Co-funded by the European Union

CircularPV

Project acronym	CIRCULAR-PV
Project full title	Towards long-lived and recyclable perovskite photovoltaics
Call identifier	CETP-FP-2023-00528
Instrument	Clean Energy Partnership Transition (CETP)
Call Module	CM2023-03B (IOA) Advanced renewable energy (RE) technologies for power production
Start date of project	01/01/2025
Duration	36 months
Coordinator	Dr. Maria Hadjipanayi, University of Cyprus

Deliverable D7.1:

Risk Management Plan

Dissemination Level	Public
Nature	Report (submission on CETP portal)
Responsible partner	UCY
Contributing partners	UniFr, FZJ, Dyenamo, Solaronix
Due date of deliverable	31/12/2025 – 31/01/2026
Actual submission date	31/01/2026

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Contents

Executive summary

CIRCULAR-PV is a Clean Energy Transition (CET) Partnership project that targets to develop and test innovative circularity strategies combined with low environmental impact manufacturing of perovskite PV modules to achieve reliable, sustainable, recyclable, and potentially lower cost PV. The CIRCULAR-PV consortium comprises of five partners from four countries that bring their expertise together to address the ambitious objectives of this project, namely University of Cyprus (Cyprus), which is also the Coordinator, the University of Freiburg (Germany), the Forschungszentrum Jülich (Germany), Solaronix (Switzerland), and Dyenamo (Sweden). The CIRCULAR-PV partnership will strive to investigate eco-design modules outdoors in terms of their lifetime and stability studying links between material recovery and degradation pathways generated by real field operation. Moreover, it will aim to demonstrate successful material recovery without substantial quality loss and to study the feasibility of re-manufacturing eco-friendly PV. Ultimate target of the project is to achieve effective recycling of eco-friendly perovskite modules without sacrificing long-term stability and efficiency.

CIRCULAR-PV is expected to lead to minimisation of use of critical raw materials, to new circularity-by-design approaches, to the demonstration of the feasibility of scaling up perovskites using sustainable green approaches, circularity designs, and pre-industrial processes, as well as to the demonstration of the technology (in terms of stability and in terms of circularity effectiveness) in different climatic conditions in Cyprus and in Germany. The project's official launch date was January 2025, and it is scheduled to run for 36 months.

This report is a deliverable of Work package seven of CIRCULAR-PV (WP7. Reporting and Knowledge Community) and it provides the annual reporting (Year 1) submitted to the CETP Knowledge Community.

1. Purpose of this document

The purpose of this document is to report the Year 1 activities of the project following the format provided in the DISCCO platform by the CETP Knowledge Community. The information in this report was directly submitted on the online platform as a requirement of the CETP program monitoring.

2. Annual report for Year 1

The Year 1 report submitted on DISCCO can be found below:

Status: accepted, reporting period: 2025

Edit

CETP-FP-2023-00528
Towards long-lived and recyclable perovskite photovoltaics (CIRCULAR-PV)

TRI2 - Enhanced Zero Emission Power Technologies

CM2023-03B (IOA) Advanced renewable energy (RE) technologies for power production

Project Status: selected

Project Coordinator: Dr Maria Hadjipanayi, University of Cyprus

Facts | Participants | Persons | Clearing | Funding Partners | Funding Data | Work progress | Outreach | Challenges | Outputs

Project website
https://www.phaethon-coe.eu/circularpv/

Project duration
1.1.2025 - 31.12.2027

Total costs
1919209,4 €

TRL at start stage
TRL 5 - technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL at final stage
TRL 6 - technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

Description

Photovoltaics (PV) are expected to play a major role in the clean energy transition as part of key enabling zero-emission technologies. The need to scale up PV deployment means exponential increase of critical raw materials required and PV waste. Moving forward from existing technologies to emerging PV e.g., perovskites, will not eliminate the problem; on top of that, there will also be the need to address use and disposal of toxic materials and solvents that make up perovskite PV. The solution is to move away from the 'take-make-use-throw' model and start working in a circular economy model. CIRCULAR-PV aims to develop and test innovative circularity strategies combined with low environmental impact manufacturing of perovskite PV modules to achieve reliable, sustainable, recyclable, and potentially lower cost PV. The eco-design modules will be studied outdoors in terms of their lifetime and stability investigating links between material recovery and degradation pathways generated by real field operation. The project aims to demonstrate successful material recovery without substantial quality loss and to study the feasibility of re-manufacturing eco-friendly PV. Ultimate target is to achieve effective recycling of eco-friendly perovskite modules without sacrificing long-term stability and efficiency. CIRCULAR-PV is highly relevant to the Call as it

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

contributes through its learnings to the acceleration of clean energy transition towards climate neutral, circular economy.

Relevance

CIRCULAR-PV is important to the clean energy transition as it supports the enhancement of a promising emerging PV technology towards achieving power production of zero environmental cost. It targets minimizing the use of critical raw materials and toxic materials/solvents for the development of PV modules as well as the demonstration of eco-design modules targeting PV circularity. Both aspects together are necessary for achieving high and sustainable deployment of PV within the energy ecosystem.

Publishable Summary

Objectives

CIRCULAR-PV aims to develop and put to the test innovative circularity strategies combined with low environmental impact manufacturing of perovskite-based PV modules for the purpose of achieving reliable, sustainable, recyclable, and potentially lower cost PV modules. The minimization of the environmental impact throughout the whole lifecycle of the modules will be a priority in this project. The ultimate target is to achieve effective recycling of eco-friendly perovskite PV modules without sacrificing long-term stability and efficiency.

