



Supplement of

PV power modelling using solar radiation from ground-based measurements and CAMS: Assessing the diffuse component related uncertainties leveraging the Global Solar Energy Estimator (GSEE)

Nikolaos Papadimitriou et al.

Correspondence to: Nikolaos Papadimitriou (npapadimitriou@academyofathens.gr)

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Supplement

2 Nomenclature

Acronym	Definition
AERONET	AErosol RObotic NETwork
AE	Angström Exponent
AOD	Aerosol Optical Depth
BRL	Boland-Ridley-Lauret diffuse fraction model
BSRN	Baseline Surface Radiation Network
CAMS	Copernicus Atmosphere Monitoring Service: ECMWF tool for atmospheric composition knowledge
DHI	Diffuse Horizontal Irradiance
DNI	Direct Normal Irradiance
DWD	Deutscher Wetterdienst: German Meteorological Service
ECMWF	European Centre for Medium-Range Weather Forecasts
FMF	Fine Mode Fraction
gg	Assymetry factor
GHI	Global Horizontal Irradiance
GSEE	Global Solar Energy Estimator
MAE	Man Absolute Error
MBE	Mean Bias Error
MOL-RAO	Meteorologisches Observatorium Lindenberg, Richard-Aßmann-Observatorium: DWD Observatory Lindenberg, Lindenberg (Tauche), Germany
NEO	Navarino Environmental Observatory, Messinia, Greece
PDFs	Probability Density Functions
PMOD/WRC	Physikalisch-Meteorologisches Observatorium Davos / World Radiation Center, Davos, Switzerland
PV	Photovoltaic
QC	Quality Check
r	Weighted correlation coefficient
rMBE	Relative Mean Bias Error

RMSE	Root Mean Square Error
RTM	Radiative Transfer Model
SDA	Spectral Deconvolution Algorithm
SSA	Single Scattering Albedo
SV	Solar Visibility
SZA	Solar Zenith Angle
TOC	Total Ozone Column (in DU)
TPM	Faculty of Technology, Policy, and Management, Delft, the Netherlands
UTC	Coordinated Universal Time
WMO	World Meteorological Organisation

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5 **Evaluation Metrics**

6 The formulas for the evaluation metrics used are the following:

7 1. Root Mean Square Error (RMSE)

$$8 \quad RMSE = \sqrt{\frac{1}{N} \sum (x_{mod} - x_{obs})^2} \text{ (S1)}$$

9 2. Mean Absolute Error (MAE)

$$10 \quad MAE = \frac{1}{N} \sum |x_{mod} - x_{obs}| \text{ (S2)}$$

11 3. relative Mean Bias Error (rMBE)

$$12 \quad rMBE = \frac{1}{N} \sum \left(\frac{x_{mod} - x_{obs}}{x_{obs}} \right) \times 100\% \text{ (S3)}$$

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Figure S1. Difference between the diffuse fraction derived directly from the computations of DHI and GHI using libRadtran and the one estimated by applying BRL to the libRadtran-computed GHI for surface albedo 0.8

