Cofund

Deliverable 5.2

Impact Assessment Report

June 2022

Table of Contents

The SOLAR-ERA.NET Cofund Action is supported by funding from the European Union's HORIZON 2020 Research and Innovation Programme.

1 Introduction

This report constitutes Deliverable 5.2 Impact Assessment Report of the SOLAR-ERA.NET Cofund action, with grant agreement 691664. The assessment of the impacts resulting from the projects developed under the SOLAR-ERA.NET Cofund framework has been conducted according to the data gathered from the Final Reports and from the survey elaborated according to the ERA-LEARN template for project impact assessment questionnaire.

This report presents some key performance indicators (KPI) to evaluate the impact of the 16 projects funded under the SOLAR-ERA.NET program. Such KPI are mainly related to social impact, based on the job creation and manpower involved in each project, and the scientific impact, based on peer-reviewed papers and other dissemination indicators.

In addition to KPI assessment, this report presents a short description of the projects developed under the SOLAR-ERA.NET Cofund framework, including their final objectives. The technological impact is described in terms of TRL advance, including some targets on technical performance improvement for each project.

The evolution of PhD thesis developed in each project is a relevant indicator of the project impact in terms of technological capacity building at the European level. Additionally, the number of patents generated by the projects reflects the competence of the European industrial sector.

2 Objectives

The focus of the SOLAR-ERA.NET Cofund was on strengthening the industrial manufacturing base through innovative manufacturing techniques, mass production, new products and services as well as integration of solar energy technologies in the energy system. The objectives and topics were in line with the strategic targets defined in the SET plan (see “SET-Plan - Declaration on Strategic Targets in the context of an Initiative for Global Leadership in Photovoltaics respectively Solar Thermal Electricity).
The topics addressed by SOLAR-ERA.NET Cofund Joint Call and related transnational projects funded within the SOLAR-ERA.NET Cofund action are described in the following sections.

2.1 Innovative and low-cost PV manufacturing issues

Demonstration of advanced and innovative equipment in pilot and pre-pilot line environment for highly performing technologies with high-yield throughput and cost-effective industrial production, ultimately targeting at or being compatible with GW-scale.

Projects addressing this topic should provide:

- An improved quality of silicon wafers, through a deeper understanding of the silicon structure and composition depending on the crystallisation processes.
- The development of wafer tracking software systems in order to further improve the yield and the operating costs of the manufacturing processes, and to get feedback for the development of the next generation of processing equipment.
- The thin wafer handling up to the module encapsulation process.
- The development of in line tool characterisation yielding higher throughput.
- Innovative formation of PV layers (dielectrics, transparent conductive oxides, metallization, junction, etc.).
- Innovative cells interconnection processes and schemes enabling the design of low loss / low current modules.
- Concentrator PV (CPV) and High Concentrator PV (HCPV) technologies: advanced designs aiming at very high efficiency of solar cells and modules, optics for high concentration, industrial manufacturing processes as well as cost-efficient and reliable tracking systems.
- Processes and manufacturing issues related to production of other (non-silicon) solar cell technologies.

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The following transnational projects were supported:

- PEarl: PERC meets self-aligned selective emitter technologies based on inkjet printing and silver less plating
- NEXT-FOIL: Next generation conductive solar foil for flexible photovoltaics
- HEAVENLY: High-efficiency PERT and IBC cell development focussing on paste and CVD
- ENMESH: ENabling Micro-ConcEntrator PhotovoltaicS with Novel Interconnection MetHods
- RHINO: Realization of High efficiency Industrial N-type sOlar cells

2.2 Advanced PV products and applications

The focus is on innovative manufacturing of and solutions for building- and product-integrated PV systems.

The following issues should be addressed and goals pursued:

- Dimensional and outlook flexibility with customised sizes, shapes and colours, freeform module technology, and bifacial solar cells and modules, electrical design for energy output optimisation (shadows, various tilt and orientation angles, safety issues).
- Holistic approach for the energy performance.
- Easiness of installation / application.

The following transnational projects were supported:

- BI-FACE: High-efficiency bifacial PV Modules and Systems for flat roof applications
- CEFRABID: Clean energy from road acoustic barriers infrastructure development
- PANELPV: Sandwich panels with integrated PV with freedom of size and color
- MASTERPV: Innovative manufacturing solutions for cost-efficient semitransparent BIPV
- Cover Power: Smart Glass Coatings for Innovative BiPV Solutions
- NELL: Novel Encapsulant For Long Lifetime High Voltage Pid-Resistant Pv Modules

2.3 PV system integration

The focus is on grid integration of PV power, installations and products, decreasing the costs of electricity and increasing the value of solar power. (Only PV specific issues are addressed, more general issues are addressed by smart grid, smart cities initiatives. Links to other initiatives are welcome.)

The following issues should be addressed and goals pursued:

- An integrated approach should seek a combination of load management / self consumption, power management of the distributed PV generators and storage systems and dispatchable flexible capacities, which altogether assure a stable grid in spite of fluctuations of demand and generation.
- Design tools for the sizing of storage power as a function of PV power, load demands and share of controllable loads should be developed.
- An e-infrastructure allowing the development of innovative services in the field of PV system integration would be very beneficial to both researchers (power prediction) and end-users (remote fault detection). Then, business and market models should be developed which

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assure the active contributions of all stakeholders (PV system operators, storage system operator, aggregators consumers, etc.) to a stable grid.
- Development of better battery management systems based on a combination of hardware (which allows to better assess the state-of-charge and state-of-health) of batteries in combination with software for a better energy management incorporating short-term energy yield forecasting for PV-system.
- Demonstrations of solutions should be realised on a grid where the PV penetration may exceed 50% in terms of annual energy consumption.

For all PV topics, novel aspects of sustainability and safety issues can be addressed (e.g. resource efficiency, life cycle analysis, critical substances).

The following transnational projects were supported:
- 1500-SIC: Develop a new photovoltaic inverter with SiC for full power operation at 1500V
- Erigeneia: Enabling rising penetration and added value of photovoltaic generation by implementation of advanced storage systems
- PVTOOL: Development of tools for effective control of large PV power plants
- PROGNOSIS: Intra-hour prediction of solar electricity generation from Photovoltaics

2.4 CSP cost reduction and system integration

The focus is on significant reduction in specific investment costs and thereby electricity production costs by addressing system components, storage / dispatchability and hybrid systems. The following issues should be addressed and goals pursued:
- Innovative HTF: increased operating temperature, lower water consumption, environmental acceptability, lower storage volume. All new concepts must demonstrate full dispatchability and scalability features. The increased conversion cycle efficiency must be compared with the decrease of collector efficiency when increasing the HTF temperature.
- Improved mirrors and support structure to reduce the cost of the solar field (40 % of the cost of the power plant).
- Improved selective coatings for receivers (absorber tubes and central receivers).
- Integration of direct steam generation into process heat for industrial applications.
- Innovative storage: advantage of dispatchability, 24 h operation, grid stability.
- New smart hybridisation and better integration concepts: dispatchability, firmness, attractive concept for countries with gas/oil resources or bio mass (MENA-Region), grid stability.
- Improved control and operation tools: reduction of O&M costs.

The following transnational project was supported:
- HyConSys: Hydrogen control in solar thermal parabolic through heat transfer fluid systems

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3 General project information and technical impact by project

All the projects in the programme are summarized by topic, including some descriptive information, such as time schedule, coordinator's contact details, funding requested, project description and main objectives.
The details on the outcomes of each project are provided in Deliverable 4.5 Final Demonstration Project Progress Report.

3.1 Innovative and low-cost PV manufacturing issues

3.1.1 PEarl

Project title: PERC meets self-aligned selective emitter technologies based on inkjet printing and silver less plating
Project number: SOLAR-ERA.NET Cofund 1 N° 026
Start date of the project: 01.01.2018
End date of the project: 30.09.2020
Total project costs (EUR): 867'518
Funding (EUR): 589'402

Table 1 Pearl coordinator contact details:

Short name of organisation	Fraunhofer ISE
Full name of organisation	Fraunhofer Institute for Solar Energy Systems
Department of organisation	Division Production Technology: Structuring and Metallization
Type of organisation*	Public research organisation
First and family name of coordinator	Roman Keding
Full address	Heidenhofstrasse 2, 79110 Freiburg
Country	Germany
E-mail	Roman.keding@ise.fraunhofer.de
PIC (9-digit Participant Identification Code)	999984059

The project focus was set on the exploitation of selective emitter's potential in passivated emitter and rear contact (PERC) silicon solar cells. Compared to PERC solar cells with a homogeneous emitter, those with selective emitter predict a significant increase in conversion efficiency of at least 1.0% absolute and, in consequence, would drastically increase the yield of PV systems, decrease the levelized cost of electricity, and the total cost of ownership. Therefore, Fraunhofer ISE, Meyer Burger, RENA, and Sun Chemical brought together their complementary competences in the fields of solar cell processing, machine engineering, and material synthesis in order to develop self-aligned process techniques based on the steadily advancing inkjet and plating technology, whereby low Ag consumption has been in focus.

Within PEarl, the Technology Readiness Level (TRL) of PERC solar cells with selective emitter (at Fraunhofer ISE) could be increased from 4 up to 6. Based on specific PEarl processes and materials, especially mask&etch, solar cells with efficiencies of up to 21.7% could be processed in the industrially relevant pilot-lines of Fraunhofer ISE. Moreover, the utilization of innovative inks and machine setups led to a decrease in alignment accuracy inkjet/screen-printing of below ±20 µm. The principal feasibility of the revolutionary self-aligned process technique based on mask&etch, lift-off and plating could be evaluated. Upcoming research will focus an efficiency gain of 0.4%abs. compared to PERC with homogeneous emitter to reach significant competitiveness.

Table 2 PEarl results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	4-5	6-7	5-6	The technology could be validated in the PV-TECs of Fraunhofer ISE and, in turn, in a PV-relevant environment and industrial equipment (TRL 5). However, the demonstration (TRL 6) would be processing of at least 100 solar cells with an average conversion efficiency of 22.0%, as defined in M6.2. This could not be achieved. Ideas are available to push the TRL towards 6-7 in a follow-up project.
Performance / efficiency	Cell efficiency 21.3%	Cell Efficiency Median 22% Max 22,5%	Process route 1: 21.67% Process route 2: 19.89%	Initial value* & expected efficiencies based on simulations** Further fine-tuning and high-quality material is needed to further improve efficiency (see. M6.1) *Saint-Cast et al., pss-a 2017 **Saint-Cast et al., EU PVSEC 2016
Effective dark saturation current density of the front side	Homogenous emitter 100 fA/cm2	Selective emitter 60 fA/cm2	Results from Milestone 5.1: >40 fA/ cm_2 Cell batch ~45 fA/ cm2	
Alignment accuracy Inkjet to screen printing	With only minor adaption of process sequence +/-100 µm	With development of sophisticated algorithm and alignment procedure +/-5 µm	Coordinate measurement system +/-15 µm AOI-System +/-25 µm Cell batch +/-35 µm	Final cell batch used the AOI system. Due to the limitation of the image resolution (2540 dpi, pixel size 10 µm) and improper calibration of the AOI system the accuracy is slightly inferior to the pre-test on single cell devices

3.1.2 NEXT-FOIL

Project title: Next generation conductive solar foil for flexible photovoltaics
Project number: SOLAR-ERA.NET Cofund 1 N° 044
Start date of the project: 01.03.2018
End date of the project: 31.12.2020
Total project costs (EUR): 879’781
Funding (EUR): 543’773

Table 3 NEXT-FOIL coordinator contact details:

Short name of organisation	AIT
Full name of organisation	AIT Austrian Institute of Technology GmbH
Department of organisation	Center for Energy
Type of organisation*	Public research organisation
First and family name of coordinator	Theodoros Dimopoulos
Full address	Giefinggasse 4, 1210 Vienna
Country	Austria
E-Mail	Theodoros.dimopoulos@ait.ac.at
PIC (9-digit Participant Identification Code)	999584128

Photovoltaics (PV), based on organic, inorganic or perovskite absorbers, can be fabricated as lightweight and flexible modules, making them attractive for integration in building façades and consumer products. These PV technologies rely on substrates coated with a transparent electrode of high transparency and low sheet resistance. ITO (indium-tin-oxide) is by far the most common electrode, despite its high cost, poor mechanical stability and low figure-of-merit when applied on flexible substrates like PET.

NEXT-FOIL developed an alternative to ITO-coated PET, based on dielectric/metal/dielectric (DMD) multilayers, sputtered at rates compatible to high-throughput, industrial production. As dielectrics, compounds based on MoOx and TiOx, were used, with electronic properties that allow their use either as anodes or as cathodes in different solar cell architectures. Optimized DMD electrodes offer: (i) better performance/cost figure than ITO, (ii) sheet resistance <10 Ω/sq, without substrate heating during deposition, (iii) unsurpassed stability of the resistance against bending and (iv) adaptability to specific device energetics.

The industrial applicability of the DMD electrodes was demonstrated by their deposition in a fast, roll-to-roll process and by their implementation for the fabrication of perovskite solar cells, with performance similar to that achieved for ITO-coated substrates.

The consortium consisted of the AIT Austrian Institute of Technology, tackling the simulation and experimental realization of the DMDs, Plansee (Austria) that developed the new oxide compound sputter targets and Solaronix (Switzerland) that implemented the developed electrodes in efficient perovskite cells, together with AIT.
The proof-of-concept of continuous manufacturing and the functional validation of the DMD coated polymer substrates opens the doors for industrial applications of flexible PV devices, printed electronics, or flexible OLED displays.