Challenge(s) addressed and approach defined to go beyond state of the art

The novel nature of this project unavoidably comes with some challenges that the consortium plans to address. The overarching one is the unknown 'relationship' between device aging and recyclability. This is a question in the field and in a sense a nice opportunity for exploration by the consortium. Through the project we need to verify the connection and study the implications of the aging on the recycling and vice versa. The ambition will be to develop a recycling process that will be as robust as possible towards different degradation pathways, and this will be the way forward in this project. However, there is an uncertainty factor in the fact that perovskites can degrade in multiple ways and particularly outdoors, have not been extensively studied. In our project, systematic indoor and outdoor aging as part of the circularity aging protocol will take place in close connection to the recycling efforts in order to shed light onto the link between aging pathways and recyclability of perovskites, with the ultimate target to achieve almost 100% recovery of materials from the degraded devices of high enough purity to be utilized for remanufacturing PV modules. Another project challenge identified is on achieving the desired balance between reliability, circularity, cost, and sustainability of perovskite PV. The challenge will be on how not to sacrifice one over the other (particularly the reliability against the circularity). This lies at the core of our project. For this reason, a holistic approach is taken whereby the developed circularity strategy will cover all phases of the perovskite technology lifecycle (from material/process selection for manufacturing to aging to handling at end of life or other degraded state) and will also receive feedback from all these stages towards becoming optimized and robust. Particularly important will be the feedback from the outdoor aging studies towards improving the module stability, material choice, encapsulation/packaging, and recovery processes.
In year 1 of the project, the consortium encountered the challenge of not being able to implement a conventional LCA methodology for defining the circularity strategy of the project mainly due to othe lack of comprehensible life cycle inventories for novel materials and technologies. This was addressed by the development of an early-stage alternative environmental assessment which adopted alternative sustainability metrics including assessing material demand relative to global reserves for a 1 TW deployment and using industry-average LCAs from sector associations.

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by
Swedish Energy Agency
SOLARONIX
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Results and impact expected

Overall, the implementation of the project will generate several positive outcomes:
1) Progress towards reducing the environmental impact of perovskite PV technology
2) Minimization of the use of CRM and new circularity-by-design approaches
3) Improvement of overall cost of perovskite PV within whole value chain (material supply to EoL handling)
4) Demonstration of the feasibility of scaling up perovskites using sustainable green approaches, circularity designs, and pre-industrial processes.
5) Demonstration of the technology in different weather conditions in Cyprus and in Germany (in terms of stability and in terms of circularity effectiveness)
6) Gaining an understanding of possible links between module degradation pathways and recyclability
7) Demonstration in general of the feasibility of PV recycling as a means of reducing unnecessary exploitation of CRM and of EoL PV waste.
The most important outcome of CIRCULAR-PV will essentially be an amalgamation of all the above: the development, validation, and demonstration of innovative low environmental impact perovskite modules that have long field lifetimes, overall reduced cost, and are highly recyclable. The current state of development is at TRL4-5 (with single-lifetime modules starting to be tested long-term out in the field) and is expected to reach TRL 6 (with eco-design modules demonstrated in a real relevant environment).
In year 1, a preliminary eco-design was defined based on an alternative environmental assessment developed in the project. The manufacturing partners made progress in developing carbon-based electrode perovskite modules towards the envisaged eco-design. Some first indoor aging tests have been performed on first modules provided and a preliminary aging protocol for circularity has been devised. Finally, selective recovery of lead and substrates from perovskite samples has been achieved in preliminary recovery and recycling studies.

Keywords

perovskite, PV recycling, circular strategies, long-term stability

Keywords, predefined

Renewable energies monitoring and evaluation, Photovoltaics, Circular economy

Illustration

CircularPV

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by
Swedish Energy Agency
SOLARONIX
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

DISCCO

Status: accepted, reporting period: 2025

Edit

CETP-FP-2023-00528
Towards long-lived and recyclable perovskite photovoltaics (CIRCULAR-PV)

TRI2 - Enhanced Zero Emission Power Technologies

CM2023-03B (IOA) Advanced renewable energy (RE) technologies for power production

Project Status: selected

Project Coordinator: Dr Maria Hadjipanayi, University of Cyprus

Facts | Participants | Persons | Clearing | Funding Partners | Funding Data | **Work progress** | Outreach | Challenges | Outputs

Status of project

Any substantial change in an ongoing project has to be reported immediately to the Funding Agencies concerned with a copy (CC) to knowledgecommunity@cetpartnership.eu. Please mention the full project ID (e.g. CETP-2022-00555) in your communication. Project partners should be aware that changes may have implications on past, present and planned future funding.

Have there been any changes in the...	Type of change	Comment	Status
consortium composition?	No	Consortium composition was changed after approval of the project as the 2 Israeli partners (SOLRA-PV, HUJI) had to withdraw from the project due to lack of funding by their national agency. These changes have been approved by the relevant funding agencies, the coordinating funding agency, and communicated to the CETP Management and Monitoring teams in 2024.	solved
work progress?	No	All deliverables during the first year of the project have been submitted successfully and on time.	solved
expenses (vs budget)?	No	Overall, there have been changes to the budget of individual partners compared to our submitted proposal. Mainly due to requests from the respective funding agencies as well as due to the change in composition of the consortium (withdrawal of partners SOLAR-PV and HUJI) which resulted in changing the effort of partner UniFr as it had to undertake part of the activities of the withdrawn	solved

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Have there been any changes in the...	Type of change	Comment	Status
		partners. These changes have been communicated and approved by the relevant funding agencies, the coordinating funding agency, and communicated to the CETP Management and Monitoring teams.	