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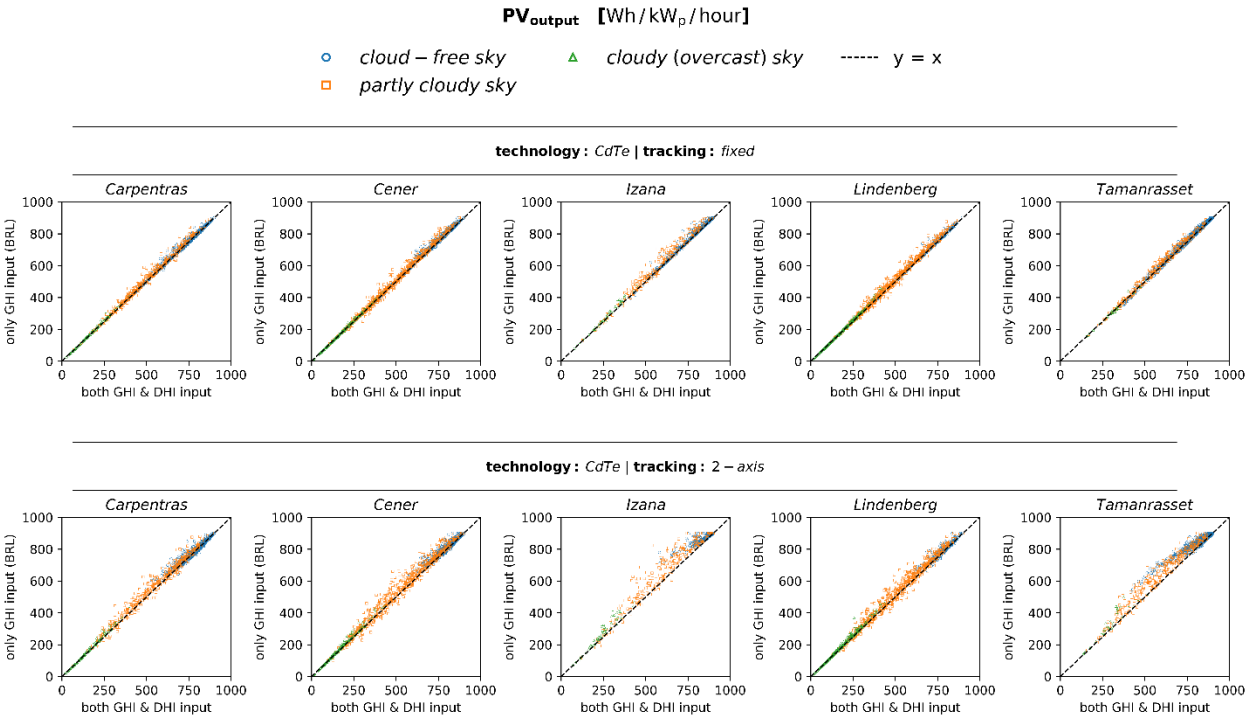


Figure S2. Comparison of the estimated hourly PV power generation between simulations performed using GSEE with input data consisting of either only GHI or both GHI and DHI under varying cloudiness conditions for panels with CdTe technology

