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Final report

IEA PVPS Task 16

Solar Resource for High Penetration and Large Scale Applications (Phase 2, 2020–2023)

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Summary

IEA PVPS Task 16 (2020–2023) – phase 2 – was the first extension phase of Task 16 which ended in June 2023. Jan Remund of Meteotest leads the Task as Task Manager on behalf of the PVPS Technology Collaboration Program with support of SFOE. From Switzerland, additionally the SPF Institute for Solar Technology of the OST University of Applied Sciences is taking part in Task 16.

The main goals of the Task are to lower barriers and costs of grid integration of PV and lowering planning and investment costs for PV by enhancing the quality of forecasts and resource assessments. The work is organized in four Subtasks:

- Subtask 1: Evaluation of current and emerging resource assessment methodologies
- Subtask 2: Enhanced data & bankable products
- Subtask 3: Evaluation of current and emerging solar resource and forecasting techniques
- Subtask 4: Dissemination and Outreach

Meteotest was mainly involved in leading, disseminating and organizing the Task (Subtask 4) but did actively work in the field of firm PV power. This final report of the Swiss supporting project includes the overview of the work done in the last three years. 50 participating organizations from 19 countries had to be coordinated. During the 3 years a total of 6 Task meetings were organized – of which 2 online and 4 in hybrid form.

The main result of Task 16 – the update of the Solar Resource Handbook (3rd edition) – was published in May 2021. The work for the 4th edition has been started and is planned to be finished early 2024. Five webinars and two workshop have been organized. Three scientific papers and four reports have been published and two websites programmed.

Zusammenfassung

IEA PVPS Task 16 (2020–2023) – Phase 2 – war die erste Erweiterungsphase vom Task 16, die im Juni 2023 endete. Jan Remund von Meteotest leitet den Task als Task Manager im Auftrag des PVPS Technology Collaboration Program mit Unterstützung des BFE. Aus der Schweiz nimmt zusätzlich das SPF Institut für Solartechnik der Fachhochschule OST am Task 16 teil.

Die Hauptziele des Tasks sind die Senkung der Barrieren und Kosten der Netzintegration von PV und die Senkung der Planungs- und Investitionskosten für PV durch die Verbesserung der Qualität von Prognosen und der Ressourcenbewertung. Die Arbeit ist in vier Unteraufgaben gegliedert:

- Subtask 1: Bewertung aktueller und neuer Methoden der Ressourcenbewertung
- Subtask 2: Verbesserte Daten und bankfähige Produkte
- Subtask 3: Bewertung aktueller und neuer Verfahren zur Bewertung von Solarressourcen und Vorhersagen
- Subtask 4: Verbreitung und Öffentlichkeitsarbeit

Meteotest war hauptsächlich an der Leitung, Verbreitung und Organisation des Tasks (Subtask 4) beteiligt, hat aber auch aktiv im Bereich der «firm» PV-Leistung gearbeitet. Der vorliegende Abschlussbericht des Schweizer Unterstützungsprojekts gibt einen Überblick über die in den letzten drei Jahren geleistete Arbeit. 50 teilnehmende Organisationen aus 19 Ländern mussten unter einen Hut gebracht werden. Während der 3 Jahre wurden insgesamt 6 Task-Treffen organisiert – davon 2 online und 4 in hybrider Form.

Das wichtigste Ergebnis des Task 16 – die Aktualisierung des «Solar Resource Handbook» (3. Auflage) - wurde im Mai 2021 veröffentlicht. Die Arbeit an der 4. Auflage wurde begonnen. Die Veröffentlichung ist für Anfang 2024 geplant.

Resumé

IEA PVPS Task 16 (2020–2023) – phase 2 – était la première phase d'extension de la Task 16 qui s'est terminée en juin 2023. Jan Remund de Meteotest dirige la tâche en tant que Task Manager au nom du programme de collaboration technologique PVPS avec le soutien de l'OFEN. En Suisse, l'Institut de technologie solaire SPF de la Haute école spécialisée OST participe également à la Task 16.

