Final report

1. Project details

Project title	IEA PVPS Task 16: Solar resource for large scale
File no.	64020-1082
Name of the funding scheme	EUDP (international collaboration)
Project managing company / institution	Danish Meteorological Institute (DMI)
CVR number (central business register)	1815 9104
Project partners	Technical University of Denmark (DTU)
Submission date	18 April 2024

2. Summary

English version:

In recent years, Photovoltaic (PV) solar energy has seen an unprecedented growth, both in terms of market penetration and size of individual systems. As a result, there is a growing need for accurate and reliable meteorological information of the solar resource, a necessity for optimal integration and reliable grid operation. Our work in this project helps to improve the accuracy of solar resource assessment and forecasting.

In the project, DMI and DTU have participated and contributed to the International Energy Agency's (IEA) Photovoltaic Power Systems program's (PVPS) Task 16, titled 'Solar resource for high penetration and large scale applications.' DMI has worked on dataset recommendations for the end users, led the work on the impact of long-term inter-annual variability, and improved accurate numerical weather prediction models and regional forecasts. DTU has been a main participant in benchmarking of solar resource data, to quantify and reduce uncertainty, and has led the work on making an open-access Python library and a practical guide to solar resource assessment.

The overall results of the international collaboration, including our contributions, are summarized in the IEA PVPS Task 16 Best Practices Handbook for Solar Resource Data.

Dansk version:

Der har i de seneste år været en vækst i solcelle-energiproduktion uden sidestykke – både mht. til markedsandele og mht. størrelsen af individuelle solcelle-anlæg. En forudsætning for optimal integrering af solcellerne i det danske el-net er nøjagtig og pålidelig information om solenergi-ressourcerne. Vores arbejde i dette projekt har bidraget til at forbedre nøjagtigheden af solressource-vurderingerne og vejrudsigter for disse.

I projektet har DMI og DTU Byg deltaget i det Internationale Energi Agenturs (IEA) solcelle-programs (PVPS) Task 16: 'Sol-ressourcer på stor skala med høj integreringsgrad.' DMI har bidraget til en rapport om, hvordan slutbrugere bedste bruger tilgængelige datasæt, har ledet undersøgelse af betydningen af flerårlige variationer af solressourcerne, og har forbedret deres vejrudsigter af potentiel solenergi og brug af disse på regional skala. DTU har været en af de primære deltagere i benchmarking af solressource-data for at kvantificere og reducere usikkerheder – og har ledet arbejdet med et open-source Python bibliotek og guide til brug af sol-ressource data.

Det samlede udbytte af dette international samarbejde – inklusive vore bidrag – er opsummerede i: "Best Practices Handbook for Solar Resource Data," som opdateres hvert 3. år af medlemmerne i IEA PVPS Task 16. Den næste version er ved at blive færdiggjort, vil blive reviewet og vil blive offentliggjort i slutningen af 2023.

3. Project objectives

- To provide accurate and reliable meteorological information of the solar resource and the quality of this.
- To improve the accuracy of solar resource assessment and forecasting.
- Publish unbiased reports and software to aid in accurate solar resource assessment.

4. Project implementation

The project evolved as planned. The only major change was to Milestone 4, which entailed the publications on a report on firm power generation forecasting and co-organizing a workshop on this topic. Do note that the workshop on firm power generation was held and a report on this (https://iea-pvps.org/key-topics/firm-power-generation/) published, however, we did not contribute from the Danish side. This change is due to the success of DTU's work with benchmarking and the open-access software library. Milestone 4 was change to focus on these instead; this change has earlier been approved by EUDP.

The main risk in this international collaboration project was that any of the key participants from either DMI or DTU would change jobs. This did not happen. We did not experience unexpected problems.

