority Part (X)	Applicable to the following parts / substances in PV panels 1) Antimony in Glass; 2) Fluorine in backsheet 3) Brominated flame retardants in plastic components	PV modules PV inverters	Substance concentration by weight (%) in homogeneous material > A%	1
				Substance concentration by weight (%) in homogeneous material ≤ A% and > B%	2
				Substance concentration by weight (%) in homogeneous material ≤ B% and > C%	3
				Substance concentration by weight (%) in homogeneous material ≤ C% and > D%	4
				Substance concentration by weight (%) in homogeneous material ≤ D%	5

Scoring Criteria: material-based parameters

N◦	Parameters	Product specific parameters	Applicability	Scoring Criteria	Points
9	Selection of materials based on their recyclability complexity in Priority Part (X)		PV modules and PV inverters	Use of materials with low recyclability (red list)	1
				Use of materials with conditional recyclability (orange list)	3
				Use of materials with high recyclability (green list)	5
10	Combination of materials used / homogeneity in Priority Part (X)		PV modules and PV inverters	Use of combined materials that are not separable.	1
				Use of combined materials that are separable (allow easy liberation)	3
				Use of homogenous material in a specific part	5

Scoring Aggregation: PV panels

Viegand Maagøe

Parameter	Score for priority part/material i [1-5]	Weight for priority part/material i [%]	Parameter Score [1-5]	Parameter Weight [%]	Final Score [1-5]
#1 Technology Identification			S_1	W_1	Recyclability Index $R = \sum_{j=1}^{10} \boldsymbol{S_j \cdot W_j}$
#2 Information on the presence (or absence) of substance of concern			S_2	W_2	
#3 Availability of dismantling instructions			S_3	W_3	
#4.1 Disclosure of material composition			$S_{4.1}$	$W_{4.1}$	
#4.2 Disclosure of presence and location of Critical, Strategic and Environmental Relevant materials			$S_{4.2}$	$W_{4.2}$	
#5 Dismantling depth	$S_{5,i}$	$\omega_{5,i}$	$S_5 = \sum_{i=1}^{N} S_{5,i} \cdot \omega_i$	W_5	
#6 Tools (type)	$S_{6,i}$	$\omega_{6,i}$	$S_6 = \sum_{i=1}^{N} S_{6,i} \cdot \omega_i$	W_6	
Optional # 7.2 or #7.3 Removability of the encapsulant after heating process			$S_{7.2}$ or $S_{7.3}$	$W_{7.2}$ or $W_{7.3}$	
Optional #7.4 Removability of the frame (only applicable to PV modules with frame)			$S_{7.4}$	$W_{7.4}$	
#8 Substances of concern	$S_{8,i}$	$\omega_{8,i}$	$S_8 = \sum_{i=1}^{N} S_{,i} \cdot \omega_i$	W_8	
#9 Selection of materials based on their recyclability complexity	$S_{9,i}$	$\omega_{9,i}$	$S_9 = \sum_{i=1}^{N} S_{,i} \cdot \omega_i$	W_9	
#10 Combination of materials used / homogeneity	$S_{10,i}$	$\omega_{10,i}$	$S_{10} = \sum_{i=1}^{N} S_{,i} \cdot \omega_i$	W_{10}	

Viegand Maagøe

Scoring Aggregation: PV inverters

Parameter	Score for priority part/material i [1-5]	Weight for priority part/material i [%]	Parameter Score [1-5]	Parameter Weight [%]	Final Score [1-5]
#2 Information on the presence (or absence) of substance of concern			S_2	W_2	$R = \sum_{j=1}^{10} S_j \cdot W_j$
#3 Availability of dismantling instructions			S_3	W_3	
#4.1 Disclosure of material composition			$S_{4.1}$	$W_{4.1}$	
#4.2 Disclosure of presence and location of Critical, Strategic and Environmental Relevant materials			$S_{4.2}$	$W_{4.2}$	
#5 Dismantling depth	$S_{5,i}$	$\omega_{5,i}$	$S_5 = \sum_{i=1}^{N} S_{5,i} \cdot \omega_i$	W_5	
#6 Tools (type)	$S_{6,i}$	$\omega_{6,i}$	$S_6 = \sum_{i=1}^{N} S_{6,i} \cdot \omega_i$	W_6	
#7.1 Fasteners (type)	$S_{7,i}$	$\omega_{7,i}$	$S_{7.1} = \sum_{i=1}^{N} S_{7,i} \cdot \omega_i$	$W_{7.1}$	
#8 Substances of concern	$S_{8,i}$	$\omega_{8,i}$	$S_8 = \sum_{i=1}^{N} S_{8,i} \cdot \omega_i$	W_8	
#9 Selection of materials based on their recyclability complexity	$S_{9,i}$	$\omega_{9,i}$	$S_9 = \sum_{i=1}^{N} S_{9,i} \cdot \omega_i$	W_9	
#10 Combination of materials used / homogeneity	$S_{10,i}$	$\omega_{10,i}$	$S_{10} = \sum_{i=1}^{N} S_{10,i} \cdot \omega_i$	W_{10}	