Les principaux objectifs de la tâche sont de réduire les obstacles et les coûts de l'intégration du photovoltaïque dans le réseau et de réduire les coûts de planification et d'investissement pour le photovoltaïque en améliorant la qualité des prévisions et des évaluations des ressources. Le travail est organisé en quatre sous-tâches :

- Sous-tâche 1: Évaluation des méthodologies actuelles et émergentes d'évaluation des ressources
- Sous-tâche 2: Données améliorées et produits bancables
- Sous-tâche 3: évaluation des ressources solaires actuelles et émergentes et des techniques de prévision
- Sous-tâche 4: diffusion et sensibilisation

Meteotest a été principalement impliqué dans la direction, la diffusion et l'organisation de la tâche (sous-tâche 4), mais a travaillé activement dans le domaine de la puissance photovoltaïque ferme. Ce rapport final du projet soutenu par la Suisse comprend une vue d'ensemble du travail effectué au cours des trois dernières années. 50 organisations participantes de 19 pays ont dû être maintenues ensemble. Au cours de ces trois années, un total de 6 réunions de la tâche ont été organisées – dont 2 en ligne et 4 sous forme hybride.

Le principal résultat de la tâche 16 – la mise à jour du Solar Resource Handbook (3e édition) – a été publié en mai 2021. Le travail pour la 4ème édition a commencé et est prévu pour janvier 2024.

Contents

List of abbreviations

IEA	International Energy Agency
NREL	National Renewable Energy Laboratory of USA
PV	Photovoltaic
PVPS	Photovoltaic Power System, TCP of IEA
SFOE	Swiss Federal Office of Energy
SolarPACES	IEA TCP for concentrating solar and chemistry
TCP	Technology Collaboration Programme

1 Introduction

IEA PVPS Task 16[1] (T16) started in July 2017. The first phase ended after three years in June 2020. The first extension phase – confirmed in the Exco meeting of November 2019 – started in July 2020 and ended in June 2023. This is the final report of this 2nd phase.

T16 is a joint Task with the TCP SolarPACES (Task V). It keeps also minimal collaboration with the Solar Heating and Cooling (SHC) – the Technology Collaboration Programme of the preceding solar resource and forecast Tasks.

Meteotest leads the Task as OA on behalf of the PVPS TCP with support of Swiss Federal Office of Energy (SFOE). Manuel Silva of Univ. of Sevilla, Spain leads the Task V since summer 2018 on behalf of SolarPACES.

The main work of Meteotest was to organize to ongoing work of the Task – meetings, workshops and reports – and informing the Exco about the updates.

From Switzerland, additionally the SPF Institute for Solar Technology of the OST University of Applied Sciences is taking part in Task 16.

Task 16 is one of the larger Tasks regarding the number of organizations (50) and countries (19). It's also a rather scientific Task including many research organizations and universities.

2 Workplan

The main goals of the 2nd phase of T16 are lowering barriers and costs of grid integration of PV and lowering planning and investment costs for PV by enhancing the quality of the forecasts and the resources assessments.

To reach this main goal the Task has the following objectives:

- Lowering uncertainty of satellite retrievals and of Numerical Weather Prediction (NWP) models for solar resource assessments and nowcasting.
- Develop enhanced analysis of long-term inter-annual variability and trends in the solar resource also induced by climate change.
- Develop and compare methods for
    - Estimating the spectral and angular distributions of solar radiation (clear and all-sky conditions)
    - Describing the spatial and temporal variabilities of the solar resource
    - Modelling point to area forecasts
    - Probabilistic forecasting
- Contribute to or setup international benchmark for data sets and for forecast evaluation.