If there are any minor or substantial changes, please report on the issues, their reasons, remedies taken and consequences occurred in the Comments section.
Text length suggested 200 characters per issue

Milestones and (publishable) Deliverables
Set up the list of milestones and deliverables (complete list of planned milestones and deliverables as reflected in the project plan, achievements according to the progress reported annually) and fill in updated information as well as upload the respective milestones and deliverables on the project hub on DISCCO (no specific template requested).

List of Milestones:

	No.	Title	Publishable	Planned / expected in project month	Achieved in project month	Status
▶	MS1	Benchmark of material criticality against EU defined list of criticality materials	No	5	5	finished
▶	MS2	Validate and quantify the environmental and economic advantages of integrating recycling into our production process via extended life cycle analysis and techno-economic modelling.	No	10	10	finished
▶	MS3	Delivery of preliminary eco-friendly modules for outdoor tests	No	15		not started
▶	MS4	Intrinsic stability of eco-designed	No	16		not started

	No.	Title	Publishable	Planned / expected in project month	Achieved in project month	Status
		perovskite solar cells demonstrated				
▶	MS5	Eco-friendly cells passing IEC TC (-40C to +85C, 200cycles), DH (85C, 85%RH, 1000h), ISOS-L (1sun, 55C, 1000h)	No	18		not started
▶	MS6	Unencapsulated eco-design perovskite modules with 200 cm^2 area realized	No	21		not started
▶	MS7	Eco-friendly hermetic sealing compatible with perovskite cell stack demonstrated	No	21		not started
▶	MS8	Demonstration of effective and robust recycling procedure for perovskite modules	No	30		not started

Note: Save your document in your project's file-repository on DISCCO Projects Hub and "copy link" to the file/folder and save it in this field OR if the document is on your website or in an external location please use a direct URL to that document.

List of Deliverables:

	No.	Title	Publishable	Planned / expected in project month	Achieved in project month	Status
▶	D1.1	Risk Management Plan	No	4	4	finished
▶	D1.2	Data Management Plan	Yes	6	6	finished
▶	D1.3	Mid-term progress report (transnational)	No	18		not started

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by
Swedish Energy Agency
SOLARONIX
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

	No.	Title	Publishable	Planned / expected in project month	Achieved in project month	Status
▶	D1.4	Final progress report (transnational)	No	36		not started
▶	D2.1	Dissemination, Exploitation, Communication Plan	Yes	6	6	finished
▶	D2.2	Final report on dissemination-communication actions	Yes	36		not started
▶	D2.3	Technological exploitation actions	No	36		not started
▶	D3.1	Extended LCA and strategy for optimal environmental footprint	Yes	12	12	finished
▶	D3.2	Evaluating material criticality and supply chains for perovskite solar cells	Yes	6	6	finished
▶	D3.3	Sustainability interventions are analysed and module design over the entire lifecycle is concluded. At least one demonstrator is constructed, and the environmental impact is characterized.	Yes	30		not started
▶	D4.1	Eco-design perovskite PV module with area =200 cm^2 and PCE >18%	Yes	36		not started
▶	D4.2	Encapsulation strategies for perovskite modules with low environmental impact and design for recycling	No	30		not started

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

	No.	Title	Publishable	Planned / expected in project month	Achieved in project month	Status
▶	D4.3	Report on eco-device optimization loop for optimal reliability – sustainability balance	Yes	36		not started
▶	D5.1	Eco-designed perovskite cells passing IEC TC (-40C to +85C, 200cycles), DH (85C, 85%RH, 1000h), ISOS-L (1sun, 55C, 1000h)	No	24		not started
▶	D5.2	Eco-designed perovskite modules passing IEC TC (-40C to +85C, 200cycles), DH (85C, 85%RH, 1000h), ISOS-L (1sun, 55C, 1000h)	No	36		not started
▶	D5.3	Indoor characterization of modules using LBIC, DLIT, potentiostatic PL, Raman spectroscopy, EQE, spatially resolved EL/PL before and after outdoor exposure and indoor accelerated lifetime tests	No	36		not started
▶	D5.4	Comparison of outdoor performance degradation of different eco-design perovskite structures with the indoor lifetime studies	No	36		not started
▶	D6.1	Analysis of the purity of recovered and treated material. Comparison with pristine material	No	31		not started

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by
Swedish Energy Agency
SOLARONIX
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

	No.	Title	Publishable	Planned / expected in project month	Achieved in project month	Status
▶	D6.2	Successful eco-friendly module re-manufacturing. Preliminary analysis on stability and reliability	No	36		not started
▶	D7.1	Annual reporting (Year 1) for CETP Knowledge Community	Yes	12		not started
▶	D7.2	Annual reporting (Year 2) for CETP Knowledge Community	Yes	24		not started
▶	D7.3	Final reporting for CETP Knowledge Community	Yes	36		not started
▶	D7.4	Abstract of Project Main Results for CETP Knowledge Community	Yes	36		not started

Note: Save your document in your project's file-repository on DISCCO Projects Hub and "copy link" to the file/folder and save it in this field OR if the document is on your website or in an external location please use a direct URL to that document.