Scoring Aggregation: PV inverters

Viegand Maagøe

EUSurvey — 19 Hello Nieves ESPINOSA (logout) | Help | Language

Save a backup on your local computer (disable if you are using a public/shared computer)

Weighting of parameters for the recyclability index of PV modules and inverters

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Introduction

This questionnaire is part of the study commissioned by The European Climate, Infrastructure and Environment Executive Agency (CINEA), for the development of recyclability indexes for photovoltaic products (PV modules and inverters).

In particular, the aim is to assess the importance of the weighting that the parameters that compose the index can have.

For further details about recycling parameters and definitions please check the Interim Report for Consultation at the project website: https://www.pv-recyclability-index.eu/documents/

Note: please be aware that all responses will be treated confidentially, no answer will be linked to any respondent.

General information

Company name

Country of operation

Type of organisation
- Recycler
- Manufacturer
- Research institution
- Other (please specify)
- Answer 5

Please specify here (other type of organisation)

Service-related parameters

Please prioritise the following parameters of the recyclability index, indicating their level of importance to a successful recycling
Use drag&drop or the up/down buttons to change the order or accept the initial order.
- Technology Identification
- Information on the presence (or absence) of substances of concern
- Dismantling information and condition for access
- Information on composition (including critical and strategic raw materials)

Do they have the same level of importance? i.e. 25% each, or do you consider that there is one that has higher relevance?
- Same level, 25%
- Different level, see Table below
- Don't know

Provide here the level of importance in percentage, that the parameter should have (sum up to 100%)

	Weighting (%)
Technology identification	
Information on the presence/absence of substances of concern	
Dismantling information and condition for access	
Information on composition (including critical and strategic raw materials)	

If we look at "Information on composition (including critical and strategic raw materials)", which sub parameter out of the following has a higher level of importance to a successful recycling
Use drag&drop or the up/down buttons to change the order or accept the initial order.
- Disclosure of material composition
- Disclosure of presence and location of Critical, Strategic and Environmental Relevant materials

Dismantling-related parameters

Please prioritise the following parameters of the recyclability index, indicating their level of importance to a successful recycling
Use drag&drop or the up/down buttons to change the order or accept the initial order.
- Number of steps for the dismantling of priority parts (dismantling depth)
- Types of tools to dismantle priority parts
- Removability of fasteners to dismantle priority parts, reversibility of sealants and encapsulants

Material-based parameters

Please prioritise the following parameters of the recyclability index, indicating their level of importance to a successful recycling
Use drag&drop or the up/down buttons to change the order or accept the initial order.
- Level of concentration of hazardous substances and other substances affecting the recycling process
- Selection of materials based on recyclability complexity
- Combination of materials used / homogeneity