In this phase the following focus points were defined:

1. Modelling of spectral data (activity 1.2)
2. Providing a public set of quality proofed meteorological data (activity 1.4)

[1] https://iea-pvps.org/research-tasks/solar-resource-for-high-penetration-and-large-scale-applications/

3. Analyzing extreme conditions long term trends induced by climate change (activity 2.4)
4. Analyzing solar data on urban scales (new activity 2.6)
5. Modelling of meteorological data and albedo for bifacial modules (activity 2.7)
6. Providing models and information for firm power production (new activity 3.5)
7. Delivering code as supplement to reports (new activity 4.5)

The scope of the work in Task 16 concentrates on meteorological and climatological topics needed to plan and run PV, solar thermal, concentrating solar power stations and buildings. As in the preceding Task solar resource assessment and forecasting are the main focus.

To handle this scope the work programme is organized into three main technical Subtasks (Subtasks 1 – 3) and one dissemination Subtask (Subtask 4) (Table 1):

Table 1: Subtasks and Activities of Task 16 (2020-2023)

Subtask	Activity
Subtask 1: Evaluation of current and emerging resource assessment methodologies	1.1 Ground based methods
	1.2 Modelling for NWP / satellite data
	1.4 Benchmarking framework
Subtask 2: Enhanced data & bankable products	2.1 Data quality and format
	2.4 Long-term inter-annual variability
	2.5 Products for the end-users
	2.6 PV at urban scales
	2.7: Data and models for bifacial modules
Subtask 3: Evaluation of current and emerging solar resource and forecasting techniques	3.2 Regional solar power forecasting
	3.3 Probabilistic solar forecasting
	3.4 Forecasts based on all sky imagers
	3.5 Firm power generation
Subtask 4: Dissemination and Outreach	4.2 Produce a periodic Task newsletter
	4.3 Conduct periodic (annual) Subtask-level webinars and/or conference presentations
	4.4 Update of solar resource handbook
	4.5 Solar resource assessment in Python

Whereas Subtasks 1 and 3 are mainly focused on ongoing scientific work, Subtask 2 and 4 are mostly focused on user aspects and dissemination.

In Table 2 and Figure 1 the Task participants are listed.

Table 2: Participating countries (19) and organizations (51) of Task 16.

Country	TCP	PM	Partners
AUS	PVPS	5	University of South Australia, Univ. of NSW (UNSW)
AUT	PVPS	4	Fachhochschule Oberösterreich (FH OOE)
CAN	PVPS	3	Natural Resources Canada
CHE	PVPS	21	Meteotest, HSR (SPF)
CHN	PVPS	4	Public Meteorological Service Center (China Meteorological Administration - CMA)
DEU	PVPS SolarPACES	42	Fraunhofer (ISE & IEE), DLR (both TCP)
DNK	PVPS	18	Danish Meteorological Institute (DMI), Technical University of Denmark (DTU)
ESP	PVPS SolarPACES	51	CIEMAT, CENER, Public University of Navarra, Univ. Almeria, Univ. Jaen, Univ. Malaga, University of Seville (US), Univ. des Las Palmas de Gran Canaria, Mactech
EU	PVPS	3	JRC
FRA	PVPS	10	CNRS-Promes, MINES ParisTech, Laboratoire PIMENT, Université la Réunion, Univ. des Antilles et de la Guyane, Ecole Polytechnique à Palaiseau, EDF R&D, RTE
ITA	PVPS SolarPACES	7	i-em, RSE, Uni Tor Vergata, ENEA
NLD	PVPS	2	Univ. Utrecht
NOR	PVPS	2	IFE and Met. Norway
SWE	PVPS	5	SMHI, Uni Uppsala
USA	PVPS	17	Dep. of Energy/National Renewable Energy Laboratory (NREL), National Aeronautics and Space Administration (NASA), State Univ. of New York at Albany (SUNY), University of Oregon, Clean Power Research (CPR), Solar Consulting Services (SCS)
GBR	SHC	4	Peakdesign Ltd., Rina Consulting, World Energy & Meteorology Council (WEMC), Univ. Glasgow
GRE	SolarPACES	1	Univ. of Patras
MOR	SolarPACES	1	IRESEN
SVK	SHC	2	Solargis