5. Project results

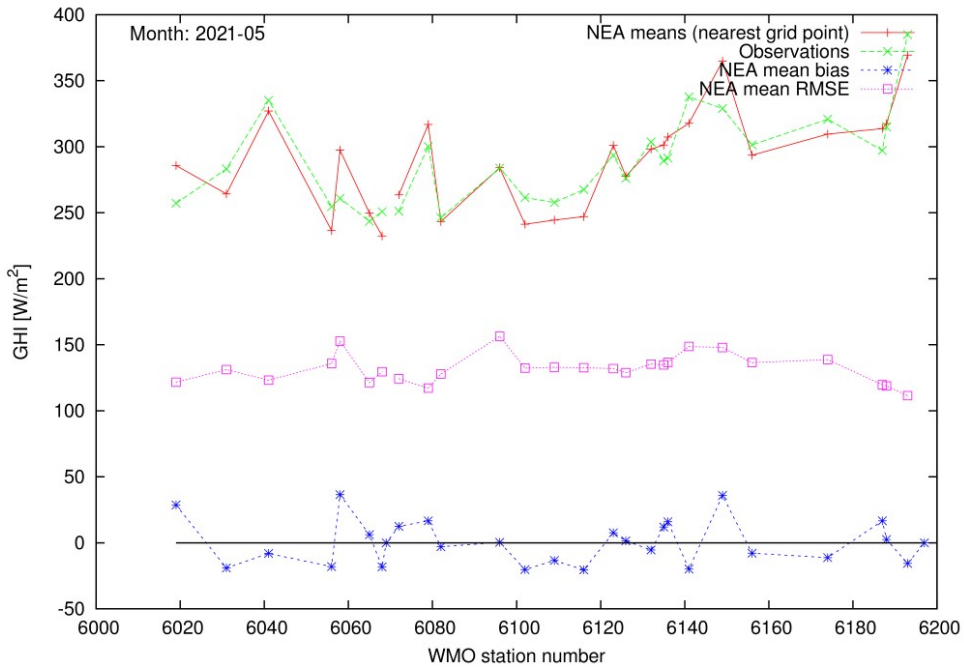
The project objective was obtained with good success, with DMI and DTU taking the lead of activities in the international project. Here, particularly the open-access software pvlib iotools and the interactive guide AssesingSolar.org, developed by Adam R. Jensen should be emphasized. This can be recommended to solar energy consultants, students, and others working with solar resource data. A conference article describing the efforts was published, see Jensen, A. et al. (2022). At the time of this report, the interactive guide has been seen by an impressive 9000 unique visitors.

The global benchmarking study of a range of solar resource datasets (https://iea-pvps.org/key-topics/worldwide-benchmark-of-modelled-solar-irradiance-data/) was published in June 2023. Knowing the

quality of these datasets is useful for planning of individual solar energy systems and energy planning at larger scales. As part of this work a comprehensive quality control procedure was developed and published, see Forstinger, A. et al. (2022). The results were also presented in the form of a webinar held on June 28th 2022 and as part of the 2022 PVPMC Workshop. Additionally, conference presentations were given at EMS 2022, 2022 BSRN Scientific Review and Workshop, and 2022 EUPVSEV.

Results from the previous stage of the tasks were also published in a journal article, see Tschopp, D. et al. (2022). This included the development of an enhanced transposition model and an open-source dataset from ground irradiance measurements from DTU.

The results of DMI's weather model improvements have been presented at meetings in the ACCORD weather model consortium, of which DMI is a member. The weather models are continually monitored and validated against global horizontal irradiance measurements across Denmark. A basic example is shown below. The validations are also done for the daily cycle and for clear-sky normalized irradiance.



Example plot of average hourly statistics (May 2021) for global horizontal irradiance for Danish synoptic stations. Green: Observations. Red: The HARMONIE-AROME weather model for the 'NEA' domain. Magenta: Root mean square difference between these two. Blue: Absolute difference between these two.