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

DISCCO

Status: accepted, reporting period: 2025

Edit

CETP-FP-2023-00528
Towards long-lived and recyclable perovskite photovoltaics (CIRCULAR-PV)

TRI2 - Enhanced Zero Emission Power Technologies

CM2023-03B (IOA) Advanced renewable energy (RE) technologies for power production

Project Status: selected

Project Coordinator: Dr Maria Hadjipanayi, University of Cyprus

Facts | Participants | Persons | Clearing | Funding Partners | Funding Data | Work progress | Outreach | **Challenges** | Outputs

Thematic challenges addressed and approaches adopted
Summarise the clean energy transition challenge(s) addressed and the approach(es) adopted and describe the innovation and solution your project provides for the clean energy transition. The summary should be specific and comprehensi-ble (without detailed technicalities nor meaningless generalities).

CIRCULAR-PV strives to achieve good balance between reliability, circularity, cost, and reduced environmental footprint of perovskite photovoltaics. The project contributes through its learning outcomes to the acceleration of clean energy transition to a climate neutral and, most importantly, circular economy. It aspires through the proposed measures to address the challenge TRI2 of enhancing zero-emission power technologies (in particular perovskite PV) in terms of reliable (and long-term) performance, cost, scalability, and circularity. Moreover, CIRCULAR-PV is well placed and timely to contribute towards the implementation of the SET Plan particularly to help '...minimize life-cycle environmental impact along the whole value chain of PV electricity generation, and increase recyclability of system components (in particular: of modules) and '... progress with eco-design requirements in preparation of implementing measures supporting maximum energy yield (kWh/kWp) and lowest life-cycle environmental impact'

Cross-cutting challenges addressed and approaches (to be) adopted
CETPartnership addresses cross-cutting challenges (defined in the CETPartnership SRIA) that may be of higher or lower relevance for your project. The idea is to collect information on how you perceive and address these challenges and needs as well as how you (suggest to) deal with them and provide solutions if relevant for the project and field you are working on. These cross-cutting issues are part of dedicated CETPartnership activities and fora. Rate the cross-cutting issues (range from 1 to 5 / not relevant to highly relevant) and provide a short description of how the project is tackling with these issues and what insights already gained / lessons learnt are particularly useful for your project. The cross-

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

cutting issues are prioritized and further developed in an iterative approach in CETPartnership knowledge community.

Issue	Relevance	Description
Regulation and market design to support optimal resource allocation and value creation both in the short term and long term	3	While this project does not directly address regulation or market design, it provides evidence that can support informed decision-making in these areas. By analysing the percentage of material bound in a 1 TW scale-up relative to estimated global metal reserves, the project identifies which materials may pose supply risks and which can be deployed at scale without significantly impacting global availability. Similarly, the project aims to investigate the total production of solvents and compare it to the quantity used in the development of a perovskite module. This approach supports optimal resource allocation by highlighting material choices that minimise long-term supply constraints. In addition, the project contributes to value creation by enabling the deployment of low-carbon energy technologies that rely on resource-efficient material selection. These findings can therefore inform regulatory and market frameworks aimed at supporting sustainable, scalable renewable energy systems in both the short and long term.
Policy and actions in support of fair, just and democratic transition	4	Although this project does not directly address energy transition policy, its findings can inform and support policies that promote the responsible deployment of perovskite-based solar technologies and the simultaneous development of perovskite module recycling infrastructure. By promoting resource efficiency, material security, and circularity, these insights can help enable a fair and just transition to low-carbon energy systems while supporting long-term sustainability and public benefit.
Encouraging transition based on resource efficiency and circularity principles	5 (highly relevant)	This project evaluates the resource availability and environmental impact of metals for scaling perovskite solar modules using estimated global reserve data and industry-based life-cycle assessments. These insights support the selection of the most feasible materials for the large-scale deployment that is necessary for the energy transition. Resource efficiency and reusability are further demonstrated through successful solar cell recycling, confirming the feasibility of a circular module design. These results encourage the continued development and research into a solar-based energy transition.
Identifying robust pathways as alternative strategies towards a net zero society (environmental and socio-economic aspects)	5 (highly relevant)	Life cycle assessments (LCAs) are the most comprehensive tool for identifying optimal strategies toward a net-zero society. However, this project found that reliable LCA data are limited due to the specialised materials used in perovskite modules. To address this gap, alternative approaches were developed, including assessing material demand for a 1 TW scale-up; using industry-average LCAs from material associations rather than single datapoint studies and estimations; and applying established frameworks to identify non-toxic, environmentally sustainable solvents. These metrics served as

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by
Swedish Energy Agency
SOLARONIX
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Issue	Relevance	Description
		a more robust guide towards environmentally responsible decision making.
Encouraging digitalisation of the energy transition processes	1 (not relevant)	This project does not deal with the encouragement of digitalisation of the energy transition.
Accelerate the transition through innovation ecosystems (Education and training)	2	Although education and training are essential to accelerate the transition – particularly for emerging technologies such as perovskite modules – this project has not yet directly developed innovation ecosystems. Project partners have, however, engaged with existing workshops and training activities that can then, in turn, be used within this project.

