INTRODUCING THE SUPER PV PROJECT – COST REDUCTION AND ENHANCED PERFORMANCE OF PV SYSTEMS

Juras Ulbikas[1] , Vaidvile Ulbikaite[1], Julius Denafas[2], Robert Witteck[3], Marc Köntges[3], Marko Topič[4], F. Frontini[5], P. Bonomo[5], Philippe Macé[6] , Pieter Jan Bolt[7] , Alexander Ulyashin[8] , Torstein Haarberg[9], Wolfram Palitzsch[10] , Barbara Terheiden[11], Ingrid Weiss[12]
[1]Applied Research Institute for Prospective Technologies (Protech), Vismaliukų g. 34, Vilnius LT 10243, Lithuania
[2]SOLITEK R&D, Mokslininku g. 6A, Vilnius 08412, Lithuania
[3]Institute for Solar Energy Research Hamelin (ISFH)
Am Ohrberg 1, 31860 Emmerthal, Germany
[4]University of Ljubljana, Faculty of Elec Eng, Trzaska 25, 1000 Ljubljana, Slovenia
[5]SUPSI-ISAAC, Campus Trevano, CH 6952, Canobbio, Switzerland
[6]Becquerel Institute, Rue Royale 146, 1000 Brussels, Belgium
[7]Netherlands Organisation for Applied Scientific Research (TNO),
Thin Film Technology, High Tech Campus 21, 5656 AE Eindhoven, The Netherlands
[8]Foundation for Scientific and Industrial Research (SINTEF), Strindevegen 4, 7465 Trondheim, Norway
[9]BNW-Energy, Sildråpevegen 28 B, 7048 Trondheim, Norway
[10]Loser Chemie, Bahnhofstrasse 10, 08134 Langenweissbach, Germany
[11]University of Konstanz, Universitatsstrasse 10, 78457 Konstanz, Germany
[12] WIP Renewable Energies, Sylvensteinstrasse 2, 81369 Munich, Germany

ABSTRACT:
Today photovoltaics (PV) has become one of the most cost-effective forms of electricity production globally and in some regions is already the most competitive unsubsidised form of electricity. Despite positive cost and growing developments, European PV manufacturers are facing a decline in production due to competition from third countries. This decrease in the competitiveness of European PV actors is due to several factors, including a greater fragmentation of the value chain compared to competing actors. Chinese manufacturers have in particular been able to achieve synergies, economies of scale and information sharing throughout the value chain.
SUPER PV is a collaborative European-funded project initiated in 2018 by 26 partners in reaction to this trend. Together, they target a significant LCOE reduction (26%-37%) for European-made PV by adopting a hybrid approach combining technological innovations and data management methods.

Keywords:

1 INTRODUCTION

PV deployment growth is an unmatched success story in the energy sector over recent years. In just a decade the world's cumulative solar capacity increased by over 4,500% - from merely 6.6 GW in 2006 to 307 GW in 2016[1]. Today PV has become one of the cheapest forms of electricity production globally and in some regions is now the most competitive unsubsidised form of electricity with emerging business models based purely on levelized cost of electricity (LCOE) estimations. Despite the positive cost and growth developments, due to competition from third countries European PV manufacturers are facing decline in production (utilization of the module factories in the EU continued to decline to 40% in 2016, from 46% the year before) and without fast measures can completely disappear from the market.
Competitiveness decrease of the European PV actors is due to several factors: Europe PV landscape is today characterized by **fragmentation of the value chain,** while major solar actors are vertically integrated. This fragmentation is believed to be the major threat for the competitiveness of the European PV sector. In fact, substantial share of cost for the PV electricity (kWh/Eur) is related to a fragmented process inefficiency that affects the final cost.
In the SUPER PV project we are proposing a combined solution addressing both, product technological quality and business operation, targeting a significant reduction of LCOE. This reduction will be achieved through demonstration of a careful selection of innovations, which will improve the main components of the LCOE (CAPEX, OPEX and PR[2]). Introducing **SUPER**ior quality **PV** systems will create conditions for accelerating large scale deployment of PV in Europe for both utility (non-urban) and residential (urban) scenarios and help EU PV businesses to regain leadership and competitiveness on world market.
--SUPER PV is based on a hybrid combination of technological innovations integrated into PV systems and utilization of Big Data Analytics and Data management along the PV value chain. Implementation into PV systems will be ensured by (i) innovations requiring lowest possible investment into upgrade of manufacturing lines, (ii) compatible with state of the art PV module and Power Electronics (PE) products (iii) while for business operation improvements Digitalization and Data Management solutions based on Industry 4.0 approach will be used through the whole value chain. We will explore several of these applications by adopting already available solutions from the