Experiments have been made to improve the validation statistics. Particularly, the representation of the cloud droplet number concentration in the weather model HARMONIE-AROME has been tested and modified in DMI's operational models. Further work has been done on this topic on using aerosol data from the CAMS model in the initial state of the HARMONIE-AROME model. This will mean more accurate clear-sky solar irradiance forecasts, and the explicit calculation of cloud-aerosol interactions in the model is expected to improve the cloud droplet number concentration representation, which again improves the cloudy weather solar irradiance forecasts. This is being tested and is planned to be used in the next update of the HARMONIE-AROME weather model.

A web page (https://www.solarpaces.org/solar-radiation-products-for-the-end-users/) has been with the recommendations from the activity on solar radiation products for end users. A report (https://www.solarpaces.org/wp-content/uploads/SunUpReport_210419-V2-web.pdf) was also published on this in April 2021.

Updates on the activity of long-term inter-annual variability have been made at the Task 16 meetings with a particular focus on volcanic eruptions and investigating how periods of long-term “dimming” and “brightening” of solar irradiance can be explained. The following can be concluded regarding the latter:

- Dimming and brightening periods can be seen consistently in solar irradiance datasets across regions.
- They follow changes in polluting aerosols due to increased industrialization during the 20th century, during dimming periods, and brightening periods following political “clean air act” type decisions.
- According to IPCC the explanation is mainly sulfate aerosol in the atmospheric boundary layer, and their indirect effect on clouds, that is more sulfate aerosols mean higher cloud droplet number concentration.
- Current climate models miss future volcanic eruptions, and most also do not include varying aerosol scenarios for the future. This is important to know for those who do long-term energy system planning.

The updated ”Best Practices Handbook for Solar Resource Data” is due to be published by the end of 2023 or the start of 2024. DMI has been responsible for the section on weather prediction models and the section on long-term inter-annual variability. DTU has been responsible for leading the work with the new chapter on quality assessment. Likewise, the current edition was published in 2021, during this project period. It can be found here: https://iea-pvps.org/key-topics/best-practices-handbook-for-the-collection-and-use-of-solar-resource-data-for-solar-energy-applications-third-edition/

6. Utilisation of project results

The reports and software developed during this project should be helpful to all working in the field of solar resources and forecasting. This includes solar energy system planners and operators, academics and engineers, consultants, meteorologists, and private companies.

This is not a commercial project, and there are no competitors that we are aware of. In fact many of the actors in this field from both the private and the public sector contribute to this international task, as they see a benefit of doing so.

The project helps to map the potential possibilities and challenges of using solar energy for electricity generation, heating and energy storage. Often these are larger than is broadly realised at the political level.

7. Project conclusion and perspective

The project has been a success and will be continued in the period 2023-2026. The Danish contribution in this period will be led by DTU collaborating with DMI. It is supported by EUDP grant No. 134232-510237.

8. Appendices

Links to relevant reports and web pages are made inline in the text above.

Tschopp, D., Jensen, A. R., Dragsted, J., Ohnewein, P., & Furbo, S. (2022). Measurement and modeling of diffuse irradiance masking on tilted planes for solar engineering applications. In Solar Energy (Vol. 231, pp. 365–378). Elsevier BV. https://doi.org/10.1016/j.solener.2021.10.083

Jensen, A. R., Jensen, A. R., Lopez Lorente, J., Blanc, P., & Saint-Drenan, Y.-M. (2021). Assessingsolar: An Interactive Guide to Solar Resource Assessment in Python. In Proceedings of the ISES Solar World Congress 2021. ISES Solar World Congress 2021. International Solar Energy Society. https://doi.org/10.18086/swc.2021.37.03

Forstinger, A., Wilbert, S., Kraas, B., Fernández Peruchena, C., Gueymard, C. A., Collino, E., Ruiz-Arias, J. A., Polo Martinez, J., Saint-Drenan, Y.-M., Ronzio, D., Hanrieder, N., Jensen, A. R., & Yang, D. (2021). Expert Quality Control of Solar Radiation Ground Data Sets. In Proceedings of the ISES Solar World Congress 2021. ISES Solar World Congress 2021. International Solar Energy Society. https://doi.org/10.18086/swc.2021.38.02