DISCCO

Status: accepted, reporting period: 2025

Edit

CETP-FP-2023-00528
Towards long-lived and recyclable perovskite photovoltaics (CIRCULAR-PV)

TRI2 - Enhanced Zero Emission Power Technologies

CM2023-03B (IOA) Advanced renewable energy (RE) technologies for power production

Project Status: selected

Project Coordinator: Dr Maria Hadjipanayi, University of Cyprus

Facts | Participants | Persons | Clearing | Funding Partners | Funding Data | Work progress | Outreach | Challenges | **Outputs**

Results
Summarise the main quantitative and qualitative results expected and (partly) achieved (depending on the reporting cycle), contributing to the clean energy transition. Present them according to the five dimensions (technological, economical, societal, ecological and scientific) and their relevance for your project.
The description should cover the outputs, outcomes and impacts* resulting from your project as well as relevant and specific indicators reflecting the objectives and progress your project aims to achieve / has achieved.
* Defined as: i) outputs: concrete immediate to very short-term outputs created during the implementation of your project, ii) outcomes: : short to mid-term effects of your project such as uptake, diffusion, use and deployment of the project's results by direct target groups and iii) impacts: long-term effects produced by your project.
The Exploitation Guidelines provide further information on some aspects assessed in this Results and exploitation section.

Results in a nutshell
Provide a compact description covering the main outputs, outcomes and impacts.

Expected outputs:
1) demonstration of eco-design perovskite modules passing IEC/ISOS indoor aging
2) study of link between material recyclability and degradation pathways from field operation and indoor accelerated aging.
3) successful material recovery without substantial quality loss.
4) successful eco-friendly module remanufacturing

Expected outcomes and impacts:
• Progress towards reducing the environmental impact of perovskite PV

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

• Minimization of the use of CRM and new circularity-by-design approaches
• Improvement of cost of perovskite (PSC) PV within whole value chain
• Demonstration of the feasibility of scaling up perovskites using sustainable approaches, pre-industrial processes.
• Demonstration of the technology in different climates (Cyprus, Germany)
• Gaining an understanding of possible links between module degradation pathways and recyclability

Year 1 progress: An alternative environmental assessment was developed (FZJ) to enable meaningful sustainability screening due to lack of comprehensive life cycle inventories for novel materials required for LCA. Criticality of materials assessed (Dyenamo). Based on these, recommendations on what to avoid were made to the project manufacturers e.g. metals (indium, cesium, silver), solvents (DMF, NMP). A fully printable mesoporous structure was scaled up from cells to 10×10 cm^2 modules (Solaronix). Green solvents and screen-printing of carbon electrodes used. The 1st modules were sent for characterization (EL/PL/DLIT/Raman) and stability studies at UFR and UCY. 69%rel of initial PCE after 1500h at 65°C, with faster degradation during light-heat test, hinting to intrinsic light-induced decay. First outdoor tests in Germany show stable PCE, long-term monitoring in place until 20%rel of initial PCE; however in Cyprus, degradation of PSC modules occurred after few days of testing. UFR fabricated p-i-n PSC mini-modules (8 cells, 50×50 mm^2) with 19.1% PCE and 97.8% gFF. PSCs with laminated and printed carbon electrodes were realized (cells up to 20.4% PCE) but scribing and alignment still limit modules. Modules (UFr, Solaronix) sent to FZJ for delamination and recycling tests. PSCs sent to UCY for Raman assessment of metal-contact degradation upon air exposure. Investigations into the correlation of material recyclability and degradation pathways are in progress. Disassembly of a degraded module and assessment of degradation impact on material circularity (FZJ). Material recovery status: cover glass and electrodes successfully reclaimed without loss of quality; the recovered perovskite material exhibited trace metal contamination and a stoichiometric iodine loss of 18–21%, quantified via XRD and ICP-OES measurements.

Technological dimension

Use relevant and specific indicators reflecting the progress your project provides for instance in terms of efficiency rate, life time, storage capacity, system performance etc.
Mandatory: Technology readiness level, expected: key performance indicators of highest relevance that reflect how the project provides progress going beyond state-of-the-art

Technological indicators	Initial value at project start	Expected value at project end	Reached value at project status	Further information
Perovskite Modules PCE (%)	7.1 (10x10cm2)	18 (200cm2)	9.55 (10x10cm2), 19.1% (5x5 cm^2)	9.55% PCE with carbon electrode, 19.1% PCE with metal electrode
Amount of materials recovered from degraded modules	30%	90%	44%	
Refabrication of modules	Unknown or N/A	90% PCE of the original module	No modules fabricated yet	

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Technological indicators	Initial value at project start	Expected value at project end	Reached value at project status	Further information
			(commences later)	
Technological readiness level	TRL4-5	TRL6	TRL4	

Key results in the technological dimension

Expected results:

1) New eco-design modules with low environmental impact materials and manufacturing processes
2) Hermetic encapsulation in a circular PV design
3) Effective perovskite module recycling methods
4) Refabrication efforts of perovskite modules

Year 1 progress:

Optimized screen-printing of carbon electrode improved 10x10cm2 mesoporous modules performance (Solaronix). Initial characterization and degradation studies (UCY, UFR) to understand stability. Perovskite modules with carbon-based electrode in planar device architecture realized (UFR). Modules with metal back electrode optimized on mini-module size (5x5 cm^2). Successful glass-glass encapsulation with UV-curable encapsulant. Delamination and recycling studies (FZJ). Modules disassembled to enable selective recovery of lead and substrates. Substrates successfully reclaimed and reused, and sent to Solaronix for refabrication. Lead was fully extracted with no detectable residue remaining, reprocessed into perovskite materials, and is currently under testing in new solar cells.