[1] **International Technology Roadmap for Photovoltaic Results 2016**

[2] CAPEX – capital expenditure, OPEX – operation expenditure, PR – system performance.

construction sector (BIM) for implementing and operating PV plants identifying it as **PV4.0 approach.**

2 PROJECT CONCEPT AND METHODOLOGY

2.1 Scope

To achieve ground breaking impact on cost reduction, **project concept is tackling in integral way following three cornerstone steps impacting PV system performance and, thus, LCOE: module, power electronics (PE) and system integration/O&M (*Figure 1*).**

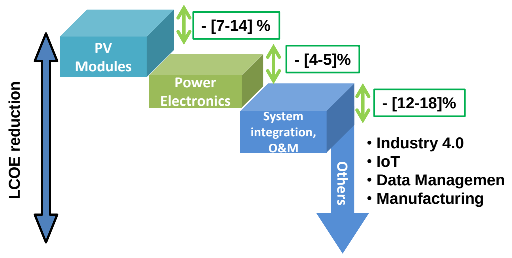


Figure 1 Project planned impact on LCOE

While module costs still represent a major part, the tendency is that this share is decreasing. In 2008, 67 % of an average project's total cost was in the PV module, but today 68 % of total cost resides in the Balance of System (BOS), which includes a variety of structural and electrical components, labour and soft costs. It is becoming clear that there is a significant room for cost reduction at the BOS meanwhile, achieving this target is challenging due to the fragmented value chain that characterizes the EU Solar landscape. Therefore, in addition to hardware level innovations, modern information management tools for PV plant implementation integrating all relevant production and plant implementation steps are needed. Consequently, based on this cost structure assessment, our project concept is addressing main value chain steps with focus on improvements of PV systems manufacturing, implementation and operation performance to achieve expected reduction of LCOE.

-- **PV module innovations**: Cost reduction on the PV module level can be achieved by three main factors: i) increase the PV module efficiency/yield with moderate/no additional production costs, ii) reduce the material cost by using less or cheaper materials, iii) increase the service lifetime by producing more reliable PV modules. The first factor (efficiency/yield increase) also reduces costs on system level because less BOS costs are expected per installed kWp with higher efficiency/yield. The second factor (material saving) reduces the production costs of the PV module. The third factor (increase reliability) is often difficult to address in cost calculations since typical assumed PV service lifetimes are equal or higher than typical financial life models for PV systems. However, we address the lifetime by choosing bifacial PV modules, which have due to its rigid structure an expected service lifetime of at least 30 years as main development basis for our innovations. Furthermore, the bifacial PV modules allow to gain 5%-25% more energy yield for the same installed capacity by additionally collecting diffuse light from the rear [1] [2].

Within the PV modules innovations, we address all three reduction factors. We increase the efficiency/yield of the PV module by increasing the optical and thermal properties of the modules. The applications of nanoparticle-based materials will improve the service lifetime of the PV modules. Furthermore, we address material cost savings for the module production by substituting and recycling expensive materials. The manufacturer SOLITEK, APOLLON and FLISOM will transfer the successful innovations on module level to a test production. The successful transferred innovations will be tested on demonstration level and the cost efficiency will be assessed to reach the final goal of LCOE cost reduction

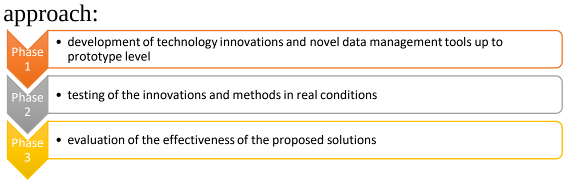
-- **Power Electronics development**: innovations for PE are focusing on module level power electronics (MLPE) and are forming integral solution ensuring significantly higher power output on the system level by ability to ensure performance monitoring and data collection on string level and long term stability of operation independently of geographical and operation conditions. Proposed hardware level innovations are also ensuring efficient utilization of innovations targeted at O&M cost reduction.

