

Final report

1. Project details

Project title	Ydelse, drift og pålidelighed af solcellesystemer - IEA PVPS Task13-II
File no.	
Name of the funding scheme	EUDP J. no 64018-0081
Project managing company / institution	SiCon
CVR number (central business register)	28950071
Project partners	IEA Task 13 community (more than 25 partners)
Submission date	01 September 2021

2. Summary

2.1 Summary in English

The project objectives have been to participate and contribute to a workgroup of international PV experts, dedicated research and dissemination of topics related to Performance, Operation and Reliability of Photovoltaic Systems within the IEA PVPS Task13. In addition, knowledge developed and collected should be disseminated to Danish stakeholders.

The specific contributions have included several chapters on silicon feedstock, crystallisation, wafering, thin solar glass, bifacial module performance, financial modelling, daylight electroluminescence and electrical impedance spectroscopy in the reports:

- Designing New Materials for Photovoltaics: Opportunities for Lowering Cost and Increasing Performance through Advanced Material Innovations (IEA-PVPS T13-13:2021)
- Bifacial Photovoltaic Modules and Systems: Experience and Results from International Research and Pilot Applications (IEA-PVPS T13-14:2020)
- Uncertainty in Yield Assessments and Photovoltaic LCOE (IEA-PVPS T13-18:2020)
- Qualification of Photovoltaic (PV) Power Plants using Mobile Test Equipment (IEA PVPS T13 24:2021)

Dissemination has been organised by Dansk Solcelleforening in various webinars together with other Danish IEA PVPS participants.

2.2 Resumé på Dansk

Projektets målsætning har været at deltage i og bidrage til den internationale arbejdsgruppe Task13, som er nedsat af IEA PVPS og dedikeret forsknings i samt formidling af emner relateret til "ydelse, drift og pålidelighed af solcellesystemer.

Det direkte bidrag til arbejdsgruppen har bestået i at levere flere kapitler om hhv. silicium råmateriale, kry-staldyrkning, skiveskæring, hærkning af tyndt solcelleglas, ydelse af bifacielle moduler, usikkerheder ifm. fi-nansielle modeller for solcelleprojekter, dagslys elektro-luminescens samt elektrisk impedans spektroskopi til følgende rapporter:

- Designing New Materials for Photovoltaics: Opportunities for Lowering Cost and Increasing Performance through Advanced Material Innovations (IEA-PVPS T13-13:2021)
- Bifacial Photovoltaic Modules and Systems: Experience and Results from International Research and Pilot Applications (IEA-PVPS T13-14:2020)
- Uncertainty in Yield Assessments and Photovoltaic LCOE (IEA-PVPS T13-18:2020)
- Qualification of Photovoltaic (PV) Power Plants using Mobile Test Equipment (IEA PVPS T13 24:2021)

Formidling af viden til danske interessenter har været organiseret af Dansk Solcelleforening i webinarer sammen med andre danske IEA PVPS deltagere.

3. Project objectives

3.1 Objective

The objective with the project has been to participate and contribute to the workgroup of PV experts who are dedicated research and dissemination of topics related to Performance, Operation and Reliability of Photo-voltaic Systems and to disseminate knowledge and news developed and obtained from this collaboration to Danish stakeholders.

The technology in focus has been solar PV

4. Project implementation

4.1 Project evolution

Since SiCon already participated in an earlier phase of this workgroup, it was easy to participate and contribute to the various subtasks due to well established personal relationships and knowledge of skills and competences of all project partners/colleagues. All elements of the project execution have taken place according to original plan with not particular challenges or requirements for reorientation of focus or objectives.

4.2 Project development according to plans and milestones

Both the underlying IEA and the specific EUDP project has developed and has been executed according to the original plans with fulfilment of all listed milestones.

4.3 Project problems

No problems were uncounted during execution of this project.

5. Project results

5.1 Original objective fulfilment

The objectives as stated above were all fulfilled according to both original and later adjusted expectation.

5.2 Technological results

The technology results were not described as specific technical achievements but rather development and dissemination of more elaborated, well researched and updated analysis and contextualisation of a range of specific topics related to Performance, Operation and Reliability of Photovoltaic Systems.