Section Title

Single Choice Question
- Answer 1
- Answer 2

Table

	A	B	C
1			
2			
3			

Closing remarks

Provide your comments

Submit

Agenda

Viegand Maagøe

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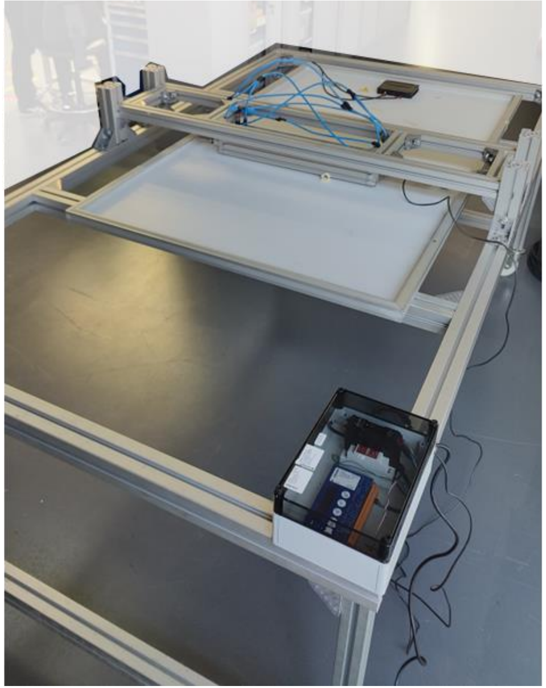
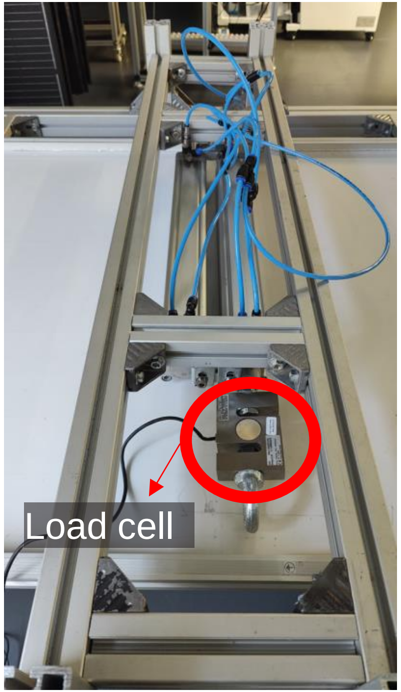
Viegand Maagøe