-- **PV system integration and process innovation:** Nowadays, PV installer dealing with PV manufacturing, invest significant amount of resources (with an impact on the final electricity cost from PV) to convert potential clients requests for a PV plant into a project proposal with a technical layout, economic offer (efficiency-performance / cost threshold) and feasibility analysis for production/installation. This process could be significantly optimized. To increase the process quality reducing costs, an optimized **digital process** based on the **information management** would reduce efforts, time, repetitive work, risk of mistakes, information losses, etc., transforming an almost "manual" and **fragmented** work into a digitized and interoperable workflow along all the value chain. The challenges to future large-scale deployment of PV could be overcome by a new methodology that we call **PIM (Photovoltaic information modelling/management)**: a digital and holistic process, supported by innovative digital tools, methodologies and platforms, ensuring clear structures, efficient processes, less time, lower costs and higher quality across the entire PV plant lifecycle.

Starting from this approach, the digitalization that we introduce in this project is expected to be replicable for the whole value chain of solar PV, to be tailored from raw material to electricity, including also building applied and integrated-PV.

2.2 Methodology

Project overall methodology is based on three phases approach:



The innovative technologies, suggested in this project, concerns both module and power electronics. All will contribute to significant cost reduction of the PV system cost. To avoid a combined effect of innovations, the testing will be made where only one Innovation Action is implemented. To ensure fastest possible uptake of the technologies in the production and reduce impact on system cost through increase of CoO, innovations were carefully selected to be compatible with production routing cards. For the SUPER PV systems state of the art module production technologies available for industrial partners were selected to provide possibility for comparable analysis of different technologies and their prospects for cost reduction.

Project results will be tested in demonstration sites in the **markets of primary importance** for European PV producers:

I. European market where roof top market is recently becoming more and more important.
II. Regions where solar irradiation and average temperature are high (South Europe, South USA, Africa and large part of Asia). This market has shown rapid growth with no limits due to already achieved cost competitiveness to other energy sources.

Testing will be performed in three different climatic regions of extreme conditions: tropical equatorial climate: i) hot, humid and salty, ii) hot desert climate (in Morocco and/or Tunisia) and iii) cold climate (winter in Lithuania).

For demonstration of the proposed innovations small systems up 1.5 kWp will be implemented for demonstration of the each PV module technology. Systems will be instrumented with sensors and data loggers. In addition, power electronics and data management innovations will be tested in field.

3 PROPOSED INNOVATIONS

Innovations developed by participating research centres will be applied to state-of-the-art modules (c-Si and flexible CIGS) and power electronics to ensure fast uptake of the project results by the industry. For cost reductions in PV system integration and operation, digitalization and data management solutions based on an Industry 4.0 approach will be adopted following the successful example of the Building Information Modelling approach in the construction sector. The developed innovations will range from nano-coatings to digital tools and will be compatible with existing manufacturing processes, thus reducing the impact on the cost of ownership and ensuring the attractiveness of the proposed technologies. Prototype SUPER PV systems will be tested in different climate conditions, from northern Europe to North Africa, to validate their cost efficiency and competitiveness. Business cases will be prepared on the basis of these demonstration results. These project activities will be complemented by a training and dissemination campaign ensuring the highest visibility and replicability of the project outcomes in both academic and professional circles.

3.1 Module level innovations

Within the PV module innovations, we increase the efficiency/yield, reduce the material costs and increase the service lifetime of the PV modules by introducing and combining five PV module innovations. We apply the innovations to crystalline silicon (c-Si) based bifacial modules and lightweight flexible Copper-Indium-Gallium-(di)Selenide (CIGS) modules. The first innovation is a combination of anti-Soiling (AS), anti-reflection (AR) and infrared (IR) reflection coating based on nanoparticles, which aims to increase the annual yield of the PV modules. The second innovation applies a white reflector to the module's rear glass within the cell gaps, which improves the light harvesting for the bifacial PV modules. This increases the optical gain for bifacial modules, which enhances the modules power output and the annual yield. Furthermore, we employ a deeply structured rear glass to increase light collection from the module rear side and to increase the thermal convection cooling to the surrounding air, which will also improve the efficiency/yield [3]. For the third innovation, we implement in-laminate bypass diodes made with solar cell processing machines, which allow omitting the junction box and requiring fewer materials for the module production. The fourth innovation applies Aluminum oxide (Al_2O_3) gas barrier coatings deposited by spatial atomic layer deposition (SALD). The coating is deposited either directly on the front electrode of the CIGS or on a low cost front-sheet. In both cases the coating will fulfill the same requirements as state of the art flexible encapsulation solutions and achieve similar or improved damp heat (DH) testing results. For the fifths innovation, we will demonstrate a laboratory-recycling tool for all considered module types (c-Si and CIGS) to evaluate the possibility to recycle and re-use the module materials. The manufacturers Solitek, Apollon and Flisom will implement the innovations in a test production. We test reference and innovative PV modules at demonstration sites with different climates, varying from cold and humid, hot and humid to hot and dry. Finally, we evaluate the cost efficiency of the innovations to reach the final goal of LCOE cost reduction.