Table 4 NEXT-FOIL results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	Initial value at the start of project	Expected value at the end of project	Reached value
Cost of product (foil)	ITO foil at 30- 200 €/m2 depending on country and performance	Lowering the cost by 20- 30% compared to ITO foil TRL5-6	Reduction of thickness by a factor of 1.5-2, and reduction of material cost by ~20%. The estimated cost reduction exceeds 30% (taking into account the cost of Ag) TRL5-6
New sputter target oxide compounds	Targets mostly metallic, sputtered in reactive atmosphere TRL2-3	New high-refractory metal oxide targets sputtered at DC mode at high rates TRL6-7	New high-refractory metal oxide targets (based on Mo and Ti oxides) sputtered at DC mode at high rates TRL6-7
Foil performance	Resistance 15- 40 Ω/sq with transparency 75%-80% TRL3	Resistance <10 Ω/sq with transparency up to 80% TRL5	Anodes based on MTO and cathodes based on NTO show sheet resistance 5-8 Ω/sq. with transparency up to 75% TRL5
Mechanical stability	Few tens of bending cycles (radius <10 mm) for ITO	5-fold increase of bending stability compared to ITO foil TRL4-5	Bending stability of anodes and cathodes at least 50 times higher than of PET/ITO for bending radii <5 mm TRL5-6
Foil upscaling	No up-scaled DMD foils based on Mo and Ti oxides TRL3	R2R-processed conductive foil implementing DMD anode and cathode TRL6	R2R-processed conductive foil implementing DMD anode and cathode TRL6
Flexible perovskite cell efficiency employing DMD	Available cells on glass TRL2	Perovskite solar cells with efficiency >14% TRL4	Flexible perovskite cells with DMD with efficiency up to ~10% TRL3-4
Perovskite flexible	11.7% for	>10% for flexible	No flexible modules achieved
Module efficiency	Modules on glass substrate. No modules done on flexible foil TRL3	perovskite modules TRL6	

3.1.3 HEAVENLY

Project title: High-efficiency PERT and IBC cell development focussing on paste and CVD optimization for long term stability
Project number: SOLAR-ERA.NET Cofund 1 N° 045
Start date of the project: 01.01.2018
End date of the project: 31.03.2021
Total project costs (EUR): 1’456’964
Funding (EUR): 1’119’890

Table 5 HEAVENLY coordinator contact details:

Short name of organisation	JM
Full name of organisation	Johnson Matthey PLC
Department of organisation	Catalysis and Materials
Type of organisation	Private - LE
First and family name of coordinator	Jonathan Booth
Full address	Blount’s Court, Sonning Common, Reading, RG4 9NH
Country	UK
E-mail	Jonathan.booth@matthey.com
PIC (9-digit Participant Identification Code)	999947102

The aim of the project was to move mature silicon based photovoltaic technology into the realms of low cost/high efficiency systems. Focussing on the development of silver pastes for screen printed contacts, atmospheric pressure chemical vapour deposited (APCVD) passivation layers for p+ or n+ doped regions, and long-term solar cell stability, the project facilitates the transfer of lab proven passivated emitter, rear totally diffused (PERT) solar cell technology to an industrial environment.

The research carried out in this project has led to a contact formation model for silver metallisation pastes on APCVD passivated silicon solar cells. The in-depth study of the etchant composition and its impact on the SiNx etching process has allowed us to tailor the paste composition to the n- and p-PERT cell architectures. APCVD processes were developed, enabling passivation qualities that allow for >22.5% solar cell efficiency with n-PERT architectures. Long-term stability was tested, ensuring the readiness level of the pastes and APCVD films.

UKN will continue to exploit the project results through follow-up projects with industrial partners. The use of APCVD technology will be further developed within the framework of ongoing research projects.

JM is currently involved in a new project with UKN exploring the use of these new silver metallisation pastes in new solar cell architectures, namely TOPCON. We are actively pursuing IP licencing opportunities and commercial partners. We are also exploring where it is appropriate to publish various findings in academic literature. The knowledge gained on tailoring the inorganic / organic component interactions with a high-solid content paste and the surface they were printed on is being applied across a variety of business units at JM, i.e. the production of hydrogen via green methods. Through analysing these samples, the Advanced Characterisation department at the JM technology centre is now able to apply this improved skill set to other research areas being carried out at the technology centre and across the business units.

Table 6 HEAVENLY results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	4-5	6-7	6	22.6% was met with the paste with a commercial firing set up (fine line printing)
Performance / efficiency	Cell 19%	Cell 22.5%	Cell 22.6% on commercial wafers.	Due to the strongly limited lab operation during the Covid-19 pandemic, it was not feasible to reach the efficiency goals experimentally within the consortium. The focus was therefore set on proof of concept and long-term stability (work package 4). Our analysis shows that the pastes, CVD layers and processes developed in this project will allow for the targeted solar cell efficiencies. However, our silver metallisation pastes have been tested by a solar cell manufacturer, they have reported a value of >22.5% solar efficiency on their manufactured wafers.
LCOE in absolute figures	0.50 US Dollar/Wp	0.35 US Dollar/Wp	Too early to comment	Depends on full balance of systems and operating costs which are not covered in this project.
LCOE decrease in %			Too early to comment	Depends on full balance of systems and operating costs which are not covered in this project.
Cost of product				Exploring the potential of licencing IP
GHG emissions decrease in absolute figures (e.g. g CO_2eq / kWh)	19% solar cell saves 66.79 g/m_2	22.5% solar cell saves 79.10 g/m_2 increase in CO_2 saving is 12.30 g/m_2	22.6% solar cell saves 79.45 g/m_2 which gives an additional saving of 0.35g/m_2 over the expected value	Average power of sun at AM1.5 = 1000 W/m2
Material use / savings				Too early to comment

3.1.4 ENMESH

Project title: ENabling Micro-ConcEntrator PhotovoltaicS with Novel Interconnection MetHods
Project number: SOLAR-ERA.NET Cofund 1 N° 075
Start date of the project: 01.02.2018
End date of the project: 31.12.2020
Total project costs (EUR): 757’284
Funding (EUR): 517’995

Table 7 ENMESH coordinator contact details:

Short name of organisation	IES-UPM
Full name of organisation	Universidad Politécnica de Madrid
Department of organisation	ISI Group, Instituto de Energía Solar
Type of organisation	Higher Education Institution
First and family name of coordinator	Ignacio Antón Hernández
Full address	Avda. Complutense, 30, 28040 Madrid
Country	Spain
E-mail	i.anton@ies.upm.es
PIC (9-digit Participant Identification Code)	999974844

The Swiss company Insolight is developing a patented PV module which promises a reduction in LCOE for roof-based solar from 0.16€/kWh to 0.011€/kWh. The system uses an array of micro-solar cells with optics and integrated microtracking to produce a low-profile rooftop-compatible solar system with an independently demonstrated efficiency of over 36%, a 100% efficiency gain over cSi.

This high efficiency is made possible by the use of advanced multi-junction cells under concentrated light, a technology known as concentrator photocoltaics (CPV). Specifically, this product represents one of the first commercial examples of micro-CPV (µCPV), wherein the cells are 1mm2 in size or less. µCPV increases performance (due to reduced cell operating temperature, higher optical efficiency and lower series resistance losses) and lowers manufacturing costs. Insolight innovation has further improved the µCPV concept by embedding sun tracking internally in a 50mm-thick panel, enabling roof-top or BIPV installations and avoiding bulky and expensive trackers.

An outstanding technological challenge in µCPV is the need to use massive cell interconnection processes due to the large number of micro-cells involved, 5000 cells/m2 for the Insolight module. The current state of the art is wire bonding, however this inherently serial process is prohibitive for thousands of cells.

The Universidad Politécnica de Madrid, in collaboration with Dycotec Materials Ltd, offer an innovative cell interconnection process involving direct printing of ultra-durable nano-particle coating systems to allow the massively parallel connection of solar cells in a cost-effective high volume roll-to-roll or sheet fed printing process, paving the way for the low-cost manufacture of µCPV.

Under the specifications of the company Insolight solar cell plane and full board prototype containing a total of 143 micro-solar cells was interconnected. The full board is on a glass substrate being semi-transparent for applications with hybrid-PV or agrivoltaics. The final prototype reached equal results as the standard technology using wire-bonding, but with a far cheaper process. TRL6 was achieved for the technology developed in this project.

Finally, the ENMESH project was the transnational team's first collaboration and the seed of the Hiperion project (H2020-LC-SC3-2018-2019-2020).

Table 8 ENMESH results, targets and achievements – technological, economic, environmental and other indicators

Indicator	Initial value at start of project	Expected value at the end of project	Reached value
Transparent conductive inks TRL progress	1	6	TRL5 Highlight transparent conductive with overcoat with demonstrated durability. Considerable formulation knowledge gained as basis for product release/development across multiple sectors.
NCI TRL progress	3	5-6	SNW coatings: TRL4 to TRL5 NCI based on SNW: From TRL3 to TRL4 NCI based on NWL process: From TRL3 to TRL6 (performance comparable to wire bonding) 1mm² Inverted metamorphic solar cells for micro-CPV: TRL4 to TRL6 (first successful application of these solar cells in CPV)
Performance / efficiency	Minimodule efficiency 36.4%	Minimodule efficiency >35.7%	For minimodule - Current efficiency for a large module is 29% Concentrator Standard Test Conditions Reached value is calculated from I-V curves on final prototype board with a form-factor of 76%, as no minimodule could be manufactured. With a form-factor of 82% (reached for a single cell on the board) and only considering the working rows of the full board the efficiency would be around 37%
LCOE in absolute figures	Expected: 12.2 €cents/kWh	Expected: 10.9 €cents/kWh	A residential rooftop solar system use case in France, over 20 years without incentives.
LCOE decrease in %	Expected: 25%	Expected: 32%	A residential rooftop solar system use case in France, over 20 years without incentives.
Cost of product	Objective: 775€/m2 Cell interconnection: 50€/m2	Objective: 692€/m2 Cell interconnection: 3€/m2	3€/m2 for the NCI-NWL

3.1.5 RHINO

Project title: Realization of High efficiency Industrial N-type sOlar cells
Project number: SOLAR-ERA.NET Cofund 1 N° 78
Start date of the project: 01.01.2018
End date of the project: 31.03.2021
Total project costs (EUR): 2’232’954
Funding (EUR): 1’377’153

Table 9 RHINO coordinator contact details:

Short name of organisation	Fraunhofer ISE
Full name of organisation	Fraunhofer Institute for Solar Energy Systems ISE
Department of organisation	Production Technologies - Surfaces and Interfaces
Type of organisation	Public research organisation
First and family name of coordinator	Andreas Wolf
Full address	Heidenhofstr. 2, 79110 Freiburg
Country	Germany
E-mail	Andreas.wolf@ise.fraunhofer.de
PIC (9-digit Participant Identification Code)	999984059

This project targeted the development of an industrially feasible manufacturing approach for an n-type cell structure that has demonstrated above 25% efficiency in a cleanroom environment. Key elements of the cell structure are an advanced or selective boron-doped emitter and a full area passivated rear contact, fabricated by low-pressure chemical vapour deposition of an in-situ phosphorous doped polysilicon layer on top of a thermally grown interface oxide. For these key elements, production capable processes and high throughput production tools have been developed and implemented in a lean solar cell production process. Both the implementation of the passivating rear contact and reducing the front carrier recombination losses by the development of advanced emitter from BBr_3 diffusion increased the efficiency of the developed industrial solar cell from 21% to 22,3% while using screen printed metallization and established production equipment.

The formation of a selective emitter structure, which is realized by laser-doping from the borosilicate glass, which is present on the wafer surface after thermal diffusion, has been intensively studied. A low contact resistance below 2 mΩcm² and a junction depth of > 1 µm could be demonstrated. However, within the project it was not possible to demonstrate an advantage of the laser-doped selective emitter over advanced homogeneous emitters with increased junction depth. High reflection losses at the laser-treated area was identified as one of the main challenges. Instead, advanced homogeneous emitters were developed. These diffusion processes enable recombination parameters of J_{0e} < 15 fA/cm² (textured, Al_2O_3/SiN_x-passivated) at industrially relevant process times of 2 hours. Further optimization of the BBr_3-process yielded a junction depth > 1 µm, which effectively reduces metallization induced recombination and these processes were successfully implemented in the solar cell process.

Test modules fabricated from these bifacial cells demonstrated high bifaciality factors of ~85%, still outperforming current passivated emitter and rear (PERC) modules in terms of bifacial properties. Modelling of bifacial module operation enabled a reliable prediction of energy yields depending on system configuration and ambient conditions.

The project contained partners from a research institute, a manufacturer of diffusion and polysilicon deposition furnaces, a laser system specialist and a module manufacturer. They all brought into this project their expertise that enabled to reach almost all the project goals. Based on the project results, follow-up projects were able to further push the development of industrial TOPCon solar cells at Fraunhofer ISE and the industry partners leading to current solar cell efficiencies of up to 23,8% at Fraunhofer ISE. Further exploitation is under way at Fraunhofer ISE with planned industry projects to transfer the developments.

Table 10 RHINO results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	4-5	5-6	5-6	
Performance / efficiency	Cell efficiency 20,7%	Cell efficiency 22,5%	Cell efficiency 22,3%	Additional development necessary at ISE for setting up the LPCVD process
Performance / efficiency	Module bifaciality ~70% (PERC)	Module bifaciality 90%	Module bifaciality 80%	Due to high parasitic absorption in the rear poly-Si layer and high thickness of this layer required for screen printed metallization, cells and modules feature a bifaciality of only ~80%
Performance / efficiency	Bifaciality gain 30%	Bifaciality gain >50%	Experimental Bifacial gain of 21.5% 35% can be reached under optimal though unrealistic condition for large scale project	Due to the limitations of our test setup: Albedo < 70%, low module height 0.3m and high μ-inverter clipping. The bifacial gain is only slightly over 20% compared to monofacial PERC. However, these parameters allowed us to verify the theoretical results. With ideal parameters (Albedo > 85%, module height of 1m, low inverter clipping and all module chains in parallel), the bifacial gain would have reached 35%.
Cost of product	Laserdoping 1.5€ct/Wafer	Laserdoping <1€ct/Wafer		
Cost of product	BBr3-Diff. >1.5€ct/Wafer	BBr3-Diff. <1.5€ct/Wafer	BBr3-Diff. 0.705 €ct/wafer	

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3.2 Advanced PV products and applications

3.2.1 BI-FACE

Project title: High-efficiency bifacial PV Modules and Systems for flat roof applications
Project number: SOLAR-ERA.NET Cofund 1 N° 028
Project website: https://www.ait.ac.at/themen/photovoltaics/projects/bi-face/
Start date of the project: 01.03.2018
End date of the project: 30.09.2020
Total project costs (EUR): 1’093’712
Funding (EUR): 858’070

Table 11 BI-FACE coordinator contact details:

Short name of organisation	AIT
Full name of organisation	AIT Austrian Institute of Technology GmbH
Department of organisation	Center for Energy
Type of organisation*	Non-profit research organisation
First and family name of coordinator	Shokufeh ZAMINI
Full address	Giefinggasse 4, 1210 Vienna
Country	Austria
E-mail	Shokufeh.Zamini@ait.ac.at
PIC (9-digit Participant Identification Code)	999584128

The scope of the project BI-FACE was to develop innovative bifacial modules and systems for flat roofs to exploit the enormous potential of this technology. The results included three novel variations for bifacial modules and systems which were tested in three different climate zones: subtropical (Cyprus), temperate (Austria, 2 sites) and maritime temperate (The Netherlands, 2 sites). The ultimate design of these systems was challenging due to the large number of parameters that influence the energy yield (tilt and distance between modules, reflecting surfaces, shading, cell spacing, materials used and weather conditions).