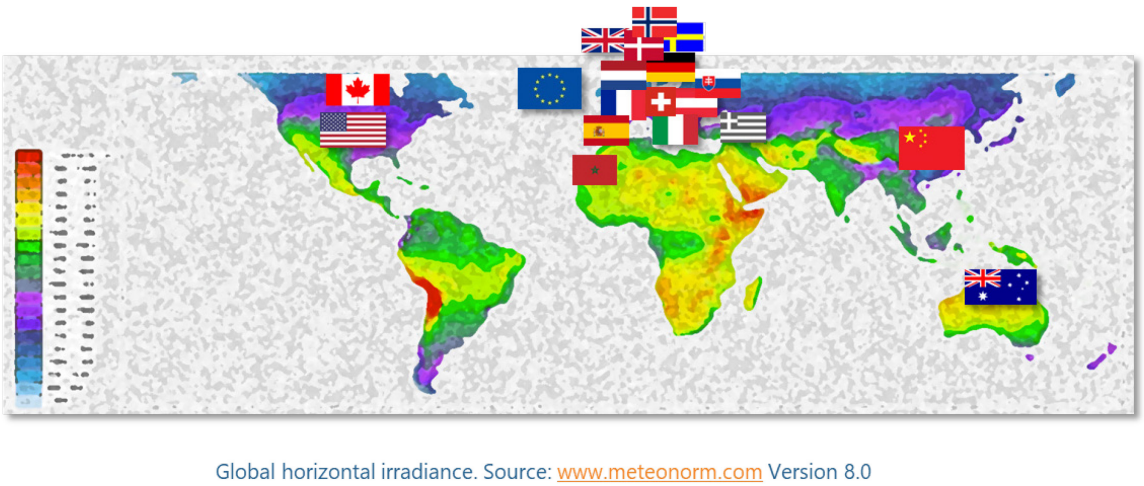

Figure 1: Countries participating in the Task 16.

3 Leading the Task

The work of the Task leader is quite diverse. Questions regarding administration, participation and organization take up quite a large share. With 80 experts in 50 organizations there are frequent changes in the membership. About 10% of the groups left the Task and were replaced with new members.

The main issue is to keep the participants on the track foreseen in the workplan. As only a few participants are directly financed for the international collaboration, many are presenting and including work they do in similar projects (on the same topic) on national or international levels. As there are hardly any finances included from the IEA side, the Task Manager needs to handle the leadership with great care and mostly by motivating partners.

Specialisation is also increasing in the field of solar resources. Therefore – (even in a relatively small area as solar resources – it's demanding to keep pace with all the ongoing scientific work. Nevertheless, to be up to date regarding the topics is important for the Task Manager – e.g. for reviewing reports and disseminating results.

Of course the work couldn't be done by the Task Manager alone. In the 2nd phase the managements tasks were shared with Manajit Sengupta of NREL, who was elected as deputy Task Manager in 2019. Much work is also done by the Subtask leaders, who organise their sessions at the meetings. Reports are written by activity groups with great support from their leaders. With the help of them it's a great pleasure to lead the Task.

The shares of the work of the individual Task members differ greatly. About 20% are quite passive, about 40% frequently deliver inputs during meetings and about 40% are working actively to reach the objectives of the Task.

4 Completed Tasks and achieved results

IEA PVPS Task 16 is among the biggest Tasks in PVPS TCP concerning number of participants (50) and countries (19). Additionally, financial resources are not adequate in many countries. Both issues made operating the Task not an easy assignment. Lacking resources as well as changes of participant's staff of also led to re-organisation and changes of activity and Subtask leads.

The main result of the first phase of the Task is the update of the solar resource handbook. This report was published in April as NREL version[2] and in May 2021 in PVPS version[3]: This report includes all major work done in 2021. Currently the 4th edition of the Solar Resource Handbook is being written. Most of the chapters (including two new ones) are in internal review. The publication is planned for early 2024.

Table 3 shows the results described in the work plan and the results achieved.