Economic / commercial dimension

Use relevant and specific indicators reflecting the progress your project provides for instance in terms of levelized cost of energy, time to market, etc.
Expected: Values for market or commercial readiness level, estimate of time-to-market (number of years)

Economic / commercial indicators	Initial value at project start	Expected value at project end	Reached value at project status	Further information
Market & commercial readiness level (MCRL)	1	3	1	

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Economic / commercial indicators	Initial value at project start	Expected value at project end	Reached value at project status	Further information
according to the Exploitation Guidelines				

Key results in the economic / commercial dimension

The manufacturing partners (Solaronix, UFR) aim to build on the existing technological maturity of their module technologies with respect to circularity strategies to increase the MCRL from basic (MCRL =1) to intermediate level (MCRL=3-4). The following aspects will be brought closer to commercialization:

1) new module designs, low environmental impact materials and manufacturing processes for stable, eco-designed perovskite devices
2) Hermetic encapsulation in a circular PV design
3) Perovskite module recycling methods

Societal dimension

Use relevant and specific indicators reflecting the progress your project provides for instance in terms of stakeholder involvement and engagement in the process, per relevant stakeholder group (research, industry, government, civil society and / or finance) or number of stakeholders having expressed their active interest in the innovation etc.

Societal indicators	Initial value at project start	Expected value at project end	Reached value at project status	Further information
Societal readiness level (SRL) according to the Exploitation Guidelines	1	3-4	1-2	

Key results in the Societal dimension

Society needs to be more circular, thus sustainable energy production by PV and their recycling are in focus of CIRCULAR-PV. PV is the cheapest electrical energy solution and accepted by large part of society (Identification of need, SRL1). Currently, solutions for delamination and recycling of components from the developed perovskite PV are proposed (SRL2). Towards the end, SRL3-4 will be reached by implementation of recycling strategies and reusing components for PV fabrication.

Year 1 : Some progress has been made in engaging stakeholders in the project until now mainly

through participation in some first networking and scientific workshops, in the submission of a manuscript to peer-review journal, and in the project website. Next in line is to participate in international conferences in year 2 for disseminating results and for networking with other stakeholders.

Ecological / environmental dimension

Use relevant and specific indicators reflecting the progress your project provides for instance in terms of CO2 emissions, land use, material use, reduction of hazardous materials and processes etc. Useful for identifying and describing ecological / environmental indicators are the "Do No Significant Harm" categories.

Ecological / environmental indicators	Initial value at project start	Expected value at project end	Reached value at project status	Further information
Energy consumption reduction	0%	45-65%	65-80%	Results of the exploratory LCA show that CO2 emissions reduce when modules are recycled. Further reduction expected when recycling procedure is improved upon. Similarly for inputs of energy consumption, water consumption, and outputs of hazardous waste.
Water consumption reduction	0%	60-75%	75-85%	Results of the exploratory LCA show that CO2 emissions reduce when modules are recycled. Further reduction expected when recycling procedure is improved upon. Similarly for inputs of energy consumption, water consumption, and outputs of hazardous waste.
Hazardous waste reduction	0%	21-26%	30-45%	Results of the exploratory LCA show that CO2 emissions reduce when modules are recycled. Further reduction expected when recycling procedure is improved upon. Similarly for inputs of energy consumption, water consumption, and outputs of hazardous waste.

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Ecological / environmental indicators	Initial value at project start	Expected value at project end	Reached value at project status	Further information
Climate change	0%	45-50%	55-65%	Results of the exploratory LCA show that impact categories reduce when recycling module.
CO2 emission reduction	0%	42-50%	60-80%	Results of the exploratory LCA show that CO2 emissions reduce when modules are recycled. Further reduction expected when recycling procedure is improved upon. Similarly for inputs of energy consumption, water consumption, and outputs of hazardous waste.

Key results in the ecological / environmental dimension

Develop eco-friendly perovskite modules which combine the following:
1) using low environmental impact approaches at fabrication
2) circularity interventions in the whole perovskite technology lifecycle

Year 1 status: First perovskite modules with carbon-based electrode in planar device architecture realized. Modules with metal back electrode optimized on mini-module size (5x5 cm^2). Modules successfully glass-glass encapsulated with UV-curable encapsulant. Encapsulated modules sent to FZJ for first delamination and recycling trials.

Scientific dimension

Use relevant and specific indicators reflecting the progress your project provides for instance in terms of publications, patents, etc.

Scientific indicator	Initial value at project start	Expected value at project end	Reached value at project status	Further information
Scientific publications	0	> 3	1	Manuscript submitted to peer-review journal
Scientific/technical webinars	0	>1 webinar annually	0	

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Scientific indicator	Initial value at project start	Expected value at project end	Reached value at project status	Further information
International conference participation	0	>2 scientific conferences annually	0	

Key results in the Scientific dimension

A manuscript titled "Unravelling the solvent-solute interactions between ?-valerolactone and FAPbI3 for realization of efficient perovskite solar cells from green solvents" was finalized by UFR. In this study, ?-valerolactone (GVL) was employed as green solvent and the implications of its use for coating of photoactive perovskite thin films were assessed by a combination of solution characterization, COSMO-RS calculations and comparison of photovoltaic performance of devices processed from GVL and DMF:DMSO. The paper was submitted and is expected to be published in Q1/2026.

Further dimensions

Use relevant and specific indicators reflecting the progress your project provides in other terms not assessed above. They may cover further concepts like Integrated System Readiness Level, Manufacturing Readiness Level, Organisational Readiness Level, Legal Readiness Level etc.