A holistic approach to energy performance took the aspect of standardization into account. This standardization was not available at the beginning of the project for bifacial modules, hindering rapid market introduction. Therefore, critical efforts were put in to harmonize performance characterization of bifacial PV modules in a factory and laboratory setting and correlate this with the outdoor performance. The results were communicated with the standardization committees.

The layout and mounting design of a bifacial system was critical to obtain the maximum possible performance on flat roofs. The construction demands with respect to wind load, stability, total weight (incl. ballast) and maximum allowed weight on a roof were directly influenced by ballast design and needed to be critically examined in parallel. The intended approach compared theoretical investigations with tests in the laboratory and in the field.

Performance simulations of bifacial modules and systems were developed and compared to laboratory and in field test results. Finally, all innovations were collected, synthesized and validated on a flat roof where the need for lightweight was an additional challenge.

The project BI-FACE aims to develop technically as well as economically novel bifacial PV systems to exploit the enormous potential of this technology. Also, the customer of the “aesthetically beautiful” modules will be in favour of the project BI-FACE.

The expected main results of the project were achieved:
- Novel lightweight bifacial modules and systems for flat roofs for representative climates in Europe
- Innovative, comprehensive models for design and installation of bifacial modules and systems including construction requirements
- Novel manufacturing strategies
- New performance and characterization measurements
- Innovative mounting structures

Table 12 BI-FACE results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	3	7	9	There was a big jump from the beginning of the project to the end in bifacial technology
Performance / efficiency	-	+20%	+20%	Yield increase in comparison to mono-facial systems by up to 20% were achieved according to the results. The original 30% yield increase cannot be realized with light roofs, since the PV-System is not allowed to have a higher height. The higher the system, the heavier it will be, and this is not in coincident with the rules of light roofs.
LCOE in absolute figures			0.062 €	The simple LCOE calculation was done based on: life-cycle cost of solar project/lifetime energy production of solar project
LCOE decrease in %			11.4%	LCOE decrease is in comparison to monofacial black non-transparent backsheet LCOE, which was 0.070 €
Cost of product			195€	Bifacial 310Wp modules (2x2 mm Glass-Glass)
Material use / savings				20% increase yield, saves at least 20% material in comparison with mono-facial systems
Standards	Lack of standards for bifacial modules	Standards to standardization committees	Contribution of Austrian representative in TS	

3.2.2 CEFRABID

Project title: Clean energy from road acoustic barriers infrastructure development
Project number: SOLAR-ERA.NET Cofund 1 N° 043
Start date of the project: 01.09.2018
End date of the project: 30.11.2020
Total project costs (EUR): 451'613
Funding (EUR): 387'626

Table 13 CEFRABID coordinator contact details

Short name of organisation	GIG
Full name of organisation	Główny Instytut Górnictwa
Department of organisation	Department of Acoustics, Electronics and IT Solutions - BR
Type of organisation*	Public research organisation
First and family name of coordinator	Zbigniew MOTYKA
Full address	40-166 Katowice, Plac Gwarków 1
Country	POLAND
E-mail	z_motyka@wp.pl
PIC (9-digit Participant Identification Code)	999516616

The CEFRABID project concentrated on advanced photovoltaic (PV) product applications in road and rail (r&r) transport infrastructure. It also focused on related grid integration with noise barriers and passenger stop shelters along local r&r infrastructure for needs of powering this infrastructure, e.g. for signalling, lighting of neuralgic sections of roads and rail platforms, including r&r crossings and, last but not least, warming or cooling passenger stop shelters of special innovatory design.

The focus was on innovative manufacturing of end solutions for r&r infrastructure integrated PV systems. The following issues were addressed and goals pursued:

- Dimensional and outlook flexibility with customised sizes, shapes and colours, freeform module technology, and bifacial (especially for N-S oriented r&r) solar cells and modules, electrical design for energy output optimization: shadows, various tilt and orientation angles, safety issues, all of which had been part of extended preliminary tests at specialized Partner's facilities of their different configurations, including both laboratory tests, as well as outdoor tests on partially movable platforms (PMPs).
- Holistic approach for the energy performance, enabling accumulation of energy for night or worsening weather conditions periods, assuming also backup power supplies from conventional electric grid in emergency states.
- Easiness of installation/application based on modular designs of largely independent and self-sufficient Hybrid PV Noise Road (Rail) Barriers' (HPVNRBs) modular sections, which may be easily prolonged and included in the grid (in series when independent, and in parallel layout for mutual replacement needs).

The traditional road transport infrastructure will be supplemented with the help of these new solutions for HPVNRBs and other surfaces of r&r infrastructure, using innovative and reinforced PV products.

Table 14 CEFRABID results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	Initial value at the start of project	Expected value at the end of project	Reached value	Further information
TRL progress	4-5	6-7	6-7	The in situ durability tests and appropriate final costs of admissions of prototype solutions will be needed for achieving TRL8
Performance / efficiency	Separate PV and acoustical Modules efficiency (20%, 34 dB)	Complex HPVNRB Module efficiency (18%, 31dB)	Insulation class B2 15-24 dB	Such acoustical efficiency was measured for short (8 m long) in situ noise PV road barrier at ML System location. To obtain the actual value the development of full dimensional (of prolongated length) PV road noise barrier will be necessary.
LCOE in absolute figures	9 €cents per kWh	10 €cents per kWh	7.3 €cents per kWh Cost for 4 m long (2 PV panels within HPVNRB prototype with electrical equipment)	Explain reference system (including location / irradiance)
LCOE decrease in %		min. 15%	18%	Corresponds to proportional reduction of average PV part installation costs using advantages of noise barrier as the ready-to-use (or only slightly modified) PV support (in most cases without necessity of additional stiffening aluminium frames).
Cost of product	Cost of Separate PV and acoustical Modules	75% Cost of Separate PV and acoustical Modules	75%-100% costs of separate PV + separate acoustical Modules	Additional cost of PV panels with electrical equipment per 1 m of noise barrier has to be differentiated for different solutions (e.g., close to 100% with PV panels added/attached to the noise barrier or by replacing part of its insulating transparent filling – reduction up to 75% of total separate costs)
GHG emissions decrease in absolute figures (e.g. g CO_{2eq} / kWh)	800 g CO_{2eq} / kWh (PL) 440 g CO_{2eq} / kWh (E)	800 g CO_{2eq} / kWh (PL) 440 g CO_{2eq} / kWh (E)	800 g CO_{2eq} / kWh (PL) 440 g CO_{2eq} / kWh (E)	Decrease to 725 g CO_{2eq} / kWh in PL, when project results finally will be applied to all express roads (1600 km), highways (1600 km) and railways (18500 km) in PL (Poland), only.

Material use / savings	Materials for Separate PV and acoustical Modules	75% of Materials for Separate PV and acoustical Modules	75%-100% of Materials for Separate PV and acoustical Modules	Up to 50% of costs of acoustical noise protection panel fill replaced by PV panels in the case of most material effective Cyprus solution (and 25% in the case of GIG solution) has to be differentiated for different solutions (e.g., close to 100% with PV panels added/attached to the noise barrier or by replacing part of its insulating transparent filling – reduction up to 75% of total separate costs depending on the sort of applied otherwise noise protection material).

3.2.3 PanelPV

Project title: Sandwich panels with integrated PV with freedom of size and color
Project number: SOLAR-ERA.NET Cofund 1 N° 511
Start date of the project: 01.01.2018
End date of the project: 31.12.2020
Total project costs (EUR): 965’198
Funding (EUR): 619’602

Table 15 PanelPV coordinator contact details

Short name of organisation	TNO (former ECN, now part of TNO)
Full name of organisation	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek
Department of organisation	Solliance
Type of organisation*	Public research organisation
First and family name of coordinator	Veronique Gevaerts
Full address	High Tech Campus 21, 5656 AE Eindhoven
Country	The Netherlands
E-mail	veronique.gevaerts@solliance.eu
PIC (9-digit Participant Identification Code)	999988715

The project PanelPV aimed at the development of new façade elements with integrated PV. Starting components are sandwich panels made by Panelen Holland and CIGS based PV foil made by Flisom that were integrated into new power generating façade elements. Translucent PV films were developed to allow for colour coming from the outside of the sandwich panel. This gives the producer of the sandwich panels full freedom in colour or print selection. This is an impressive achievement, especially in view of the often observed shunting that can be induced by such laser patterning steps.

The project has fabricated a demo façade at Panelen Holland in which several sandwich panels having two different sizes and with different colours were integrated. Kiwa BDA established a knowledge base related to the product properties, the construction and product regulations.

Table 16 PanelPV Results, targets and achievements – technological, economic, environmental and other indicators

Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	4	7	5-7	Due to bankruptcy of SunPartner the laser processing of the PV foil could not be shown in an industrial way (beyond TRL5). PV foil fabrication and sandwich panel fabrication are > TRL7.
Performance / efficiency	-	>40% at 50% translucency	50%	Compared to original efficiency of the PV module, only loss in current due to removal of area by translucency.
Power output	-	50 Wp/m2	-	In full colored sandwich panel; due to travel of unprotected modules no power output was obtained in the full sandwich panel.
Throughput	-	1 m_2/hr	> 1 m_2/hr	Number for the shunt free laser ablation process on a pilot scale roll2roll process – note: not possible on roll2roll due to bankruptcy SunPartner. Laser ablation speed however can easily be obtained in industrial setting.
Cost of product	200 €/m2	100 €/m2	100 €/m_2 is achievable	Cost at start of project is estimated. Expected value is using design for large scale production (not planned in the project). The value is difficult to assess due to the lack of an industrial partner for the laser processing, however 100 €/m_2 should be achievable. The additional cost of the translucent PV should be below 80 €/m_2 according to assessment of the business plan of Panelen Holland.

Successful development of this product will open a big potential market for Flisom PV foils being installed in many façades in the Netherlands, as well as any other geographical area were Panelen Holland is having distribution channels.

Regarding technology progress, a new patent is being drafted by TNO on the development of the laser processing of Flisom PV foil including the removal of the polyimide substrate for translucent modules. These can be integrated in the sandwich panel as is the goal of this project but can also serve different purposes where translucency and power generation can be combined such as skylights and office windows.

The SOLAR-ERA.NET Cofund Action is supported by funding from the European Union's HORIZON 2020 Research and Innovation Programme.

3.2.4 MasterPV

Project title: Innovative manufacturing solutions for cost-efficient semitransparent BIPV
Project number: SOLAR-ERA.NET Cofund 1 N° 024
Start date of the project: 01.09.2018
End date of the project: 31.07.2021
Total project costs (EUR): 562'931
Funding (EUR): 479'422

Table 17 MasterPV coordinator contact details:

Short name of organisation	IREC
Full name of organisation	Institut de Recerca de l'Energia de Catalunya
Department of organisation	Solar Energy Materials & Systems Group
Type of organisation*	Public research organisation
First and family name of coordinator	Victor Izquierdo
Full address	C Jardins de les Dones de Negre 1, 2a planta 08930 Sant Adrià de Besòs (Barcelona), Spain
Country	Spain
E-mail	vizquierdo@irec.cat
PIC (9-digit Participant Identification Code)	996435993

MasterPV has addressed the development of innovative transparent back contacts in $Cu(In,Ga)Se_2$ (CIGS) solar cells for cost efficient semi-transparent modules. CIGS semi-transparent modules can be achieved with transparency levels up to 30%-40% by selectively removal of part of the absorbers in the devices. However, the optical quality of state-of-the-art devices is strongly compromised by the presence of a Mo back contact that is currently used in the CIGS device architecture.

The project has involved the replacement of the Mo back contact in the traditional CIGS device architecture by chemical vacuum-free based TCO (Transparent Conductive Oxide) electrodes. This will allow achieving a significant improvement in the aesthetic quality of the semi-transparent devices, with the elimination of the back mirror effect that is determined by the remaining Mo regions in the semi-transparent modules. Use of chemical based processes for the fabrication of the back contacts will also allow a reduction of the manufacturing costs, because of the replacement of the expensive vacuum-based Mo sputtering deposition processes by lower cost approaches that are based in vacuum-free chemical processes.

The main scientific challenge achieved in the project is related to the development of optimal transparent back contact configurations allowing for solar cell efficiencies comparable to the high efficiency values that have already been achieved in CIGS technologies with the standard Mo based back contacts. This has required a special effort in the optimization of TCO based contacts suitable for high efficiency devices, which has been based on the development of back contact configurations including nanometric sized functional layers deposited onto the TCO back contact. Optimal back contact configurations identified in the project correspond to the use of chalcogenide (MoSe2, MoS2) nanometric functional layers and ITO as the TCO.

The SOLAR-ERA.NET Cofund Action is supported by funding from the European Union's HORIZON 2020 Research and Innovation Programme.

The main technological challenge is related to the implementation of low cost vacuum-free ink-jet printing processes for the growth of the optimal ITO based transparent back contacts configurations and to the adaptation of these processes for the fabrication of efficient semi-transparent CIGS modules. At commercial level, the improvement of the aesthetic quality of the semi-transparent modules and the decrease of their cost will contribute to the consolidation of CIGS as one of the main commercial technologies able to answer the increasing demand of cost-efficient and reliable semi-transparent products in the BIPV market. This will allow the development of semi-transparent modules with higher optical quality and combining the high efficiency and high stability characteristic of CIGS solar cells.

Table 18 MasterPV results, targets and achievements – technological, economic, environmental and other indicators:

Issue / Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	4-5	6-7	5-6	The project has allowed achieving a final TRL value 5-6, with the assessment and demonstration at real world outdoor conditions of an operational semi-transparent module prototype
Efficiency	Device efficiency ≤ 56% of efficiency reached in reference Mo-based CIGS devices	Cell/Module efficiency > 80% (70%) of efficiency reached in reference Mo-based CIGS devices	Cell efficiency > 80% of efficiency reached in reference Mo-based CIGS device. Chemically based cell efficiency > 65% of efficiency reached in reference Mo-based CIGS device.	MasterPV has allowed the demonstration of optimised back contacts leading to device efficiencies ≥ 80% (for vacuum based processes) and ≥ 65% (for vacuum-free processes) of the efficiency achieved with reference Mo-based CIGS devices.
Performance	a-Si based products with 20%-30% transparency in visible region	Medium size CIGS modules with 20-30% transparency in visible region	Mini-module prototypes with 10%-35% transparency in visible region.	The project has allowed the demonstration of mini-module CIGS operational prototypes (with sizes up to 10x10 cm2) with 10% - 35% transparency and improved efficiency in relation to that achieved with a-Si based products that are now available in the market.