[2] https://www.nrel.gov/docs/fy21osti/77635.pdf

[3] https://iea-pvps.org/key-topics/best-practices-handbook-for-the-collection-and-use-of-solar-resource-data-for-solar-energy-applications-third-edition/

Table 3: Subtasks and Activities of Task 16 (2020-2023). The 4th edition of the solar resource handbook "(handbook") is currently written and exists as draft.

Subtask	Activity	Work plan	Result
Subtask 1:	1.1 Ground based methods	Text in Handbook Workshop	Draft Done
	1.2 Modelling for NWP / satellite data	Text in Handbook	Draft
	1.4 Benchmarking Framework	Report[1] Workshop	Done Done
Subtask 2:	2.1 Data quality and format	Report Gap-Filling[2] Text in Handbook	Done Draft
	2.4 Long-term inter-annual variability	Review Text in Handbook	Done Draft
	2.5 Products for the end-users	Workshop Report[3] Text in Handbook	Done Done Draft
	2.6 PV at urban scales	Benchmark of solar cadastres (paper[4]) Text in Handbook	Done Draft
	2.7: Data and models for bifacial modules	Text in Handbook	Draft
Subtask 3:	3.2 Regional solar power forecasting	Report[5]	Done
	3.3 Probabilistic solar forecasting	Report → paper	Draft
	3.4 Forecasts based on all sky imagers	2 Papers [6] Workshop	Done Done
	3.5 Firm power generation	Report Workshop	Done Done
Subtask 4:	4.2 Produce a periodic Task Newsletter	Newsletters	Not done
	4.3 Conduct periodic (annual) Subtask-level webinars and/or conference presentations	Organize webinars / Workshops	Done
	4.4 Update of solar resource handbook	Handbook 3rd ed. Handbook 4th ed.	Done Draft
	4.5 Solar Resource Assessment in Python	Webpages[7]	Done

[1] Forstinger et al., 2023

[2] Blanc and Amaro e Silva, 2023

[3] SolarPACES report and webpage: https://www.solarpaces.org/the-sun-up-project

[4] Amaro e Silva and Blanc 2022

[5] Betti et al. 2020

[6] Salamalikis et al., 2020 and Salamalikis et al. 2021

[7] www.solarstations.org and www.assessingsolar.org

Most of the work proposed could be achieved. Taking into account to the often not sufficient support as well as the Corona pandemic, this is a positive result. In Activity 2.1 and 3.3 additional reports have been promised. In Activity 2.1 one report was published in 2023. The additional topics will be handled in the third phase (not in reports but in scientific papers and part of the updated Handbook). The report of Activity 3.3 was switched into a scientific paper, which is currently being written. We didn't write the suggested newsletters due to missing amount of information within the Task, the big number of existing newsletters and the fact that PVPS now has its own newsletter.

4.1 Papers published

A big part of the work of Activity 1.4 (Benchmarking) dealt with finding and quality checking data for the validation. This work has been described in a special paper (Forstinger et al. 2021).

The result of activities 3.4 (All Sky Imagers) was concluded in two papers (Salamalikis et al. 2020 and Salamalikis et al. 2021).

Many more papers were published outside the task as a result of the collaboration by one or several groups active in the Task. To name some examples:

Sommer Klyve, Øyvind, Magnus Moe Nygård, Heine Nygard Riise, Jonathan Fagerström, Erik Stensrud Marstein, 2023. The value of forecasts for PV power plants operating in the past, present and future Scandinavian energy markets, Solar Energy, Volume 255, 2023, Pages 208-221, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2023.03.044

Polo, J., Martín-Chivelet, N., Alonso-Abella, M., Alonso-García, C., 2021. Photovoltaic generation on vertical façades in urban context from open satellite-derived solar resource data. Solar Energy 224, 1396–1405. doi:10.1016/j.solener.2021.07.011

Lorenz, E. et al., 2022 High resolution measurement network of global horizontal and tilted solar irradiance in southern Germany with a new quality control scheme. Sol. Energy 231, 593–606 (2022).

5 Own scientific contributions

The main work of Meteotest was leading and organizing the Task.