The specific achievements must be found in the various subtask reports that's been issued by the IEA PVPS Task13. These active subtasks were the following:

5.2.1 Subtask 1: New Module Concepts and System Designs

Where the following objectives have been addressed:

- Investigate new module concepts, designs, and materials: in specific related to innovations on new functional materials and module designs.
- Focus on quantitative studies of bifacial PV performance from fielded systems around the world: in specific investigation of new bifacial PV module and system designs.
- Focus on how to characterize the performance of innovative parts in PV systems where the current methods cannot be applied (e.g. PV with integrated energy storage).
- Investigations on the service life prediction of PV modules, where data and models for service life predictions as well as methods used to accelerate the ageing of PV modules has been explored.

The main technological outcome of this subtask relate to a detailed analysis of the compatibility of new materials to a range of new products that's currently brought to the market, including monocrystalline 182x182 or 210x210 mm wafers converted into half-cut PERC and PERT cells and supplied in large format, large power double-glass bifacial PV modules where all listed features represents significant technical developments and changes as compared to the mainstream modules available a few years ago.

5.2.2 Subtask 2: Performance of Photovoltaic Systems

Where the following objectives have been addressed:

- Review the uncertainty in yield assessments – Link the uncertainty framework and the scenarios with cash flow models and LCOE calculations comparing with real case studies.
- Analysis of the effectiveness of predictive monitoring in avoiding failures in real case studies and assess the possibility to integrate the algorithms in monitoring platforms.

- Investigate all technology related influencing factors on the energy yield of PV modules in different climates.
- Compare and summarize different approaches and methods to determine soiling losses.
- Explore the methodologies for the calculation of the degradation and performance loss rates (PLR) of PV plants.

The main technological outcome of this subtask relate to a detailed analysis and reporting of new methodologies to predict loss rates, soiling losses and performance of complex/hybrid systems as well as use of machine learning and AI in the prediction of technical failures and assessing of these performance characteristics in a relevant economical context.

5.2.3 Subtask 3: Monitoring - Operation & Maintenance

Where the following objectives have been addressed:

- Increase the knowledge of methodologies to assess technical risks and mitigation measures in terms of economic impact and effectiveness during operation.
- Provide best practice on methods and devices to qualify PV power plants in the field.
- Compile guidelines for operation & maintenance (O&M) procedures in different climates and to evaluate how effective O&M concepts will affect the quality in the field.

The main technological outcome of this subtask relate to a comprehensive systematic reporting of all mobile characterisation technics that may be applicable in the field to detect failures and characterise performance of actual PV systems including a methodology to assess the technical and economic impact of such failures.

5.2.4 Subtask 4: Information Dissemination

With the objectives to present and disseminate the Task 13 status reports completed with a direct result of having all reports reviewed, approved and disseminated in various technical and general fora.

5.3 Stakeholder value

Due to the novelty and technical detailing in the published reports, it's generally considered well justified to assess these reports as elements of value generation to the overall PV community.

All reports have been published on the IEA PVPS webpage as well as webpages from all major project participants. In a Danish context reports have been published on the webpage of Dansk Solcelleforening and also several meetings have been held for members and non-members of Dansk Solcelleforening as well as Solar City Denmark.

The more scientific content has been published at EU PVSEC and IEEE conferences as well as webinars organised by the Copper alliance and Intersolar.

Among dissemination activities the following arrangements can be mentioned:

2018-11-24 Information letter from SiCon to all Danish Stakeholders

2020: Mike Green et al. Improving Efficiency of PV Systems Using Statistical Performance

Monitoring, Webinar by Copper Alliance

2020-09-08 Workshop on ST 1.3 Workshop on Performance of New Photovoltaic System

Concepts and Designs at 37 th European PVSEC

2020-10-21 IEA PVPS STATUS MØDE. Organized by Danish participants in the IEA PVPS Tasks including SiCon open for all Danish stakeholders.

2021-07-25 "Testmetoder, bifaciale solceller og nye materialer. Task 13 arbejder med: "Performance, Operation and Reliability of Photovoltaic Systems". IEA PVPS STATUS MØDE. Organized by Danish participants in the IEA PVPS Tasks including SiCon open for all Danish stakeholders.

6. Utilisation of project results

6.1 Use of the technological results

The use of the technological results differs among stakeholders. As for developers of utility scale projects in Denmark it's clear that the improve knowledge on performance gains to be expected and modelled for bifacial modules on fixed tilt structures and trackers can be applied immediately and have demonstrated to be bankable as evaluated by the technical advisors hired by investors and banks.

Likewise, the detailed description on opportunities and challenges in use of different mobile devices in the testing of fielded modules, have already proven useful for companies involved in technical asset management of solar parks and installations.