3.2.5 Cover Power

Project title: Smart Glass Coatings for Innovative BiPV Solutions
Project number: SOLAR-ERA.NET Cofund 1 N° 030
Start date of the project: 01.10.2018
End date of the project: 30.09.2021
Total project costs (EUR): 438’213
Funding (EUR): 233’166

Table 19 Cover Power coordinator contact details

Short name of organisation	JR
Full name of organisation	JOANNEUM RESEARCH Forschungsgesellschaft mbH
Department of organisation	Materials – Institute for Surface Technologies and Photonics
Type of organisation*	Private – Non-profit research organisation
First and family name of coordinator	Dr. Roman Trattnig
Full address	Franz-Pichler-Straße 30, 8160 Weiz
Country	Austria
E-mail	roman.trattnig@joanneum.at
PIC (9-digit Participant Identification Code)	999981537

From many research & development activities on PV module applications it has been found in recent years that the optical appearance of PV modules is mainly determined by the outer side (environmental side) of the cover glass of the modules. In particular, reflections of the incident light on the cover glass surface are essentially responsible for the overall optical perception of the modules. It is precisely this fact that makes it difficult to effectively tune the aesthetics of a photovoltaic module, for example by changing the colour of the solar cells used. In contrast, it is more promising to modify the surface that is mainly responsible for the optical perception to match the design: the outer surface of the cover glass.

The project Cover Power addressed exactly this challenge. By combining different kinds of glass coating technologies, the project results allow for new degrees of freedom for the design of PV modules for BiPV solutions.

In detail, the coatings, applied were characterized optically and their chemical and physical stability was investigated. The durability of these coatings was further evaluated by performing environmental simulations and accelerated aging tests were performed on test modules to assess their performance stability.

The results show an efficient colouring of BiPV modules and also address a problem that in the past has proven to be an obstacle for some facade-integrated BiPV projects: glare. As outcome of the project prototypes of BiPV modules were developed, that are based on the typical glass-glass PV module technology in combination with Si solar cells by applying novel glass coatings to the outer side of their cover glasses.

These module prototypes feature the following properties:
- Flexible and innovative design in terms of colour and surface texture
- Minimum glare (less than 0.1% of specular reflection)
- At least 150 W/m² (STC) by exploiting back reflected light in bi-facial cells
- Aging and adhesion of surface coatings are reliable for at least 30 years

A further outcome was the realization of a BiPV installation in a façade and a roof to demonstrate the feasibility of the developed module prototypes. This installation will be operated by echoch2 beyond the end of the project.

In addition, ertex-solar as well as Joanneum Research are planning further activities as follow-up to the project Cover Power: The screen printing technology in particular has proven itself in use under real life conditions. Here, ertex-solar plans to continue the concept of screen printing with a special ink that incorporates colouring particles for a more vivid colour impression and higher module efficiency. In addition, this ink allows for a homogeneous overall appearance for a facade or roof installation.

Joanneum Research is planning further cooperative research activities in the field of sol-gel coating. The focus will be primarily set on increasing the stability of the coating with respect to weathering and to develop an industrially applicable and automated coating process together with an industrial partner.

Table 20 Cover Power results, targets and achievements – technological, economic, environmental and other indicators

Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	4-5	6-7	7	
Performance / efficiency	Module efficiency 13%	Module efficiency 15%	14%	Performance of the modules in this work were limited by the low efficiency of 16% of the reference modules. Using modules with a standard efficiency of 20%, a performance of >16% can be expected for modules coated with the presented technologies.
Coated Module Power	< 130 W/m2	> 150 W/m2	100-155 W/m2	STC Conditions – Depending on the respective coating. Optimized coatings were selected for further use.
Surface glare (specular relection)	4-8 %	0.1 %	0.01-2%	Depending on the respective coating.
Power loss due to coating	> 20%	< 10 %	7-40%	Depending on the respective coating

3.2.6 NELL

Project title: Novel Encapsulant For Long Lifetime High Voltage Pid-Resistant Pv Modules
Project number: SOLAR-ERA.NET Cofund 1 N° 077
Start date of the project: 01.01.2018
End date of the project: 31.12.2019
Total project costs (EUR): 533’675
Requested funding budget (EUR): 417’835

Table 21 NELL coordinator contact details:

Short name of organisation	STR
Full name of organisation	Specialized Technology Resources España S.A.
Department of organisation	R&D
Type of organisation*	SME
First and family name of coordinator	Roman Merino
Full address	Parque Tecnológico de Asturias,Parcela 36, 33428 Llanera
Country	Spain
E-mail	Roman.merino@stresp.com
PIC (9-digit Participant Identification Code)	929801164

Photovoltaic energy already plays a key role in the global energy market, and it is expected that it will meet 20% of the EU electricity demand in 2030. The PV industry in Europe has lost market share in the last years due to strong competition from Eastern producers. Europe has nevertheless maintained the scientific and technical leadership and should take advantage of this to further increase efficiency and reliability of PV systems, contributing thus to strengthen the competitiveness of the European PV industry and to accelerate PV deployment in Europe.

One solution to decrease system costs which is being demanded by the market is the transition to high voltage systems up to 1500 V and beyond. Higher voltage can yield to system cost savings between 3 and 10% by reducing BOS components and increasing DC yield.

High voltage, however, also implies a higher risk for potential induced degradation (PID) of PV modules. This, in turn, requires the development of new materials for PID-free PV module certification which ensure high reliability and do not increase significantly the module cost. The main goal of the NELL project is precisely to develop a highly PID-resistant encapsulant able to avoid PID even under harsh humidity and temperature conditions in high voltage systems up to 1500 V. The project will thus significantly contribute to the SET-plan goal of reducing the levelized cost of electricity by 20% in 2020, at the same time as ensuring 30 years lifetime with a guaranteed 90% power output.

The NELL consortium has a strong industry participation and is formed by entities with a very long trajectory in PV in Europe. It is led by STR, global leader in encapsulant development for the PV industry, who has strategically partnered with ZSW, technology center who has played a key role in the understanding and measurement of the PID phenomenon in recent years.

Table 22 NELL results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	4-5	6-7	7-8	Two new encapsulants ready for certification test: TRL8 New testing procedures for high load PID: TRL7
LCOE in absolute figures	9,3 € cents per kWh	7,8 € cents per kWh	8,4 € cents per kWh (average scenario)	The reference system is a 10 MW park located in Murcia (4.82 kWh/m2/day of global irradiation) with 1500 VDC.
LCOE decrease in %	-	15%	5-15%	The LCOE decrease is 15% in the optimistic scenario considering a reduction in CAPEX of 10% and a reduced degradation rate, due to elimination of PID, which could lead to a further 5% reduction in the LCOE.
Increase in cost of product (encapsulant)	-	Under 5%	0%	The cost of the product has not changed significantly with respect to existing formulations.
Durability	Power output of 80% after 25 years for 1000 V installations	Power output of 90% after 30 years for 1500 V installations	Power output of 90% after 30 years for 1500 V installations	Extended reliability tests have been conducted including 3000 hours damp-heat with successful results.

3.3 PV system integration

3.3.1 1500-SIC

Project title:Develop a new photovoltaic inverter with SiC for full power operation at 1500V
Project number: SOLAR-ERA.NET Cofund 1 N° 054
Start date of the project: 01.03.2018
End date of the project: 30.06.2020
Total project costs (EUR): 1'654'443
Funding (EUR): 728'875

Table 23 1500-SIC coordinator contact details

Short name of organisation	GAMESA
Full name of organisation	GAMESA ELECTRIC, S.A.
Department of organisation	R&D POLICIES AND PUBLIC FUNDING
Type of organisation*	PRIVATE - LE
First and family name of coordinator	LUCÍA PARIS
Full address	PARQUE TECNOLÓGICO DE BIZKAIA, EDIFICIO 100, 48170 ZAMUDIO
Country	SPAIN
E-mail	LUCIA.PARIS@SIEMENSGAMESA.COM
Phone number	0034 948771000
PIC (9-digit Participant Identification Code)	921858222

The aim of 1500-SIC was to develop enabling power electronics solutions capable of delivering nominal power at 1500 V with very high efficiency and high volumetric power density at competitive cost. The consortium includes Gamesa Electric from Spain, worldwide supplier of PV inverters; Infineon Technologies Austria, worldwide supplier of semiconductors for power electronics; and ETH Zurich Advanced Power Semiconductor Laboratory from Switzerland, a world-class research centre focused on semiconductor devices and power modules. Specifically, the consortium has worked together to develop a novel Silicon-Carbide diode and a MW-class inverter optimized to deliver nominal power at voltage levels up to 1500 V. The developed technologies have been built and tested at full scale through a comprehensive testing campaign.

The consortium includes key industrial actors in the supply chain of power electronics for PV solutions and a research centre. This maximizes the impact of the R&D outcomes of this programme into the European Renewable Energy Industry.

The SOLAR-ERA.NET Cofund Action is supported by funding from the European Union's HORIZON 2020 Research and Innovation Programme.

Table 24 1500-SIC results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	4 for Inverter 3 for Diode	6 for Inverter 5 for Diode	6 for Inverter 5 for diode	A handful of inverter prototypes have been validated and certifications is ongoing. Diode technology was successfully developed into a test sample status being usable by system engineers in real applications.
Power density		10% improvement over baseline	8%	The new inverter is outdoor (the baseline was indoor), which has a negative impact in power density.
Máximum voltage	Inverter deliver nominal power below 1300V	Deliver nominal power at 1500 V	1350V	1500 V will be achieved in 2021, in the framework of a new project already in progress.
Cost of product		Cost / kW compared to baseline solution	10%	The new inverter achieves a 10% reduction in cost / kW.
Efficiency when providing reactive power for grid supporting		Efficiency improved with respect to baseline	+0.5% absolute efficiency	CEC (California Energy Commission) efficiency has already been certified: 99.3%.
Cosmic Ray performance analysis	Limited understanding of influence of cosmic ray on FIT rates of inverter	Understanding and root cause analysis of cosmic ray performed	FIT established.	FIT comparable to Si devices; root-cause of failure is anode-cathode short.
Efficiency of power module		30% efficiency improvement of power module over baseline	21% at 1kA, 42% at 200A.	Total switching losses are reduced by 21 – 42 % of previous Si-based technology (depending on current).
Tolerance of power module to cosmic radiation		Reduction of FIT due to cosmic radiation compared to baseline		Comparable FIT rate based on similar FIT-rate at device level expected, but not tested directly.
Testing at full scale		Inverter tested at full scale validating the achieved improvements	Yes	

The SOLAR-ERA.NET Cofund Action is supported by funding from the European Union's HORIZON 2020 Research and Innovation Programme.

3.3.2 Erigeneia

Project title: Enabling rising penetration and added value of photovoltaic generation by implementation of advanced storage systems
Project number: SOLAR-ERA.NET Cofund 1 N° 58
Start date of the project: 02.05.2018
End date of the project: 22.10.2021
Total project costs (EUR): 655’570
Funding (EUR): 544’807

Table 25 Erigeneia coordinator contact details:

Short name of organisation	UCY
Full name of organisation	University of Cyprus
Department of organisation	FOSS Research Centre for Sustainable Energy, Electrical and Computer Engineering
Type of organisation*	Higher Education Institution
First and family name of coordinator	Dr. George Georghiou
Full address	Panepistimiou 1, Aglantzia, 20537, 2109 Lefkosia
Country	Cyprus
E-mail	geg@ucy.ac.cy
PIC (9-digit Participant Identification Code)	999835843

The Erigeneia project targeted to enable the high penetration of PV technology and to utilize its potential value in the energy system by developing a local and central energy management system (EMS) that will combine photovoltaics (PV) with battery energy storage systems (BESS). The project matched the technical requirements imposed by the distribution system operators (DSO) with the upcoming new market regulations, capitalising on the positive effects of PV and BESS combination. In addition, a tool for intra-hour energy forecasting was developed and integrated into the EMS to provide a more accurate and reliable operation plan for the DSO. Finally, a versatile algorithm capable of estimating the optimum size of BESS and PV to meet all the needs of prosumers was also developed. Field trials took place in Cyprus (residential EMS) and Turkey (community EMS) and novel or more effective ancillary services were provided to the network operators (e.g. power smoothing, voltage regulation). Finally, the economic impact of the proposed solutions was quantified.

The work is expected to have significant impact on the further penetration of PV given that the existing grid infrastructure will be utilized in a more efficient way, by increasing the hosting capacity hence deferring grid reinforcement. By promoting grid-friendly self-consumption of PV generation, grid congestion issues will be avoided. Since the EMS will increase the power usage predictability, the current expensive power reserves will be replaced by the local EMS control strategies of the combined PV and BESS EMS. Furthermore, the users will take advantage of the provided flexibility in order to lower their cost of electricity, by gaining from the new upcoming policies of Time of Use (ToU) and dynamic tariffs.

The project was fully in line with the SET plan for effective integration of solar energy technologies in the energy system.

Table 26 Erigeneia results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	3	6-7	7	The solution was tested in the lab and at pilot sites.
Rate of change of power	-	<10%/min	9%/min	It was not feasible to reduce it lower than 9%/min at the pilot site test.
Hour-ahead forecasting	-	5% RMSE	9% for day-ahead 13% for hour-ahead	The hour-ahead forecasting was only studied theoretically by AIT due to the lack of data from the pilot sites, i.e. more pilot sites were required to implement it. It could achieve an RMSE of 13%. Instead, the day-ahead forecasting from UCY was implemented with an RMSE of 9%. The day-ahead was predicting the PV generation for every hour in the next 24 hours.
LCOE				Development of the sizing algorithm for the BESS
Increase of the hosting capacity for PV	-	>50% of local generation for the particular use cases	-60.5%	The PV energy export to grid was reduced by -60.5% on average. With this energy reduction, the reduction of the peak PV power injected into the grid was higher than 50%. This exceeded the KPI target of 50% reduction of the local PV power generation.
Increase of self-consumption	-	>50% reduction of energy consumption	-33.9%	The energy import from the grid (energy consumption) decreased by 33.9% on average. To meet the 50% target, a PV and/or BESS with higher capacity was required depending on the load profile of each pilot site.
Distribution losses reduction	-	Min. 10% loss reduction	-30.8%	Due to the local energy storage in the BESS at the residential pilot sites, the grid distribution feeder losses were decreased by 30.8% on average. For the central pilot site, the grid losses remained practically the same.
Demonstration of proposed solutions in real environment	-	1 central + 5 prosumers	1 central + 5 prosumers	1 central in Turkey and 5 residential prosumers in Cyprus.