Recyclability can be planned - that is why we use the many years of experience of Loser Chemie GmbH in the field of photovoltaic recycling in order to be able to offer a recycling strategy with the newly developed products. The focus should be on a recycling all the used materials. Especially the glass of these new solar modules should be used for the production of the next generations of solar cells and relevant modules.

3.2 Power Electronics innovations

Innovations will be focused on module level power electronics (MLPE) to form integral solution ensuring significantly higher power output and to ensure performance monitoring and data collection on string level and long term stability of operation. Proposed hardware level innovations are (i) micro-inverters with advanced switching elements based on GaN, (ii) micro-inverters with smart functionality such as active/reactive power generation and (iii) fault-tolerant converter topologies and converter algorithms, (iv) MPP Optimizers or Smart Boxes with Rapid Shut Down (RSD) functionality that represent dramatic increase of Power Plants fire safety, long-term energy yield, module reliability and PV power plant design flexibility, modularity and longer operation times without maintenance. MLPE will be coupled with wireless communication solutions - gateways (GW) as the heart of the intelligent system of two way connectivity, exchange of information, analytical function, and security assurance towards a cloud and provide the optimum functioning of the PV power plant as a whole.

3.3 Integrated Process and Information Management

A hybrid combination of technological innovations integrated with Data management along the PV value chain with the introduction of PV Information Management (PIM) is the main goal of WP5 for reducing time and therefore costs for PV system design, manufacturing, installation and maintenance. As a general approach, the methodology BIM (Building Information Modeling) widely used in construction industry will be "tailored" and transferred to PV process within this project and we will call it "PIM (Photovoltaic Information Modeling/Management)". The main objectives to implement innovation will be:

- To adopt digital software and hardware tools ensuring integrated information flow through the PV value chain this way reducing costs related to the PV projects implementation and operation:
- Development of a digital platform for design, simulation and operation supporting the cost reduction of PV systems. The platform will allow reducing the cost of PV electricity along the value chain by enhancing the process and by integrating PIM models with LCOE.
- Development of a tool for extending the PIM-based platform functionalities for O&M operations through a Digital Twin Model, continually updated to include the events sustained while in use, thanks to a sensor-enabled digital model that simulates the object in a live setting.

As a first step we will define a map of the PV process and its informative categories and contents, in order to find current bottlenecks, detect strategies to optimize the workflows and reduce costs thanks to the digital implementation. A generic framework of data mining in combination with the PIM will support this stage. An innovative digital platform for the design, co-simulation and operation of PV system and for the implementation of collaborative approaches through the PV value chain, will allow analyzing PV design scenarios against criteria of the minimal cost-to-power ratio. To address also a cost reduction in O&M, the platform developments will also embrace the Internet of Things (IoT) and the adoption of Digital Twin Models for PV plants, by real-time monitoring with the possibility of adding living data and smart knowledge to the digital model to improve reliability and cost reduction.

3.4 Demonstration

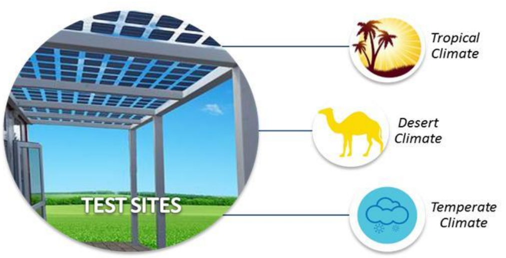


Figure 2: Demonstration sites selection

Conditions of the demonstration sites cover the **markets of primary importance** for European PV producers:

I. European market where roof top market is recently becoming more and more important.

II. Regions where solar irradiation and average temperature are high (South Europe, South USA, Africa and large part of Asia). This market has shown rapid growth with no limits due to already achieved cost competitiveness to other energy sources.