TESTING

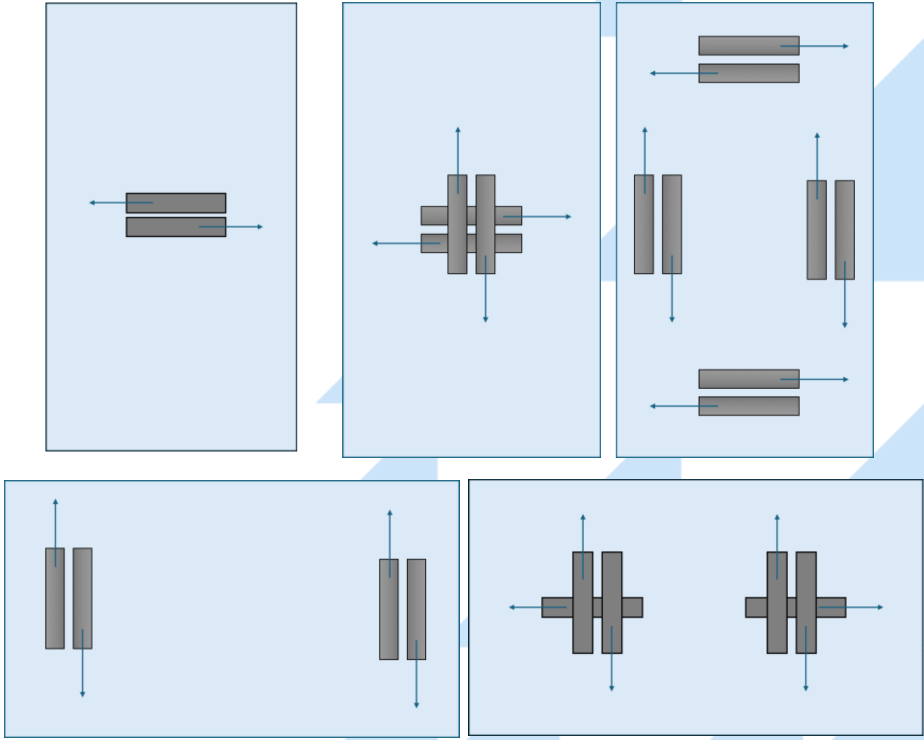
Aluminium frame removal



Preliminary setup



Other possible schemes

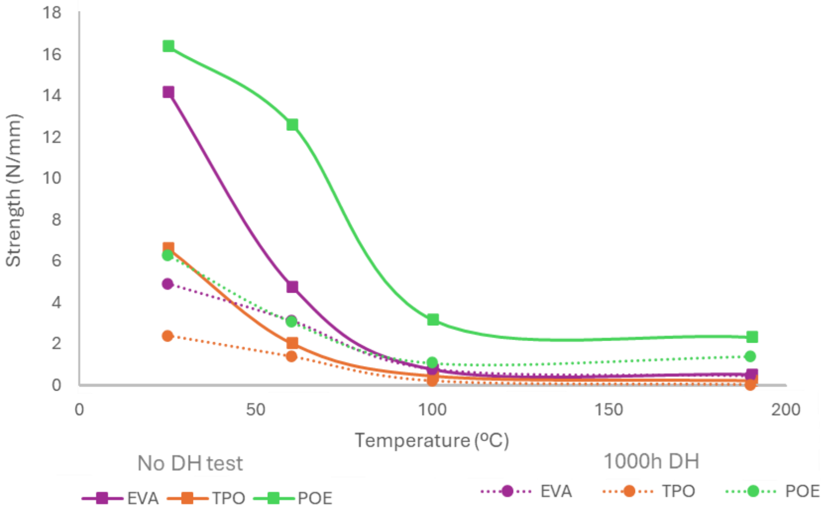


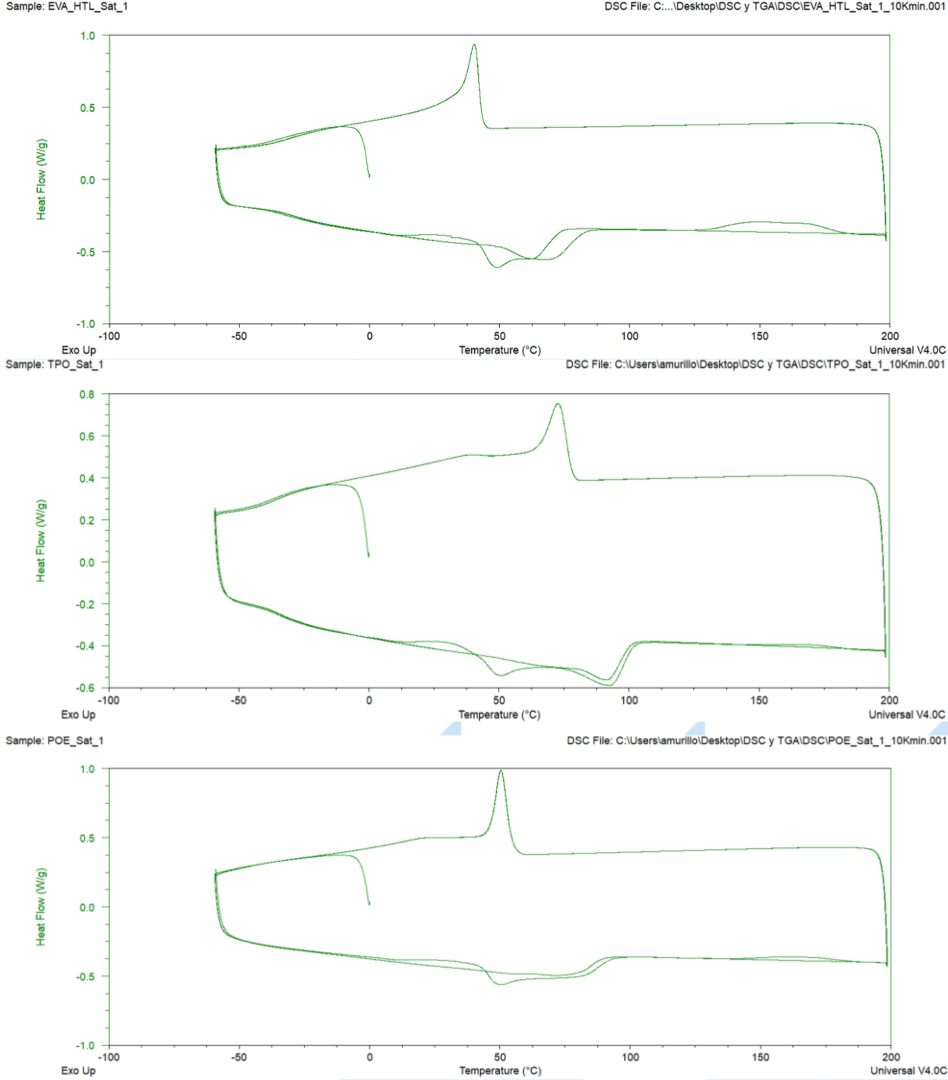
TESTING

Peel-off test (@ different temperatures)

- Backsheet-encapsulant adhesion
- Encapsulant-glass adhesion

Relation with the TGA (thermogravimetric analysis) measurements of the different types of encapsulants