The SOLAR-ERA.NET Cofund Action is supported by funding from the European Union's HORIZON 2020 Research and Innovation Programme.

3.3.3 PVTOOL

Project title: Development of tools for effective control of large PV power plants
Project number: SOLAR-ERA.NET Cofund 1 N° 76
Project website: https://pvtool.eu/
Start date of the project: 01.09.2018
End date of the project: 31.10.2021
Total project costs (EUR): 1.228’538
Requested funding budget (EUR): 951’003

Table 27 PVTOOL coordinator contact details:

Short name of organisation	CITCEA-UPC
Full name of organisation	Technical University of Catalonia (UPC)
Department of organisation	CITCEA
Type of organisation*	Higher Education Institution
First and family name of coordinator	Oriol Gomis-Bellmunt
Full address	Av Diagonal 647, 08028 Barcelona
Country	Spain
E-mail	Oriol.gomis@upc.edu
PIC (9-digit Participant Identification Code)	999976202

The important proliferation of medium and large size PV power plants in Europe and worldwide is raising the attention to its important role in providing support to the electrical network. Large PV power plants need to ensure a smooth injection of the generated renewable power into the grid where they are connected, while providing the required ancillary services. Depending on the grid nature, such requirements can differ considerably, ranging from frequency or voltage support for PV power plants connected to power systems based on conventional synchronous generators, to grid-forming capability in systems or microgrids where PV is the main generation source.

The project aimed at developing relevant control architectures and control algorithms to ensure optimal performance in different kinds of systems. In relation to control architectures, alternative control architectures where analysed, including decentralized, distributed and hierarchical options. A methodology was presented to select the most appropriate control architecture for each service. As a result, the hierarchical control was highlighted as a relevant alternative to provide frequency support services. Regarding the interaction analysis and control algorithms, detailed small-signal models were developed to analyse the potential interactions derived from more demanding and faster grid support services. The application of different stability analysis methods confirmed the possibility of interactions, especially between the PV inverters and the Power Plant Controller. Also, a control tuning method was suggested to achieve fast grid support services. This method was validated in simulation and in an experimental platform.

In addition, the project aimed at strengthening the relations between the universities and industrial partners. In this direction, a follow-up of research ideas will be addressed by the universities and the industrial partner is planning to test the control tuning methods developed during the project in real-time simulators and eventually real power plants.

Table 28 PVTool results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
TRL progress	4-5	6-7	6	
Tuning time for power plant controllers	1 week	1 h	3 days	The tuning is going to be automatized using existing models and scripts
Number of studies needed to identify system issues	16	1	5	Reduce number of studies to single model and tool to reduce time to implement models.
Time for solving stability issues prior to the power plant commissioning	1 month	1 week	3 weeks	Stability issues are going to be analyzed using reduced models and stability criteria instead of time-domain simulations.
Number of control architectures to be developed	2	4	3	Different control architectures were presented, but at the end just an additional option was feasible to be analyzed

The SOLAR-ERA.NET Cofund Action is supported by funding from the European Union's HORIZON 2020 Research and Innovation Programme.

3.3.4 PROGNOSIS

Project title: Intra-hour prediction of solar electricity generation from Photovoltaics
Project number: SOLAR-ERA.NET Cofund No 091
Project website: www.energylab.ac.cy/projects/prognosis/en/
Start date of the project: 01.04.2018
End date of the project: 31.10.2021
Total project costs (EUR): 283'720
Requested funding budget (EUR): 245'764

Table 29 PROGNOSIS coordinator contact details

Short name of organisation	CUT
Full name of organisation	Cyprus University of Technology
Department of organisation	Department of Environmental Science and Technology
Type of organisation*	Higher Education Institution
First and family name of coordinator	Alexandros Charalambides
Full address	Department of Environmental Science and Technology. Cuprus University of Technology. Corner of Athinon and Anexartisias, 57 3603, Limassol, Cyprus.
Country	Cyprus
E-mail	a.charalambides@cut.ac.cy
PIC (9-digit Participant Identification Code)	999597223

The PROGNOSIS project is related to the development of a tool for intra-hour forecasting of solar irradiance over a specific area. The innovative concept of PROGNOSIS is based on the fact that the tool is based on models that do not utilize any meteorological data or specialized equipment but only the power output of a dense grid of connected Photovoltaics (PVs).

The continuous PV input data has been integrated to energy maps over various regions and the attenuation from the normalized power output has been calculated to predict the motion and development of clouds/aerosols in time as these clouds can cause a decrease in the solar irradiance reaching the PV when they cast a shadow over it. Through the development of this dynamic flow map of the power output of the PVs, the solar irradiance can be visualized and predicted, not only for individual PVs, but over entire regions.

Regarding the development of the forecasting model, a machine learning approach was adopted, which can provide accurate predictions based only on the knowledge acquired from historical data. For PROGNOSIS, a model based on the "Recurrent Neural Network" architecture has been built using the historical PV power data. The estimation of clear-sky PV electricity production is also important for determining the attenuation in the energy maps. Thus, a data-driven method was developed for the calculation of the clear-sky signal. The issue of incorporating spatial dependency into our forecasting model was also examined. Results indicate that our model can capture the overall trend and fluctuations of the power output and provide good predictions, not only for PVs in Cyprus and Spain but also in countries with different climates.

PROGNOSIS is essentially a real-time decision-making tool primarily for the energy sector since the resulting forecasting can facilitate the decision-making process for the visualization, management and optimization of microgrids and electricity systems.

The main technological outcomes of the project were the improvement of the algorithms – both in terms of accuracy but also to include spatial variability and the incorporation of real-time data from PV inverters into the developed software. Furthermore, on the business side, the PROGNOSIS tool has potential in a sector that is under a complex transition to becoming more decentralized, with near-zero marginal costs, and especially digitalized. Digital tools that allow automatic and rapid actions will be increasingly important and PROGNOSIS can provide even more value than the one suggested in this report.

Table 30 PROGNOSIS results, targets and achievements – technological, economic, environmental and other indicators

Initial value at the start of project		Expected value at the end of project	Reached value
TRL progress	4	7	6
Performance / efficiency	Accuracy of the existing solar power forecasting models	*	Not quantified
Cost of product	20 000€		Not quantified

The SOLAR-ERA.NET Cofund Action is supported by funding from the European Union's HORIZON 2020 Research and Innovation Programme.

3.4 CSP cost reduction and system integration

3.4.1 HyConSys

Project title: Hydrogen control in solar thermal parabolic through heat transfer fluid systems
Project number: SOLAR-ERA.NET Cofund 1 N° 60
Start date of the project: 01.01.2018
End date of the project: 31.12.2020
Total project costs (EUR): 990’727
Funding (EUR): 766’030

Table 31 HyConSys coordinator contact details:

Short name of organisation	DLR
Full name of organisation	Deutsches Zentrum für Luft- und Raumfahrt e. V.
Department of organisation	Institut für Solarforschung
Type of organisation*	Public research organisation
First and family name of coordinator	Christian Jung
Full address	Linder Höhe, 51147 Köln
Country	Germany
E-mail	christian.jung@dlr.de
Phone number	+49 (2203) 601 2940

The project aimed at controlling hydrogen (H2) in the heat transfer fluid (HTF) of solar thermal parabolic trough plants within acceptable limits. H2 is slowly formed by the HTF that is currently used in the plants and which is based on aromatic hydrocarbons. The formation rate depends on the operating temperature and the condition of the fluid. Aged qualities reveal higher formation rates. H2 permeates through the steel pipes of the heat collecting elements (receivers). If the gas would accumulate inside the annular gap of the receivers the insulating vacuum would be lost and unacceptable heat losses would result as a consequence.

In order to prevent this condition, getter materials are located inside the annular gap. The getters absorb H2 and therefore maintain the vacuum insulation. If the design conditions in terms of H2 concentration in the HTF are maintained, the getters will be saturated not before the specified lifetime of the receivers. A problem is caused if the H2 concentration is larger than specified at the maximum operating temperatures. This would cause unacceptably low useful lifetimes of the receivers.

The HyConSys project aimed at testing measures against H2 accumulation in the HTF like removal of H2 by nitrogen exchange from the system and by processing steps. This was guided by detailed lab analysis in order to provide in-depth understanding of the relevant processes. Hereby economic measures for H2 removal were identified and optimized.

The results were integrated within a computer model together with cost models to develop a tool for identification of the most economic H2 control strategy for specific CSP systems.

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This approach was supported by developing new catalysts for H2 removal and by easy to use techniques for H2 analysis.

It is expected that this combination of analysis, development and improving knowledge will significantly help to overcome the currently upcoming H2 problems in CSP systems.

Table 32 HyConSys results, targets and achievements – technological, economic, environmental and other indicators

Objective	Issue / Indicator	Initial value at start of project	Expected value at the end of project	Reached value	Further information
H2 concentration control by nitrogen exchange	TRL progress	2	5	5	
Selective H2 removal with catalysts	TRL progress	2	4	4	
Control of H2 formation rate via HTF processing	TRL progress	2	5	5	
Selective H2 removal with nano catalysts	TRL progress	2	4	4	
H2 sensor for ppm-range in nitrogen	TRL progress	2	5	5	
Device for quantification of H2 in HTF via at-line analysis	TRL progress	2	5	5	
Quantification of H2 permeation through HCEs	TRL progress	2	4	-	Not completed
Identification of mayor factors for self-amplifying H2 formation	TRL progress	2	4	4	
Quantification of H2 formation rate and concentration of amplifiers	TRL progress	2	4	4	
Evaluation of removal costs of amplifiers	TRL progress	2	5	5	
Computer model for controlling of H2 concentration in HTF-systems	TRL progress	2	5	5	

4 TRL progress

The following section summarises the outcomes in relation to TRL progression per topic.

The topic "**Innovative and low-cost PV manufacturing issues**" focuses on materials and processes aimed at reducing the manufacturing costs and LCOE for all PV technologies. Innovative active and functional materials are being tested in combination with pioneer and alternative fabrication techniques in order to achieve low-cost and high throughput industrially scalable technologies. In general, materials and processing techniques with low maturity (TRL4) tested in lab conditions at the beginning of the projects are taken to higher TRL6 through the successful development achieved within the duration of the project:

- The Pearl project developed self-aligned process techniques focusing on low Ag consumption for passivated emitter and rear contact silicon solar cells by means of inkjet and plating technology. The TRL was raised from 4 to 6 giving rise to solar cells with efficiencies up to 21.7% processed in relevant pilot lines with decreased fabrication costs.
- The NEXT-FOIL project successfully demonstrated a new generation of substrates based on dielectric/metal/dielectric structure with improved performance with respect to ITO-coated PET for the fabrication of organic and perovskite flexible solar cells.
- The HEAVENLY project developed alternative deposition processes of silver pastes for passivated emitted layers and rear totally diffused solar cells resulting in an industrial process that produces passivation layers of improved quality and allows the fabrication of solar cells with efficiencies over 22.5% with n-PERT architectures.
- The ENMESH project demonstrated an innovative and pioneer PV module based on an array of micro-solar cells with optics and integrated micro tracking. Cell interconnection process was made by direct printing of ultra-durable nano-particle coating systems. The mini module efficiency was around 37% with a decrease LCOE of around 30%.
- The RHINO project developed an industrially feasible manufacturing approach for a n-type cell structure with a selective boron doped emitter and a full area passivated rear contact. Test modules fabricated from these bifacial cells showed bifaciality factors of ~85%, and efficiencies above 25%, outperforming current passivated emitter and rear modules.

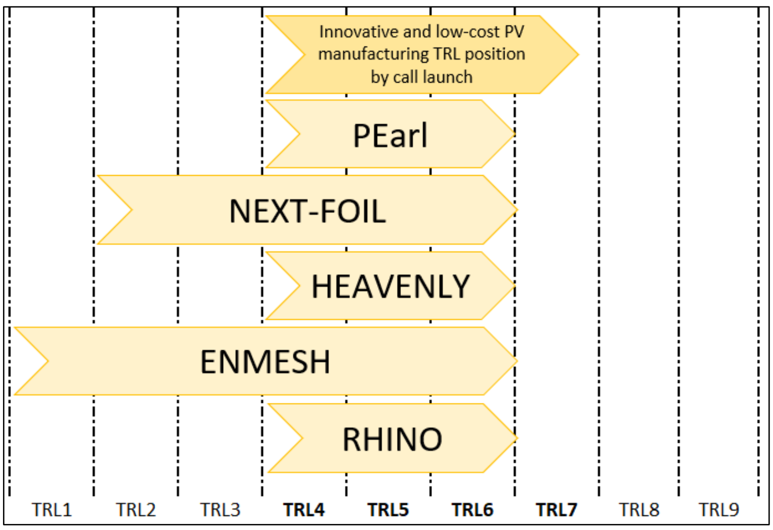

Figure 1 TRL progression in topic "Innovative and low-cost PV manufacturing issues"

The topic "**Advanced PV products and applications**" focuses on innovative approaches applied to cell and modules in order to address and fulfil different market specifications and integrate them into appealing applications from the aesthetic and functional point of view. In general, initial TRL belong to functional cells that are later modified according to specifications to reach higher TRLs corresponding with the targeted application:

- The BI-FACE project developed innovative bifacial modules and systems tailored and designed at wish to the specific weather conditions under operation by adjusting system variables and parameters like tilt and distance between modules, reflecting surfaces, shading, cell spacing, etc). The results included three novel variations for bifacial modules and systems which were tested in three different climate zones with improved results with respect to standard approaches.
- The CEFRABID project focused on innovative manufacturing of end-solutions to use road and rail noise barriers infrastructure surface as support for photovoltaic panels that allow conversion of solar energy into heat and electricity, while maintaining their noise attenuation and isolation properties. The project developed 5 new solutions and their subsequent in situ installation and validation. The obtained results confirmed that the PV energy obtained from these installations can be successfully used to power associated applications as street lights, air-conditioning devices or charge electric cars.
- The PanelPV developed new façade elements with integrated PV. Translucent PV films were developed to allow for full freedom in colour or print selection resulting in a demo façade in which several sandwich panels with two different sizes and different colours were integrated taking into account construction and product regulations.
- The Master PV project developed innovative transparent back contacts in CIGS cells for cost efficient semi-transparent modules. Significant improvement was achieved in the aesthetic quality of semi-transparent devices with the elimination of the back mirror effect showing transparency levels up to 30-40% while maintaining competitive conversion efficiencies.
- The Cover Power project addressed the optical perception of modules combining different kinds of glass coating technologies in order to manage reflections of the incident light and glares, and tune the aesthetics of the PV module. The results showed an efficient colouring of BIPV modules of Si solar cells by applying novel glass coatings to the outer side of their cover glasses.
- The NELL project developed a low cost highly resistant encapsulant able to avoid potential induced degradation in high voltage systems up to 1500V even under harsh humidity and temperature conditions. This contributed to reduce the LCOE and increase the lifetime of PV modules with a guaranteed 90% power output.