As provider of solar resource and forecast data we were also part of different activities. Meteotest prepared data and took part in the benchmark of modelled solar resource data (Activity 1.4, Forstinger et al., 2023) and all sky imagers (Activity 3.4, Salamalikis et al., 2020 and Salamalikis et al., 2021).

The main scientific input was made for Activity 3.5. In the SFOE (2022) project "Firm PV Power Switzerland" we investigated the concept of Firm PV power in Switzerland (Remund et al., 2022). The results have been disseminated also via energeia[4]: Optimally 10-20% of the energy produced by PV is curtailed. The analysis showed that curtailment lowers the costs of the energy transition significantly.

6 Conclusions and outlook

The collaboration in IEA PVPS Task 16 offers unique possibilities. There is no other comparable worldwide network of experts in energy-meteorology aside this Task. The main results are descriptions of state-of-the-art and benchmarking reports. However, also new aspects as e.g. integration of renewables in the electricity grid were initiated. During 2022 an updated workplan for the third phase (2023–2026) has been elaborated during Task meetings.

The third phase of Task 16 has been confirmed at the end of 2022 and started in July 2023. It will go on for another three years. The work plan of this phase foresees five reports, four scientific papers and three to four webinars or workshops.

[4] https://energeiaplus.com/2022/06/27/solarstrom-im-schweizer-stromsystem-effektiv-und-wirtschaftlich-dank-ueberdimensionierung-und-abregelung

7 Publications

Amaro e Silva, R. and P. Blanc, 2022: Estimating Global Horizontal Irradiance at the Urban Level: a Sensitivity Analysis Using Different Digital Surface Models. Proceedings of WCPEC-8, 4BV.4.27. 26-30.9.2023, Milano, Italy. https://doi.org/10.4229/WCPEC-82022-4BV.4.27

Betti, A. et al., 2020: Regional solar power forecasting. IEA PVPS Report T16-01:2020. ISBN: 978-3-906042-88-6. https://iea-pvps.org/key-topics/regional-solar-power-forecasting-2020/

Blanc, P. and R. Amaro e Silva, 2023: Framework for benchmarking of GHI gap-filling methods. IEA PVPS Report T16-03:2023. ISBN: 978-3-907281-37-6. https://iea-pvps.org/key-topics/framework-for-benchmarking-of-ghi-gap-filling-methods/

Forstinger, A., Wilbert, S., Kraas, B. & Gueymard, C., 2021: Expert quality control of solar radiation ground data sets. in *ISES Solar World Conference* (2021).

Forstinger, A. et al., 2023: Worldwide benchmark of modelled solar irradiance data. IEA PVPS Report T16-05:2023. ISBN: 978-3-907281-44-44. https://iea-pvps.org/key-topics/worldwide-benchmark-of-modelled-solar-irradiance-data/

Salamalikis, Vasileios, Ioannis Vamvakas, Christian A. Gueymard, Andreas Kazantzidis, 2020: Atmospheric water vapor radiative effects on shortwave radiation under clear skies: A global spatiotemporal analysis, Atmospheric Research, Volume 251, 2021, 105418, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2020.105418.

Salamalikis, Vasileios, Ioannis Vamvakas, Philippe Blanc, Andreas Kazantzidis, 2021: Ground-based validation of aerosol optical depth from CAMS reanalysis project: An uncertainty input on direct normal irradiance under cloud-free conditions, Renewable Energy, Volume 170, 2021, Pages 847-857, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2021.02.025.

Sengupta, M., Habte, A., Wilbert, S., Gueymard, C. & Remund, J. *Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications*. (2021). IEA PVPS Report T16-02:2021. ISBN: 978-3-907281-19-2. https://iea-pvps.org/key-topics/best-practices-handbook-for-the-collection-and-use-of-solar-resource-data-for-solar-energy-applications-third-edition/

8 References

Remund, J., Perez, M. J. & Perez, R. *Firm PV power generation for Switzerland*. (2022). Report on behalf of SFOE. https://www.aramis.admin.ch/Grunddaten/?ProjectID=49486