Testing will performed in three different climatic regions of extreme conditions: tropical equatorial climate: i) hot, humid and salty, ii) hot desert climate (in Morocco and/or Tunisia) and iii) cold climate (winter in Lithuania).

4 RESULTS ASSESMENT

To assess the innovation potential from innovations to be developed in SUPER PV, a set of *Key Performance Indicators* (KPI's) are defined:

- ✓ KPI 1: Solar module cost reduction
- ✓ KPI 2: BoS components costs (EUR/Wp)
- ✓ KPI 3: Total installation cost (EUR/Wp)
- ✓ KPI 4: Performance Ratio (PR) over the lifetime
- ✓ KPI 5: Reduction of lifecycle costs per kWh, expressed by the Levelized Cost of Energy (LCOE)
- ✓ KPI 6: Recyclability and environmental footprint of solar modules.

Reaching the defined KPI's will be instrumental for the success of SUPER PV. In Figure 3 calculated LCOE improvement from proposed innovations is shown.

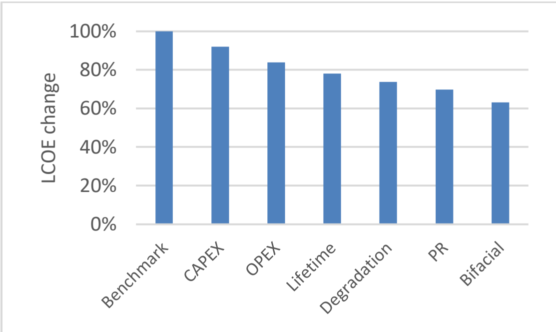


Figure 3: Estimated LCOE change from successive SUPER PV innovations.

The stated ambition in LCOE reduction of 26-37 % refers to the identified state-of-the-art situation as described in the SUPER PV proposal, submitted in September 2017. Hence, to maintain consistency in the SUPER PV Project, benchmark values from the SUPER PV proposal will be used as state-of-the-art at project start. Nonetheless, the technology and market evolution of the PV sector will be closely monitored, to ensure relevance of the results. This crucial task will not only be conducted from a market competition perspective, but also from a SUPER PV technology development point-of-view, as SUPER PV will not cover the entire supply chain needed to produce PV electricity at the lowest possible cost. Hence, SUPER technologies, in combination with relevant technologies outside the scope of the SUPER PV project, may form winning combinations on the market.

5 SUMMARY and CONCLUSIONS

Overall the project will have a twofold impact on the European PV sector: It will on one hand contribute to creating conditions for an accelerated large scale deployment of PV in Europe for both utility (non-urban) and residential (urban) contexts, and on the other hand will help European PV businesses regain leadership on the world market.

Besides the general project overview, results available for presentation at the time of the conference will include a first estimation and sensitivity analysis for the action’s impact on PV LCOE. Technical specifications for the innovations to be developed are also expected.

6 ACKNOWLEDGEMENT

The SUPER PV project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement
No. 792245.

7 REFERENCES

[1] B. V. Aken, L. Okel, J. Liu, S. Luxembourg and J. v. Roosmalen, "White Bifacial Modules – Improved STC Performance Combined with Bifacial Energy Yield," *32nd EUPVSEC,* pp. 42 - 47, 2016.

[2] U. A. Yusufoglu, T. M. Pletzer, L. J. Koduvelikulathu, C. Comparotto, R. Kopecek and H. Kurz, "Analysis of the Annual Performance of Bifacial," *IEEE JPV,* vol. 5, pp. 320-328, 2015.

[3] M. R. Vogt, H. Schulte-Huxel, M. Offer, S. Blankemeyer, R. Witteck, M. Köntges, K. Bothe and R. Brendel, "Reduced Module Operating Temperature and Increased Yield of Modules With PERC Instead of Al-BSF Solar Cells," *IEEE JPV,* vol. 7, pp. 44-50, 2017.