Further indicators	Initial value at project start	Expected value at project end	Reached value at project status	Further information
No data available in table				

Key results for further dimensions

Exploitation, valorisation and stakeholder interaction

Impact and exploitation activities

Provide an overview of the impact and exploitation activities according to the various impact dimensions, including tech-nological, economical, societal, ecological and scientific aspects. Specifically, share the updates into your exploitation strategy for further valorisation: your project's progress concerning the commercial exploitation of your findings, address-ing potential barriers and encompassing critical

milestones such as testing and validation, intellectual property protection strategies, value chain integration, business model development, and market entry strategies.

Exploitation will aim to capitalize on the results and learning outcomes towards development of further activities in the topic of interest e.g. new projects, publications, IP generation, etc. The aim is to ensure that the proposed technology turns into economic, social, scientific advantages for EU and partner countries. Exploitation strategy will be strongly enhanced by the industrial partners which will translate the outcomes of research towards economically viable products and their use. The consortium intents to build on the new knowledge acquired from implementing/optimizing the circularity strategy in the project particularly focusing on helping the scientific community to achieve low environmental impact perovskite modules that can be fully recovered after their EoL and remanufactured into reliable modules for field operation.

Year 1 status: To date, the activities have focused on evaluating material availability, environmental impact, circularity, and cost drivers relevant to lab-scale research and industrial deployment. Circularity has been partially validated through successful recovery of ITO/FTO glass substrates and silver contacts, with an exploratory LCA suggesting that recycling the modules will lower the environmental impact of the modules. A lab-scale cost analysis identified key cost drivers and highlighted materials and solvents requiring optimisation before industrialization. Advanced degradation and reliability tests were implemented, including extended ageing protocols in climatic chambers. Reuse of TCO substrates and contacts is expected to reduce material consumption and processing costs, while extended degradation testing will help identify degradation mechanisms and protection strategies, guiding further optimisation and industrial deployment. In parallel, the need to supply a large number of modules to project partners has driven improved standardisation of production processes, supporting more reproducible fabrication.

Stakeholder engagement activities

Report your stakeholder engagement activities, namely efforts to engage with key stakeholders and partners like technol-ogy providers and need owners relevant to the project's success by increasing effectiveness and impact. Choose from the stakeholder categories* for project consortium members and external stakeholders.

Stakeholder	Short description of engagement activities
Any other (please specify)	Stakeholder: Scientific Community. Expected engagement activities: Use journal publications, scientific conferences, conference proceedings, workshops for knowledge generation and exploitation, project involvement, synergy building with other teams working in the field. Year 1 progress: UCY: A synergy between UCY team with other CETPartnership projects working on fabrication and recyclability of perovskite-based devices was implemented the first year of the project and set the next joint activities between the 2 consortia. Solaronix : Through participation in other related Horizon projects, Solaronix transfers relevant knowledge and experience to enhance the effectiveness of this project. UFR: A synergy between this and other European projects or project proposals in which UFR is participating is created.
Industrial end-users, off-takers & networks of SMEs	Expected engagement activities: Using web and social media, Industry events (e.g. Intersolar, PV-Kongress Austria, LOPEC, PVSEC), workshops, open lab days to build synergies/collaborations, knowledge exploitation Year 1 progress: UFR: By close collaboration with the Fraunhofer Institute for Solar Energy Systems, UFR transfers

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by
Swedish Energy Agency
SOLARONIX
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Stakeholder	Short description of engagement activities
	knowledge from this project to a wider scientific audience and brings its research closer to stakeholders from the industrial sector outside of this project.
Innovation ecosystems / clusters / hubs	Stakeholder: Technology innovation platforms. Expected engagement activities: connect with working groups on PV circularity and perovskites to join discussions, Web and social media, participation in workshops involving or organized by such TIP platforms and working groups Year 1 progress: Solaronix : Engagement with a startup located on the same campus through informal technical exchanges to share insights and discuss challenges
Any other (please specify)	Stakeholder: General public. Expected engagement activities: open lab days, workshops, seminars, web and social media, press releases for education and awareness. Year 1 progress: UCY: Co-organization of th Future-PV workshop in Cyprus (May 2025). Participation of the UCY team to workshop at UCY presented the project's vision and established early connections with potential collaborators. UFR, FZJ, Dyenamo, and Solaronix all had invited talks in the workshop. Dyenamo: Participation in the Photonics Industry Day workshop and a TechBlick webinar to engage with industry stakeholders and disseminate project results

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by
Swedish Energy Agency
SOLARONIX
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

DISCCO

Status: accepted, reporting period: 2025

Edit

CETP-FP-2023-00528
Towards long-lived and recyclable perovskite photovoltaics (CIRCULAR-PV)

TRI2 - Enhanced Zero Emission Power Technologies

CM2023-03B (IOA) Advanced renewable energy (RE) technologies for power production

Project Status: selected

Project Coordinator: Dr Maria Hadjipanayi, University of Cyprus

Facts | Participants | Persons | Clearing | Funding Partners | Funding Data | Work progress | **Outreach** | Challenges | Outputs

Strategy for dissemination and communication activities
Outline your strategy for dissemination and communication and report completed and planned focal activities as well as eventually changes implemented during the project's lifetime based on learnings and effectiveness to be increased.