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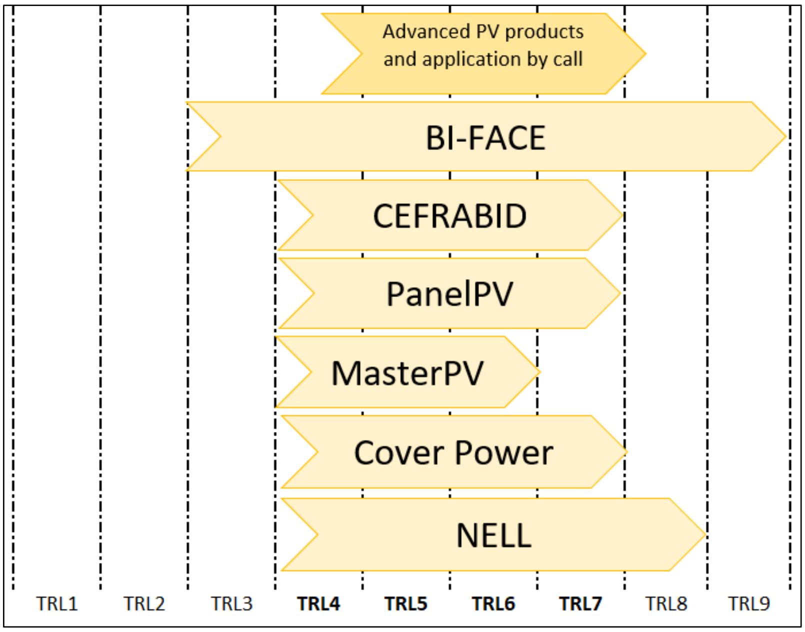

Figure 2 TRL progression in topic “Advanced PV products and applications”

The topic “**PV system integration**” focuses on potential developments made on different components of the PV system apart from the conversion panel in order to maximize the overall performance of the whole PV system. New concepts or approaches with low initial TRLs at device level, are then integrated within the project at higher levels, reaching higher TRLs in operating systems:

- The 1500-SIC project developed a novel SiC photovoltaic inverter optimized to deliver nominal power at voltage levels up to 1500 V. The developed technologies have been built and tested at full scale through a comprehensive testing campaign.
- The Erigeneia project developed an innovative energy management system that combines photovoltaic energy generations with battery energy storage systems. Field trials demonstrated a novel and more effective ancillary services provided to the network including power smoothing and voltage regulation.
- The PVTOOL project developed relevant control architectures and control algorithms to ensure optimal performance in different kind of systems. As a result, the hierarchical control was probed to provide frequency support services, while the application of different stability analysis methods confirmed the possibility of interaction between the PV inverters and the Power Plant Controller.
- The PROGNOSIS project developed a forecasting model of the solar irradiance over specific areas as a real-time decision-making tool for the energy sector. It is innovatively based on machine learning techniques and raw historical data to accurately predict the solar irradiance reaching the photovoltaic panel accounting for the motion of the sun and the formation and evolution of clouds/aerosols.

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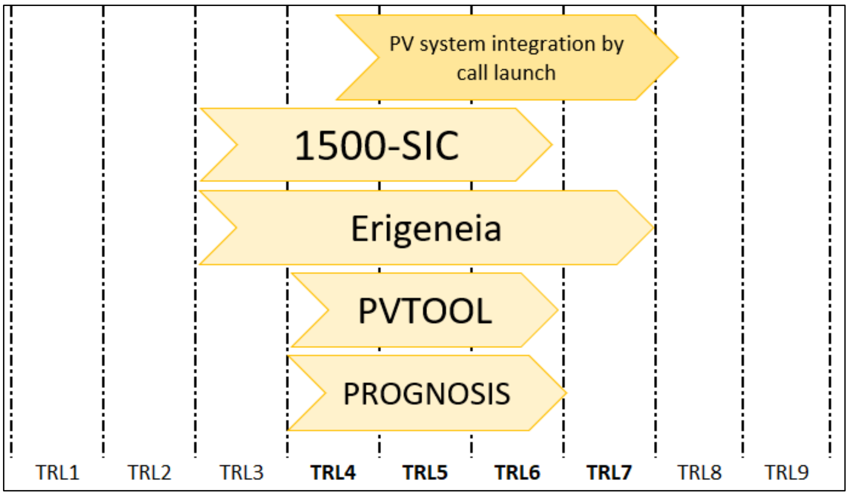

Figure 3 TRL progression in topic “PV system integration”

The topic “**CSP cost reduction and system integration**” focuses on the different aspects of concentrated solar power for different applications. Concepts with low TRL initially demonstrated in lab conditions are integrated into functional systems resulting in higher TRL thanks to the development achieved within the project:

- The HyConSys project demonstrated a tool for the identification of the most economic H2 control strategy for specific CSP systems by developing new catalysts for H2 removal and new techniques to control and analyse H2 in the heat transfer fluid of the solar thermal parabolic plant.

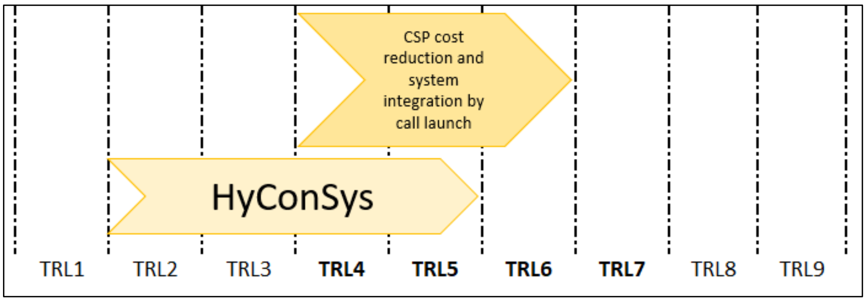

Figure 4 TRL progression in topic “CSP cost reduction and system integration”

5 Project impacts on employment

The following table shows the staff associated to each project according to the information provided in their final reports. The researchers working in the projects are categorized in staff researchers, including young researchers (which contribute to improving the European scientific capacity and growing scientific productivity) and female researchers (which contribute to balance gender inequalities in research projects). The total number of new jobs created by the SOLAR-ERA.NET Cofund shows the impact of the programme on unemployment rate reduction.

The overall result show that 260 researchers have been involved in the SOLAR-ERA.NET Cofund programme, with 68 (26%) corresponding to female researchers and 96 junior researchers (37%). The total number of new jobs created by the programme were 90,5, with 23,5 permanent positions (26%) and 67 temporary positions (74%).

Table 33 Number of researches involved and jobs created

Project	Total number of researchers involved	Number of young researchers involved	Number of female researchers involved	Number of permanent jobs created	Number of temporary jobs created
PanelPV	10	3	4	-	-
MasterPV	14	7	1	-	2
PEarl	12	5	2	-	-
BI-FACE	6	7	6	2,5	10
Cover Power	11	1	3	-	-
CEFRABID	40	8	16	1	10
NEXT-FOIL	16	5	3	-	-
HEAVENLY	13	8	4	1	9
1500-SIC	34	13	13	2	5
Erigeneia	34	15	5	16	13
HyConSys	9	2	2	-	-
ENMESH	7	2	1	-	2
PVTOOL	17	7	-	-	5
NELL	8	1	2	-	-
RHINO	14	7	2	1	2
PROGNOSIS	15	5	4	-	9
TOTAL	**260**	**96**	**68**	**23,5**	**67**

6 Scientific impact

The scientific impact of the programme has been assessed according to the indicators presented in the following table. In addition to the number of peer-reviewed publications, this table collects other activities and mechanisms addressed to present the SOLAR-ERA.NET programme evolution to the society and to disseminate its projects' results.

Type of dissemination activities achieved	
A	Peer reviewed articles, books, book chapters etc. published with or submitted to academic publishers
B	Non-peer reviewed publications (reports, briefs, books, articles targeting policy-makers, industry or other end users)
C	Citations to publications generated in the project
D	Media coverage (opinion pieces or interviews/appearances in all types of mass media)
E	Events targeting end users organised by the project (such as conferences, side events or workshops)
F	Presentations targeting end users given by project participants (including participation in panel debates)
G	In how many conferences / events did your project participate (not organised by project itself)?
H	Patent/license applications
I	PhD thesis
J	Master thesis

According to such this list of indicators, the impact of the projects funded by SOLAR-ERA.NET Cofund programme is shown in the following table.

Table 34 Scientific impact

Project	A	B	C	D	E	F	G	H	I	J
PanelPV								1		
MasterPV	4						6	1		
PEarl		2				1	2			2
BI-FACE	1	1		3		3	11			1
Cover Power	1	7								
CEFRABID	2	2		2	2	2	2	4		
NEXT-FOIL	1					2	4	2		
HEAVENLY	5	4	5			4	4		1	
1500-SIC	1	1				1		1	3	
Erigeneia	3			9		2	3			
HyConSys	2	3				5	3	5		
ENMESH	3					1	2		1	
PVTOOL	9	19	54	2	1	2	5			
NELL		1					1			
RHINO	1	1	4				1			
PROGNOSIS	4			8	1	1	6			
TOTAL	***37***	***41***	***63***	***24***	***4***	***24***	***50***	***14***	***5***	***3***

The SOLAR-ERA.NET Cofund Action is supported by funding from the European Union's HORIZON 2020 Research and Innovation Programme.

7 Impact Assessment Survey to project participants

A survey was elaborated according to the ERA-LEARN template for project impact assessment questionnaire. The survey was circulated among all the funded project coordinators. The results are shown in the following charts.

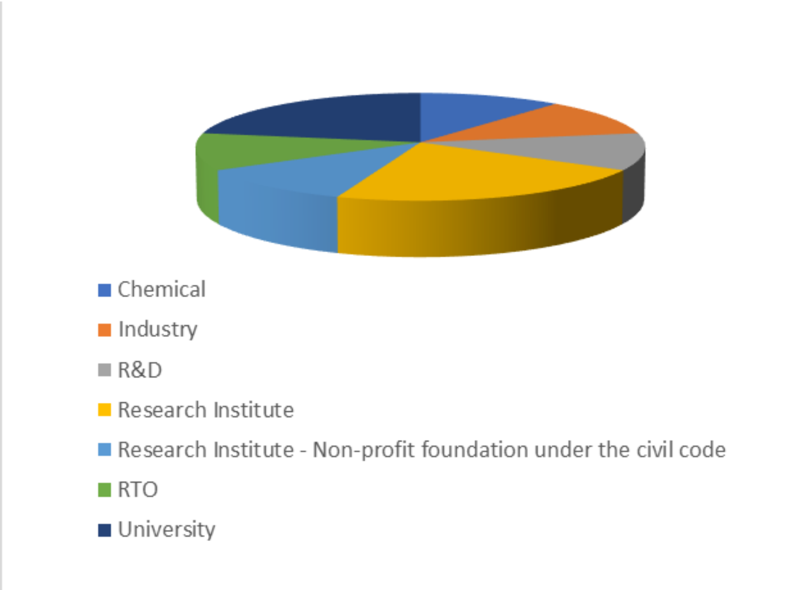

Figure 5 Organization type

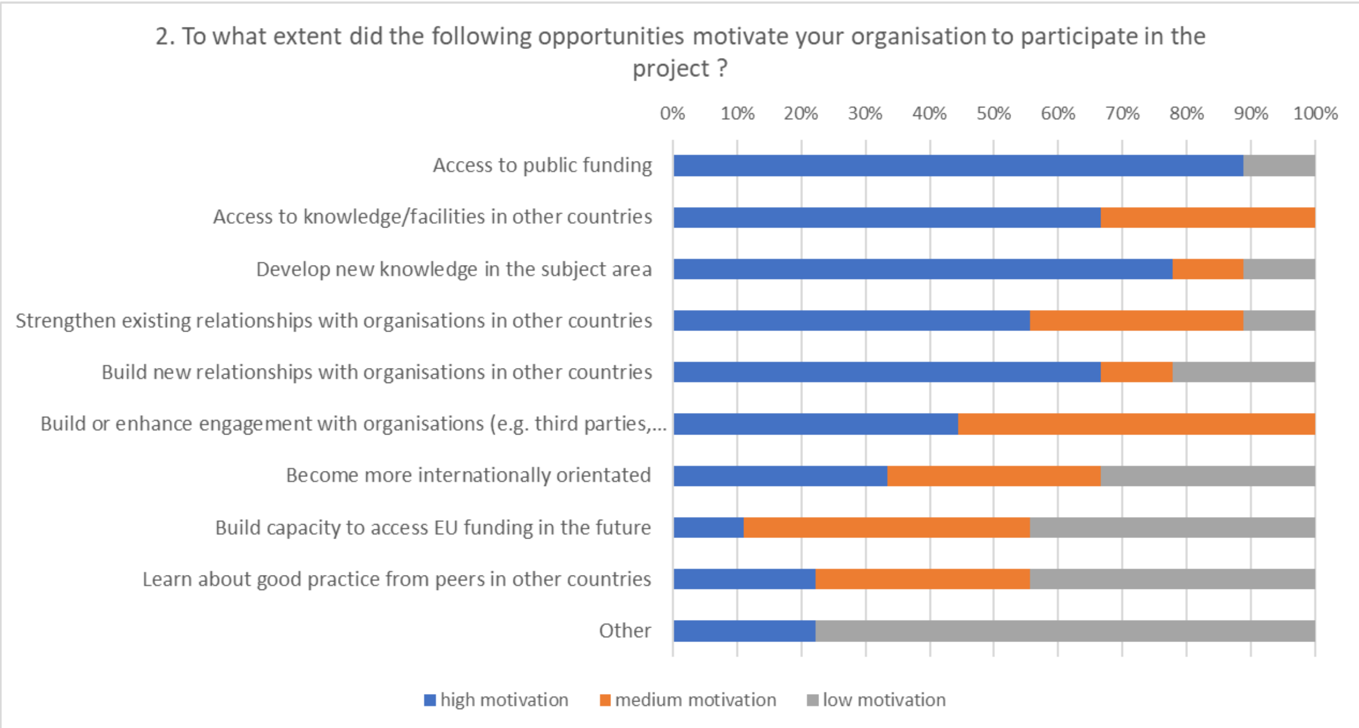

Figure 6 Opportunities and motivation

Comments to this question by the participants:

- *Joint calls like SOLAR-ERA.NET enable EU-international funding with low bureaucratic threshold. The latter because proposals are written and evaluated according to the guidelines of the well-known country-specific funding agencies. Hook-up of European manufacturing with European supply chains requires European projects with short proposal-2-funding times and European consortiums, like SOLAR-ERA.NET. It is important to keep these joint calls as an alternative to Horizon Europe, especially at higher TRL (>6).*
- *To enable funded projects with industry partners from other countries*
- *An excellent opportunity to work with excellent partners on a key sustainability technology we were looking to exploit*

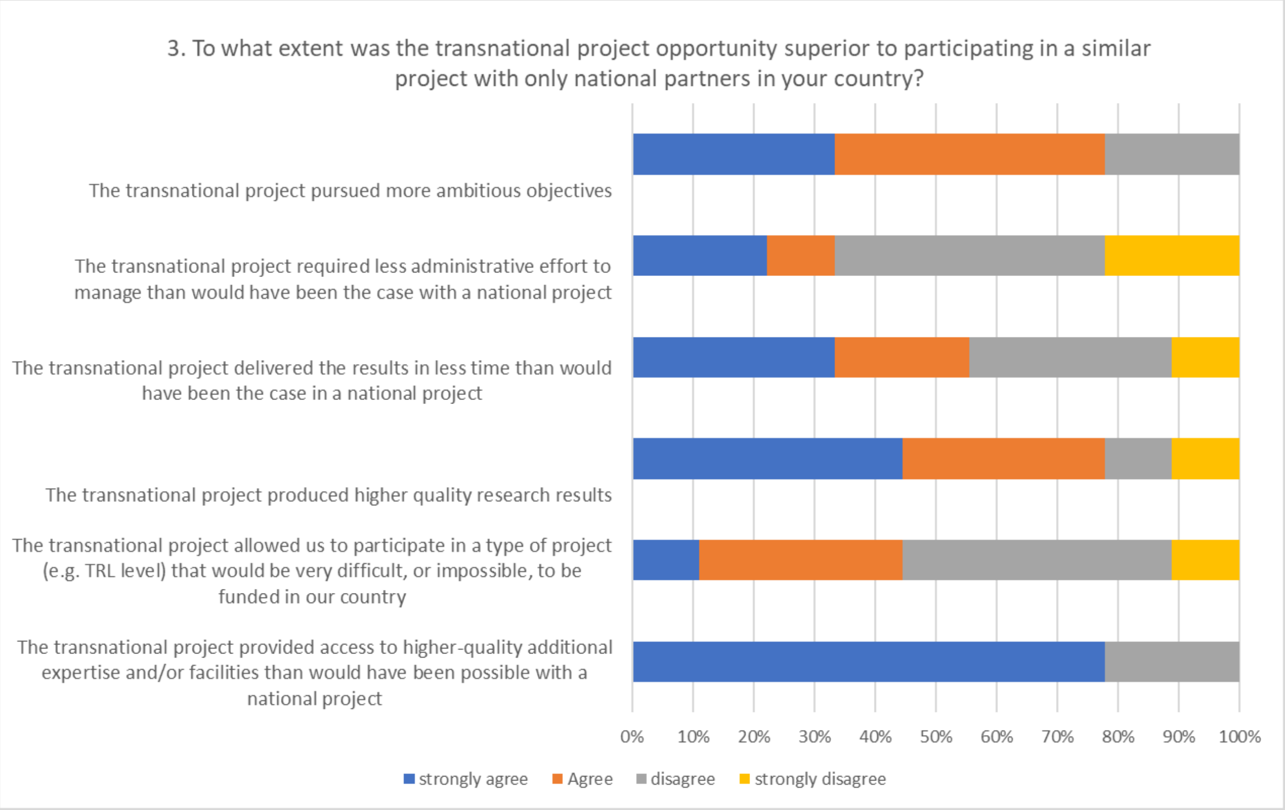

Figure 7 Transnational added value

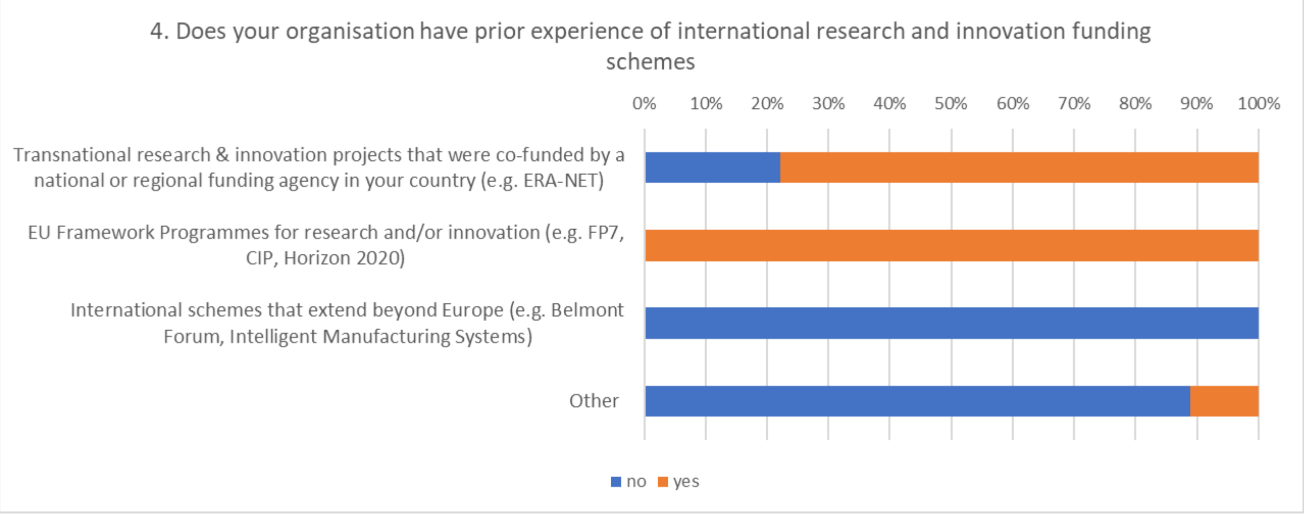

Figure 8 Prior experience in international RDTI funding schemes

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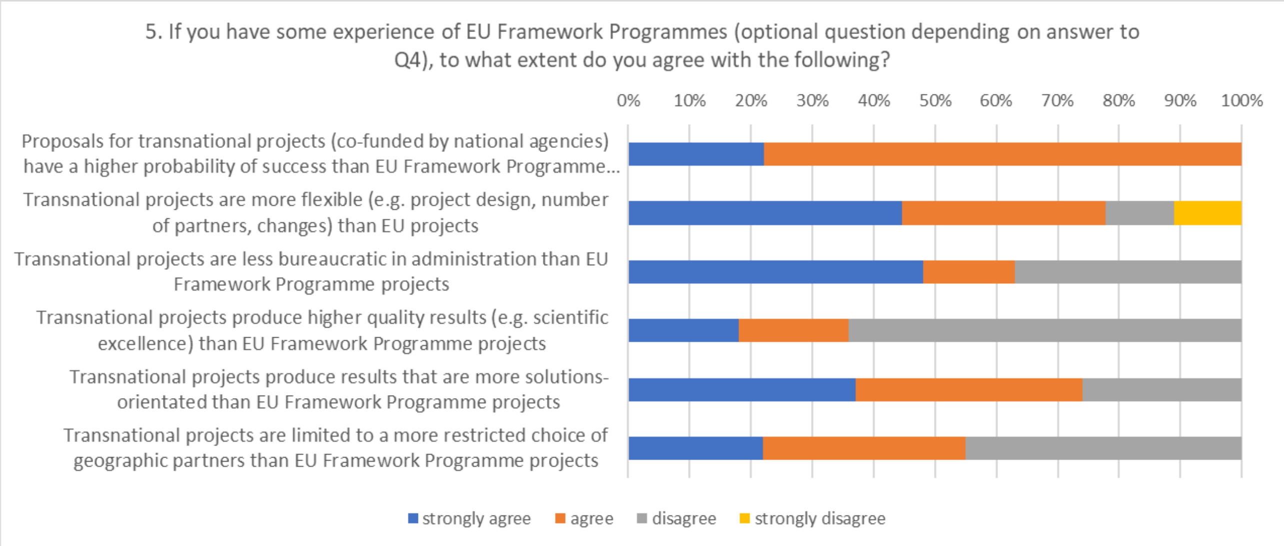

Figure 9 Transnational projects compared with experience of EU Framework Programme

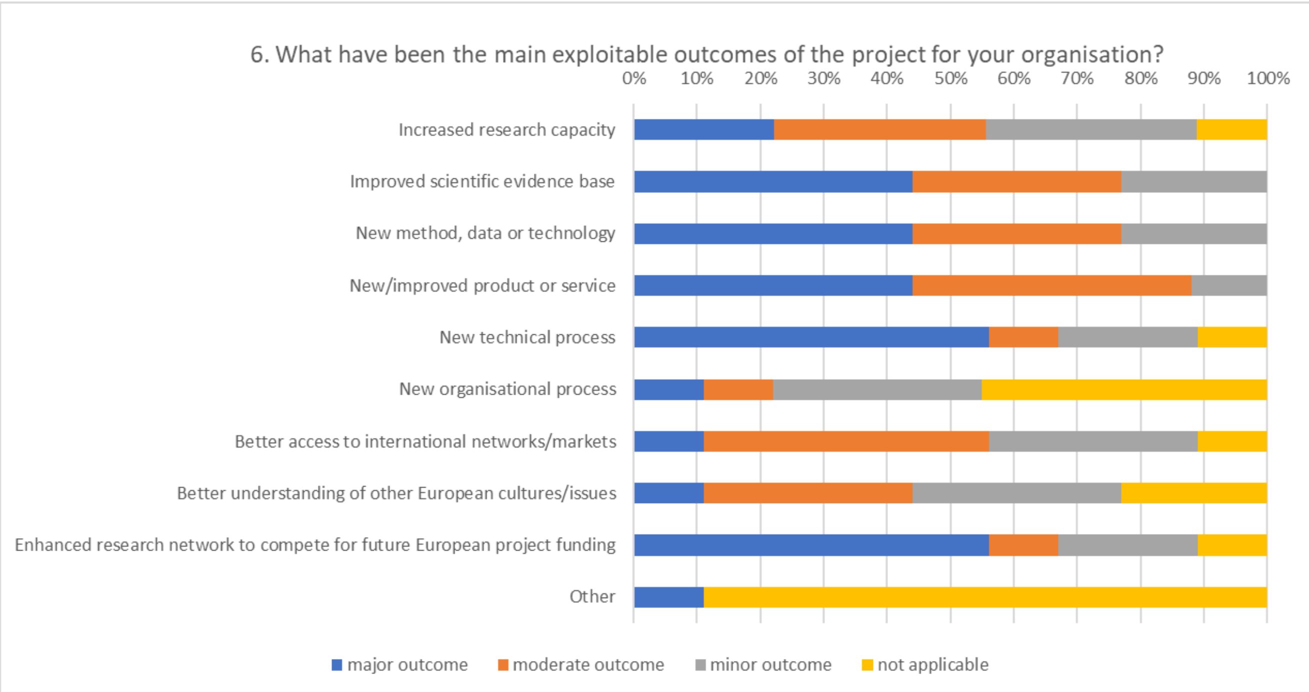

Figure 10 Main exploitable outcomes

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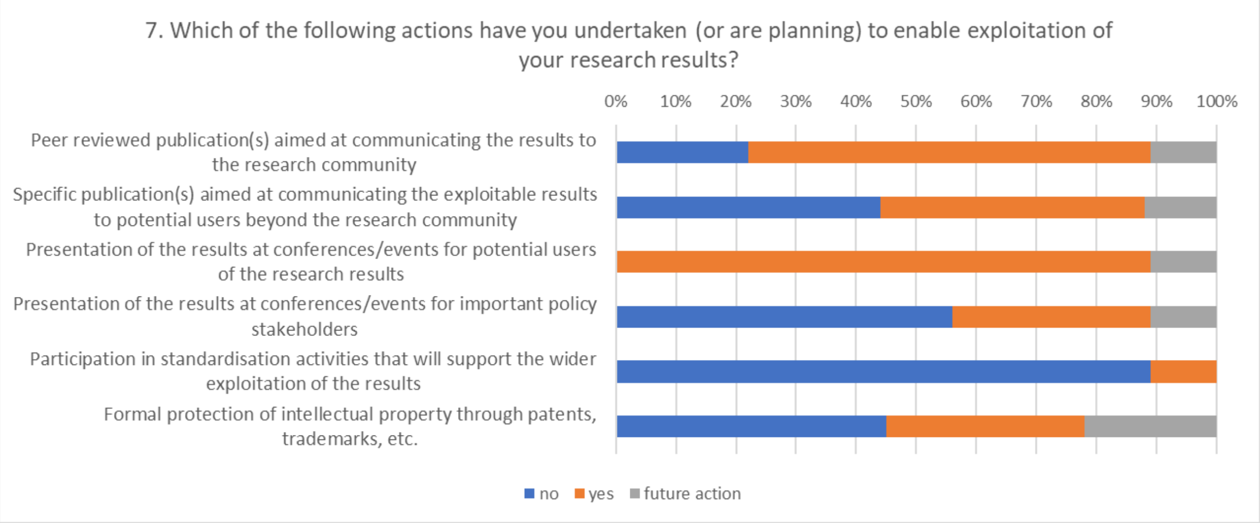