These two examples demonstrate how utility scale PV currently are considered a bankable and low-cost solution for renewable energy generation which can be exemplified by the fact that Danish developers this year intent to more than double the domestic capacity of utility scale PV capacity from 600 to 1000 MWac as reported in the SolarPower Europe Global Market Outlook 2021. Clearly in line with national energy policy objectives that call for a 100% renewable-based electricity system by 2030.

7. Project conclusion and perspective

It's difficult to assign a single conclusion to a multi-year project that have resulted in more than 12 technical reports written in collaboration among more than 30 international experts.

However, it may be possible to conclude, that the Solar PV technology is a mature and cost-efficient technology capable of generating renewable electricity in modular systems from a few hundreds of watts to several hundreds of mega-watts while also providing investor security such that institutional investors and banks are willing to finance such subsidy-free installations in most IEA countries.

An extension of the IEA PVPS task has already been planned and will include the following subtasks:

- Subtask 1 Reliability of novel PV Materials, Components and Modules
- Subtask 2 Performance and Durability of PV Applications
- Subtask 3 Techno-Economic Key Performance Indicators

And SiCon has already participated in the planning of these subtasks and announced willingness to participate and contribute within the following areas:

- Degradation modes in new PV cell and module technology with special focus on Ga-doped/n-type silicon wafers and tandem cells.
- Floating PV,
- Agri-photovoltaics

As the previous project activities have been dealing with both technical and financial performance of the various solutions, this general approach is assumed to become an important and relevant analytical approach to be applied when analysing the new project opportunities related to floating PV and Agri-photovoltaics while also requesting a detailed technical understanding on the reliability of materials, components, and modules.

8. Appendices

All reports written and published in the IEA PVPS Task 13, are free for download from the following webpage:

<https://iea-pvps.org/research-tasks/performance-operation-and-reliability-of-photovoltaic-systems/>

The specific contribution by SiCon to the technical reports can be summarised as follows:

WP1: New materials

SiCon have been participating in development of "Report IEA-PVPS T13-13:2021", issued February 2021, titled "Designing New Materials for Photovoltaics: Opportunities for Lowering Cost and Increasing Performance through Advanced Material Innovations". SiCon have a.o. written four sections on Silicon feedstock, Crystallisation, Wafering and Thin solar glass and have been reviewer in other sections.

Jan Vedde is listed as MAIN AUTHORS and the report include the following ACKNOWLEDGEMENTS: This report is supported by the Danish Energy Agency under the Energy Technology Development and Demonstration Program (EUDP) contract no 64018-0081.

WP2: Bifacial modules and systems

SiCon have been participating in development of "Report IEA-PVPS T13-14:2020" titled "Bifacial Photovoltaic Modules and Systems: Experience and Results from International Research and Pilot Applications". Within this report SiCon has established opportunity for Nicholas Riedel-Lyngskær to contribute with the chapter "European Energy Bifacial Test Site at Risø". SiCon has been reviewer of other sections of the report which also include the following ACKNOWLEDGMENTS: "The authors would like to thank the following people for reviewing this report, Laura Bruckman and Jan Vedde."

WP3: LCOE – uncertainty in financial models

SiCon have contributed to this report by analysis of various production estimates which have also been published in the paper delivered to the European solar conference EU PVSEC titled "BENCHMARKING YIELD ASSESSMENT EXERCISE IN DIFFERENT CLIMATES WITHIN AN INTERNATIONAL COLLABORATION FRAMEWORK". SiCon have contributed to the report "Report IEA-PVPS T13-18:2020" titled "Uncertainty in Yield Assessments and Photovoltaic LCOE" and have written the section on financial models. Jan Vedde is listed among MAIN AUTHORS.

WP4: Predictive maintenance

SiCon have been reviewer on the report "Internal Working Document. A Reference Guide for PV Fault Detection Systems" authors by Mike Green, as well as the "Report IEA-PVPS T13-19:2021" titled "The Use of Advanced Algorithms in PV Failure Monitoring".

WP5: Supervision and fault detection

SiCon have participated in issuing the report "Report IEA PVPS T13 24:2021" titled "Qualification of Photovoltaic (PV) Power Plants using Mobile Test Equipment". For this report SiCon have written two chapters titled:

- "Daylight electroluminescence imaging", and
- "Electrical impedance spectroscopy"

In addition, SiCon have been reviewer of the full report.

Jan Vedde is listed among MAIN AUTHORS and the report include the following ACKNOWLEDGEMENTS: This report is supported by the Danish Energy Agency under the Energy Technology Development and Demonstration Program (EUDP) contract no 64018-0081.