The dissemination and communication measures are focusing on conveying project results as well as raising awareness at European and international level to a core target audience identified, namely:

(1) Scientific community (SC): Researchers from universities and research centres active in PV research particularly focusing on the perovskite community, but also on the community working on PV circularity and PV sustainability. Partner scientific networks. Ongoing EU and other funded projects that might share synergies with CIRCULAR-PV.

(2) Industrial community (IC): Industry, SMEs, start-ups, R&D spin-off companies working on solar energy, perovskite-based PV, BIPV, and circular economy topics. Possible industrial up-takers in the field. Investors in PV energy and end-users.

(3) Technology-innovation platforms (TIP): EU and international technology-innovation platforms and working groups that hold discussions on PV (e.g. IEA PVPS Tasks 12 and 13, ETIP PV, EERA-PV, working groups for PV (IWG PV), PVQAT Tasks 8 and 15).

(4) General public (GP): Wider audience incl. schools, local and regional authorities, Local knowledge transfer networks and NGOs focusing on energy, circularity, sustainability, environment issues (e.g.Cyprus Energy Agency, IDEOPSIS, SolarTAP), policymakers.

Dissemination measures planned include: (a) conference participation and conference proceedings (e.g. IEEE PVSC, EUPVSEC, PSCO, HOPV, etc.), (b) peer reviewed scientific journal publications focusing on compliance with open-access requirements (e.g. energies, Progress in Photovoltaics, ACS Sustainable Research Management, Solar RRL, Advanced Energy Materials etc.), (c) presentations at targeted events (e.g. synergy events organized from other projects, parallel events or symposia organized as part of international conferences, targeted webinars or online workshops in the field of interest, etc.), (d) organisation of workshops (e.g. EU Sustainable Energy Day) and of open lab days, and (e) clustering/interacting with relevant EU projects and other laboratories working in the field (e.g. 'Recycle-PSC' project from JRC, PACT initiative led by Sandia Labs/NREL, DIAMOND project led by Fraunhofer ISE, and other Horizon Europe running projects in the field of Perovskite PV).

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by Swedish Energy Agency
SOLARONIX
Supported by: Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Communication activities focus on raising visibility to the project and its achievements and the circularity 'vision' it aspires to. Overall, they are meant to complement the dissemination and exploitation planning by generating and maintaining a high level of interest by all stakeholders to the project's activities throughout the project. Communication actions will be held through person-to-person (e.g. workshops), written (e.g. press releases) and technology-based channels (e.g. website and social media).

In year 1, partners have already been engaged in dissemination and communication activities including: a submitted manuscript on the use of green solvents for the fabrication of perovskite devices; participation to two international workshops with invited talks; co-organization of an international workshop in Cyprus with a number of other EU perovskite projects; participation in two networking workshops and an exhibition; and media coverage through linkedin. in addition, the project website has been in place early on.

Individual dissemination and communication activities:
Report on the individual dissemination and communication activities in the tables / lists below. The final format may be different.

List of peer reviewed articles, books, book chapters etc. published with or submitted to academic publishers:

Type	Author(s) Name(s)	Title	Published in	ISSN/ISBN/DOI	Publication date
article	Lea Schwersenz, Luis Eduardo Ramirez Cardenas, Michael Daub, Harald Scherer, Kaleb Julius Strahringer, Ivonne Rodriguez Donis, Sophie Thiebaud-Roux, Uli Würfel, Markus Kohlstädt	Unravelling the solvent-solute interactions between ?-valerolactone and FAPbI3 for realization of efficient perovskite solar cells from green solvents	Submitted	To be updated once published	

List of other dissemination activities (media coverage, workshops and events organized by project, presentations and panel debates, participation in third-party events):

Type	Link	Target audience	Publication date
presentations and panel debates	https://luma.com/becomepv25?tk=8w8ioJ	Scientific community, industry, policy makers	2025-12-02
events organized by project	https://www.testare.eu/futurepv/	Scientific community (researchers, industry), EU perorvskite projects	2025-05-20
participation in third-party events	https://www.linkedin.com/company/epc-epfl/posts/?feedView=all	Students and industrials	2025-10-09
presentations and panel	https://www.techblick.com/event-videos/perovskite-innovation-day-25	Perovskite developers	2026-01-29

Republic of Cyprus
RESEARCH & INNOVATION FOUNDATION
Co-financed by
Swedish Energy Agency
SOLARONIX
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

Type	Link	Target audience	Publication date
debates			
participation in third-party events	https://natureconferences.streamgo.live/photovoltaics/register	Scientific Community	2025-09-29
media coverage	https://www.linkedin.com/company/98464141/admin/page-posts/published/	Scientific community, Industry, General public	2026-01-15
media coverage	https://www.linkedin.com/feed/update/urn:li:activity:7414702898892230657/?actorCompanyId=98464141	Scientific community, Industry, General public	2026-01-15
media coverage	https://dyenamo.se/dyenamo_news.php	Scientific community, Industry, General public	2025-08-25

List of patents:

Patent Application Number / License	Title and owner of the patent application / license	Link or remarks
No data available in table		

3. Delay / Deviation from plan

No delays experienced for this deliverable report.

Funding acknowledgment

This research was funded by CETPartnership, the Clean Energy Transition Partnership under the 2023 joint call for research proposals, co-funded by the European Commission (GA N°101069750) and with the funding organizations detailed on https://cetpartnership.eu/funding-agencies-and-call-modules. CIRCULAR-PV project is also co-funded by the EU within the framework of the Cohesion Policy Programme "THALIA 2021-2027, through the Research & Innovation Foundation (EP/CETP/0923/0009).