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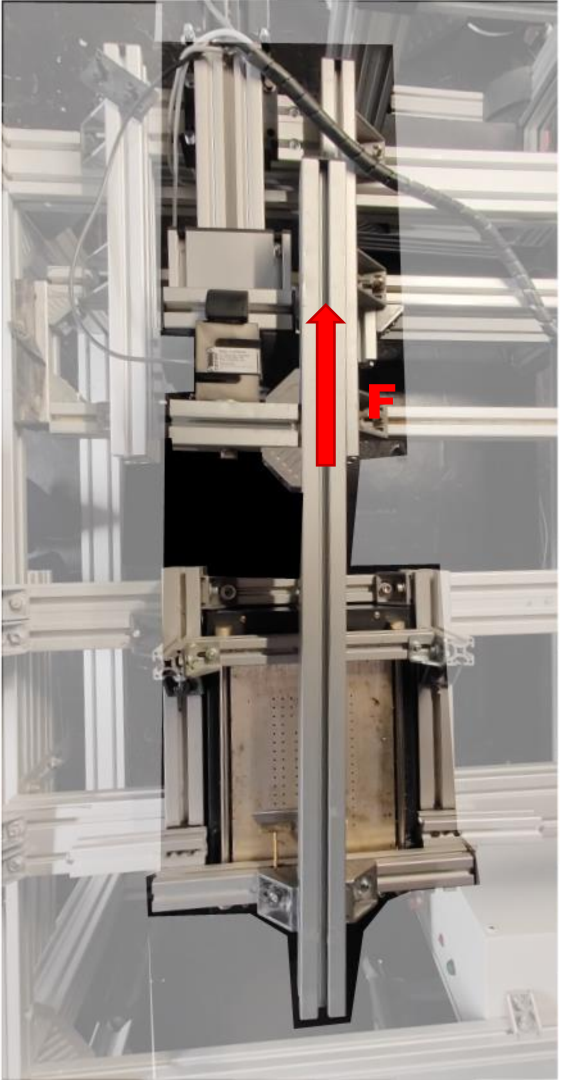
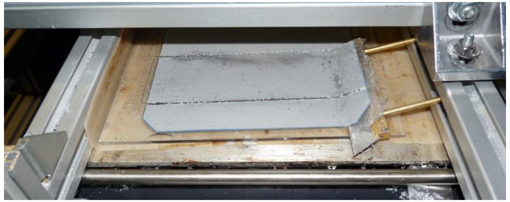


TESTING

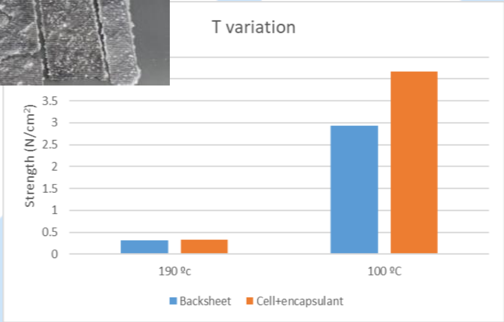
Delamination process
(monofacial PV modules)



We'll take note of the steps and tools needed for dismantle the PV modules

1. Remove the backsheet (easy to streep, good for pyrolysis)
2. Remove encapsulant + cells + encapsulant

We obtain the separation of the main components



TESTING

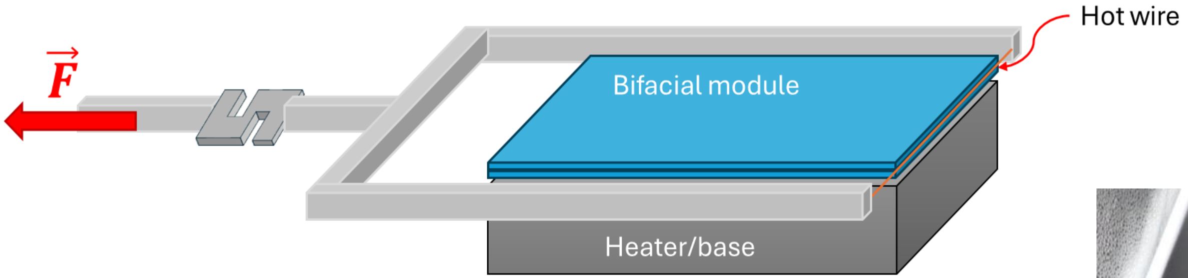
Delamination process (bifacial PV modules) @ 190 ºC