Figure 11 Exploitation activities

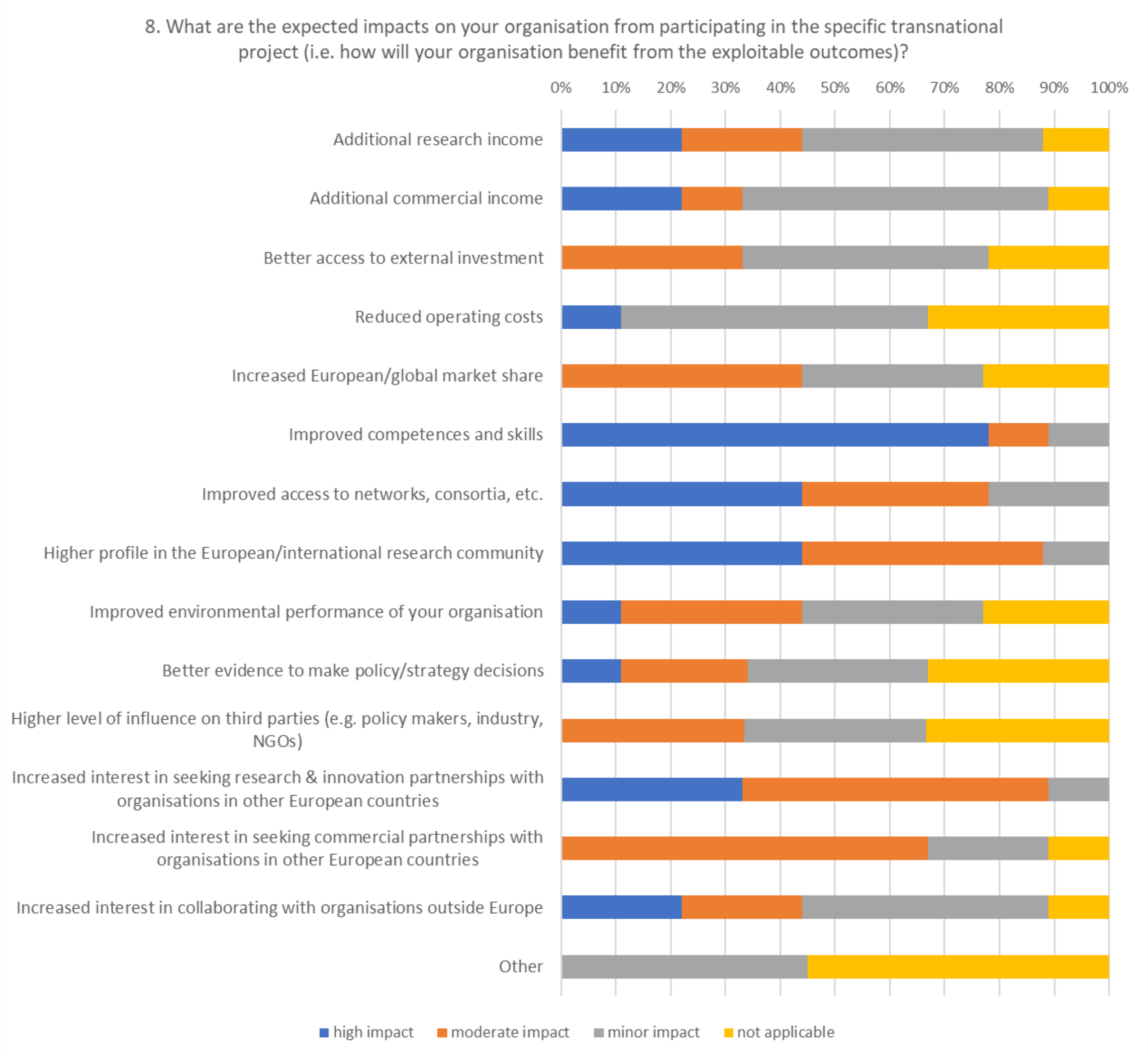

Figure 12 Expected impacts on your organisation from participating in the specific transnational project

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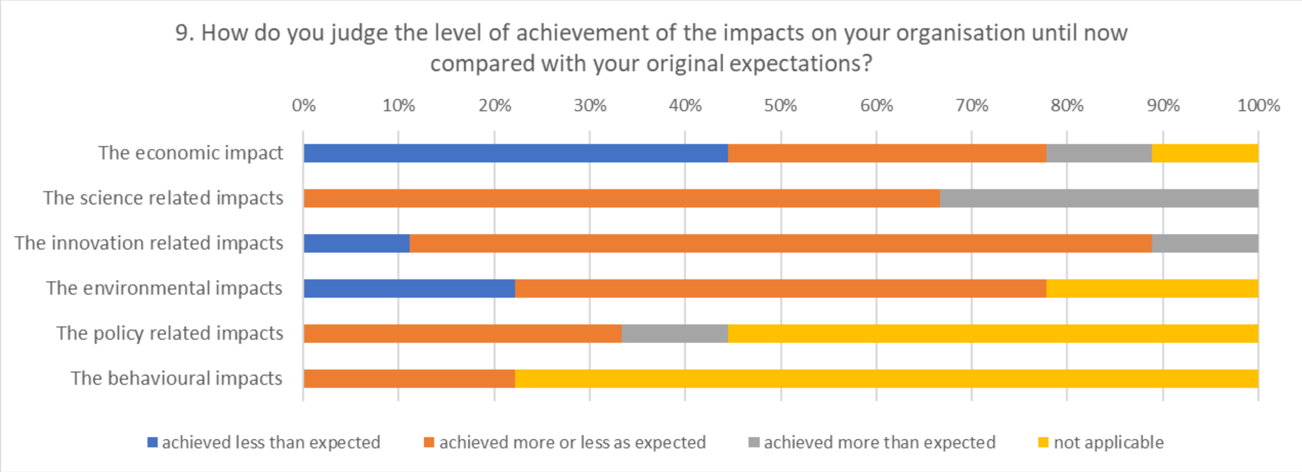

Figure 13 Level of achievement of the impacts

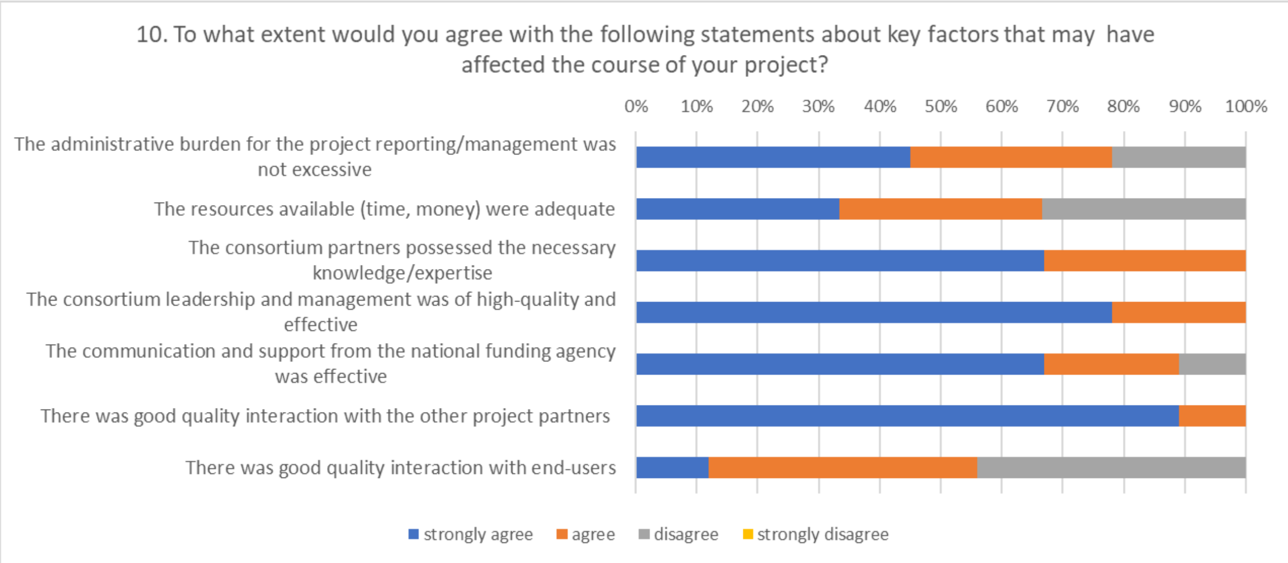

Figure 14 Statements on key factors

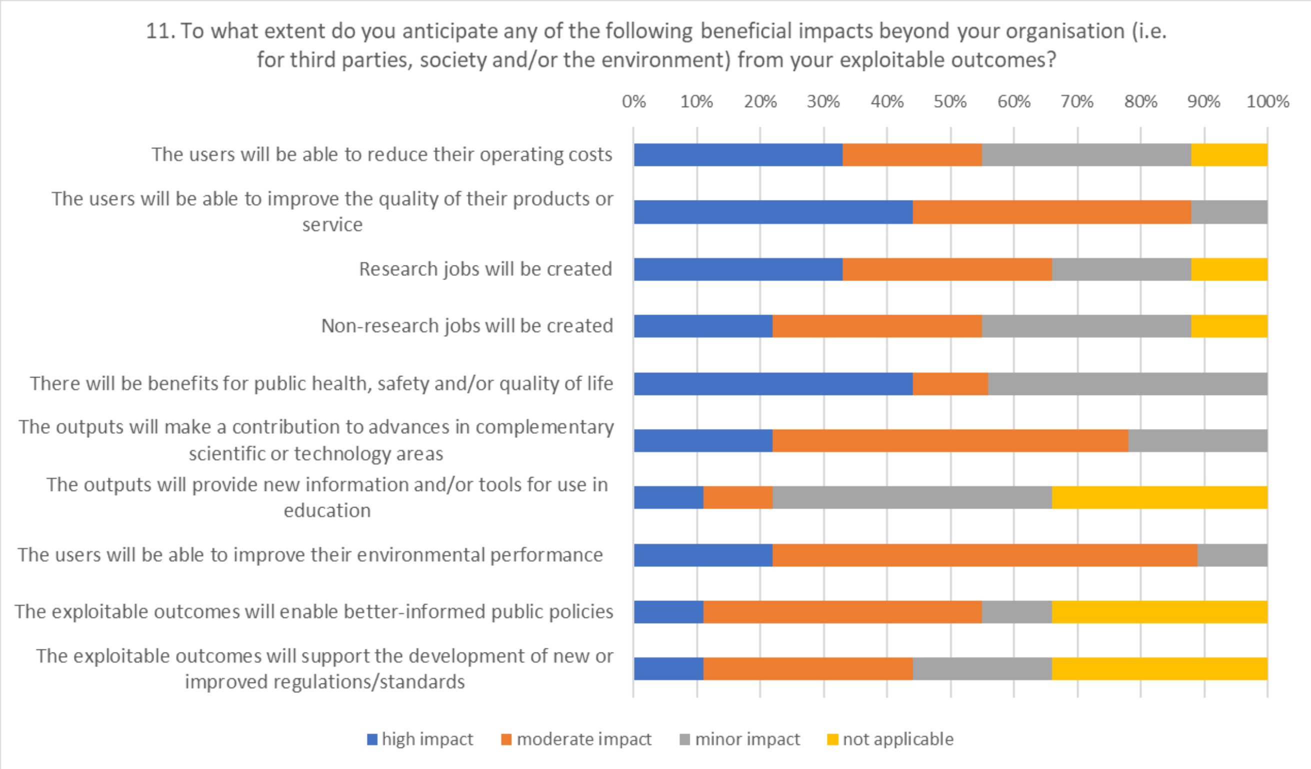

Figure 15 Anticipating beneficial impacts

Comments to the survey by the participants

- *Keep SOLAR-ERA.NET alive. We need this kind of efficient transnational, European projects for the hook-up of industry enabling independent and green energy supply in Europe.*
- *I am convinced that transnational projects in the form of joint national calls are an important. instrument to strengthen the European PV research community. These calls enable "low-threshold" accessible funding for European research consortia, especially SME, by using proven national funding schemes. This strengthens European research networks and supports re-settlement and growth of the PV manufacturing industry in Europe*
- *The timing of the funding provided by the three funding agencies was not tuned, particularly ours delivered the funding one year later than the project schedule. This is a nightmare, and it should be solved for future calls. The only way to carry out the project was using resources of our group during the first year and the excellent cooperation with the partners.*
- *Excellent project. Excellent partners. Monitoring officer very helpful. Although very good technical outcome the market had shifted and the ability to exploit and make money was too difficult.*
- *The experience was very positive. I would very much like to see new SOLAR-ERA.NET calls in the future. These programs allow European entities to collaborate with a freedom that Horizon Europe does not bring. They truly support EU companies to build technology synergies that lead to new and more competitive products and, as a consequence, more competitive EU industry.*

The SOLAR-ERA.NET Cofund Action is supported by funding from the European Union's HORIZON 2020 Research and Innovation Programme.

8 Conclusion and outlook

This report presents an impact assessment for the projects funded under the SOLAR-ERA.NET Cofund framework. This initiative has funded R&I projects covering the whole value chain of photovoltaic energy generation; from the initial point of view of improving the quality of starting supporting wafers and advanced and novel high throughput manufacturing processes to the integration of PV power, installation and ancillary services like inverters or storage solutions that all together help the final deployment of solar photovoltaic energy needed to decrease GHG emission and reach social and industrial decarbonization.

Remarkably large efforts have been dedicated to the development of new materials, silicon based and other than silicon technologies like conductive transparent inks, advanced foils, bifacial devices, encapsulants, insulators, CIGS, organic semiconductors and perovskites, oxide anodes and cathodes that need to work together in a synergic combination to fully exploit the benefit of solar power and decrease the dependence on fossil fuels.

It is not any more a competition between different generating technologies to beat the market, but to reach together a maturity level that allows resilient and local electricity generation at competitive production prices with easily scalable manufacturing techniques. Silicon and other complementary generating technologies have all their corresponding market opportunities and can be integrated in different applications/elements depending upon their intrinsic and mechanical properties.

As many as possible passive surfaces nowadays available must be covered with PV systems in order for them to become solar active and generate power. In this way, more versatile approaches like road acoustic barriers, semi-transparent BIPV or flexible / customisable shape, size and colour devices have also been funded by SOLAR-ERA.NET Cofund.

The overall impact of the funded projects has been tremendously positive. The power conversion efficiency of all the different kind of devices has always considerably progressed and achieved higher values clearly above the level at project started, overcoming in many cases 25%, and reaching 36% for concentrating technologies. In addition to more efficient devices and panels, SOLAR-ERA.NET Cofund has contributed to the cost reduction of PV electricity production for existing technologies, working first at materials and processes level, and to reach very competitive LCOEs focusing also on the whole technical chain of a PV plant.

In the case of less developed technologies, SOLAR-ERA.NET Cofund projects have in general risen TRL from lab demonstration to system prototype demonstrations in operational environments, bringing emerging technologies to the gates of industrialization and commercialization, and opening a new world of possibilities to make any suitable surface solar active and convert it into a power generator. Continued and new collaborative schemes are needed in order to address the challenges and grasp the huge opportunities related to develop and deploy a clean, renewable and decarbonised electricity / energy system thanks solar power technologies.

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Acknowledgement

Figure 16: Organisations involved in promoting the SOLAR-ERA.NET Cofund Joint Call and providing support and funding to innovative industrially relevant projects.

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