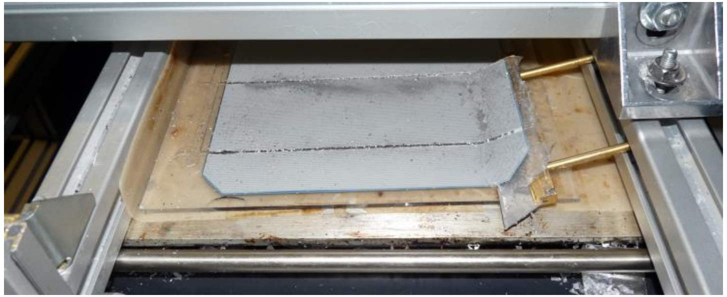
1. Hot-wire to separate both glasses
2. Remove encapsulant + cells + encapsulant (x2)

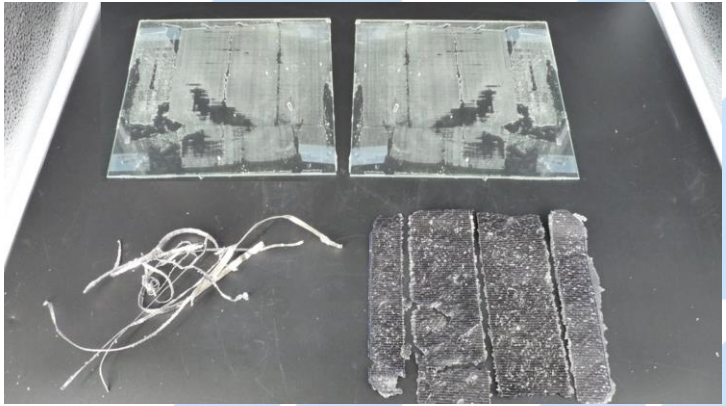
We obtain the separation of the main components

Measurable parameters:

- Force
- Temperature
- Time
- Wire has broken?







TESTING

Inverters: (dismantling test)

We will separate the priority parts

- Printed Circuit Board (PCB)
- Heat sinks (copper, aluminium)
- Casing (aluminium)
- Cables (copper)
- DC link Capacitors (palladium, tantalum).

We will take note of the number of steps, tools needed and the fasterners removed

Viegand Maagøe

SELECTION OF THE SAMPLES

PV modules (8 different types)

PV technology	PERC	TopCo n	HJT	IBC
Modules	2	3	1	2

PV configuration	Monofacial	Bifacial
Modules	4	4

PV recycling	Conventional	Easy-to-disassemble
Modules	8	2?

PV inverters (8 different types)

Inverter power	0-1 kW	1-10 kW	10-30 kW
Inverters	1	5	2

Inverter phase	Single-phase	Three-phase
Inverters	4	4

	Micro-inverter	With battery charger
Inverters	1	3

Excluded:

- Central PV packed with transformers
- DC-to- DC converters
- DC optimisers

Out of the scope of Ecodesign measures on PV products

Next steps – to be discussed

- Written comments and inputs after the meeting are welcomed, **deadline 6 June 2025**, send comments to **info@pv-recyclability-index.eu**
- Slides and minutes will be uploaded to: https://www.pv-recyclability-index.eu/documents/
- **June 2025:** Publication of drat final report of the study
- **July 2025:** Written Consultation

Study web site

Viegand Maagøe

https://www.pv-recyclability-index.eu/

- Please register not only for the meeting but also for receiving news / updates
- You will find slides and brief notes of this meeting at the project website

European Commission

Development of a recyclability index for photovoltaic products

Home | The Study | Register | Meetings | Documents | Contact

The European Climate, Infrastructure and Environment Executive Agency (CINEA) has commissioned a study for the development of recyclability indexes for photovoltaic products (PV modules and inverters).

This comprehensive study is conducted by Viegand Maagøe, in collaboration with Universidad de Murcia and Centro Nacional de Energias Renovables (CENER). This website serves as the primary information exchange platform between the study team, CINEA and the stakeholders. All the consultation documents and deliverables prepared in the context of this study will be made available through this website. Please register here for receiving updates and invitations to stakeholder meetings.

Please note that the information and views expressed in this study are those of the consultants and do not necessarily represent the official opinion of CINEA, see further Disclaimer and Copyright information for this website.

What's new

26/1/2024: Invitation to first stakeholder meeting to be held on 12 February 2024. Register for the meeting here.

01/2024: Launch of the study.