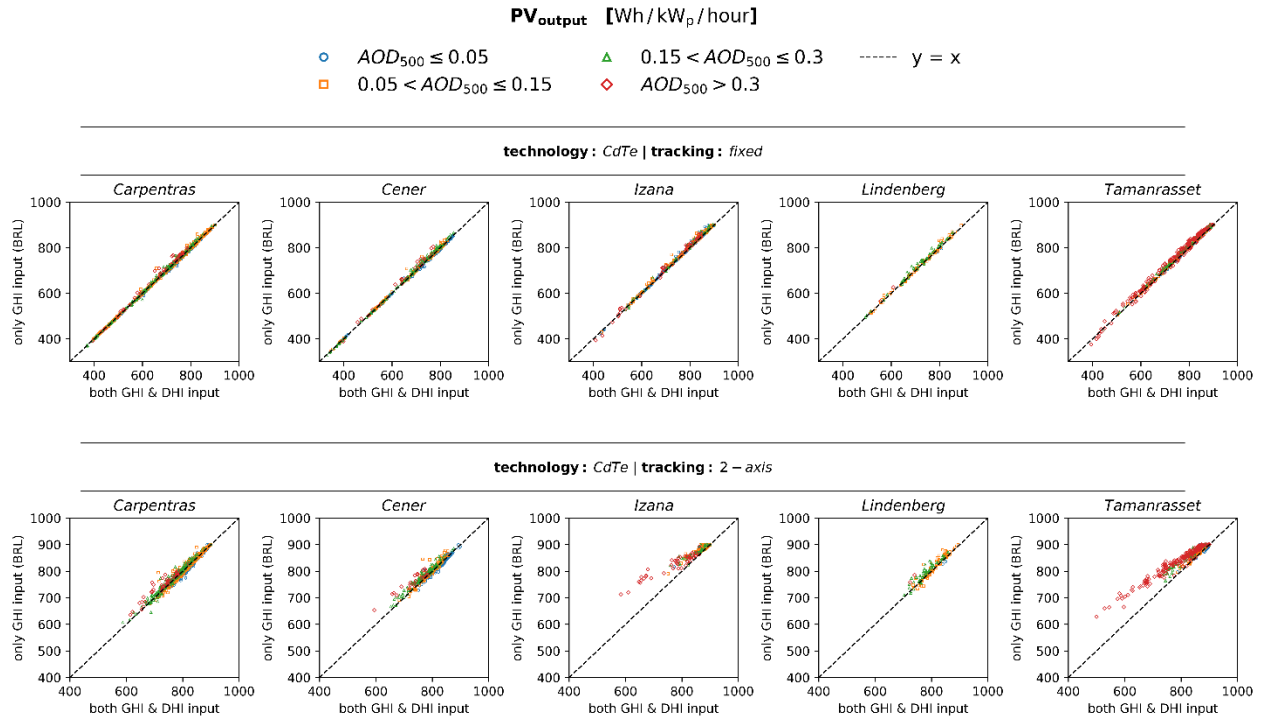


Figure S3. Comparison of the estimated hourly PV power generation between simulations performed using GSEE with input data consisting of either only GHI or both GHI and DHI under varying aerosol conditions for panels with CdTe technology

Table S1. Evaluation metrics for GSEE performance within hourly intervals in Cener, comparing simulations with diffuse fraction from measurements and from the BRL model.

STATION: Cener		fixed panels			2-axis tracking		
		RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)	RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)
All-Sky scenes		14.5	8.2	1.2	27.1	16.7	2.3
All-Sky scenes (cloudiness)	cloud-free	11.7	6.4	0.8	19.5	11.9	1.3
	partly cloudy	19.3	12.4	2.0	37.5	26.4	4.1
	cloudy (overcast)	4.7	2.7	1.6	11.2	6.3	4.6
Cloudless- Sky scenes (aerosol load)	clear sky / low	4.0	2.5	-0.2	7.9	5.5	-0.4
	moderate	6.9	3.1	0.4	11.4	6.2	0.6
	high	8.7	6.2	1.0	15.4	12.8	1.8
	very high	NaN	NaN	NaN	NaN	NaN	NaN

Table S2. Evaluation metrics for GSEE performance within hourly intervals in Lindenberg, comparing simulations with diffuse fraction from measurements and from the BRL model.

STATION: Lindenberg		fixed panels			2-axis tracking		
		RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)	RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)
All-Sky scenes		16.0	9.7	1.8	26.1	17.0	2.7
All-Sky scenes (cloudiness)	cloud-free	11.8	6.7	0.9	20.7	13.5	1.4
	partly cloudy	20.4	13.9	2.3	32.4	23.5	3.5
	cloudy (overcast)	6.7	3.6	2.4	11.7	6.5	4.6
Cloudless- Sky scenes (aerosol load)	clear sky / low	NaN	NaN	NaN	NaN	NaN	NaN
	moderate	8.9	5.5	0.5	14.9	9.7	0.6
	high	12.6	10.3	1.4	19.5	15.9	2.0
	very high	NaN	NaN	NaN	NaN	NaN	NaN

Table S3. Evaluation metrics for GSEE performance within hourly intervals in Izana, comparing simulations with diffuse fraction from measurements and from the BRL model.

STATION: Izana		fixed panels			2-axis tracking		
		RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)	RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)
All-Sky scenes		20.0	11.3	1.5	41.5	22.3	2.8
All-Sky scenes (cloudiness)	cloud-free	12.3	7.2	0.9	26.6	12.7	1.5
	partly cloudy	36.1	25.8	4.3	73.4	55.1	9.3
	cloudy (overcast)	16.8	11.8	4.6	35.5	26.0	11.8
Cloudless- Sky scenes (aerosol load)	clear sky / low	6.8	4.8	0.6	7.8	3.7	0.4
	moderate	9.3	6.5	0.9	20.8	15.0	1.8
	high	11.2	8.6	1.1	31.4	26.2	3.3
	very high	14.1	11.8	1.4	64.5	52.1	7.3

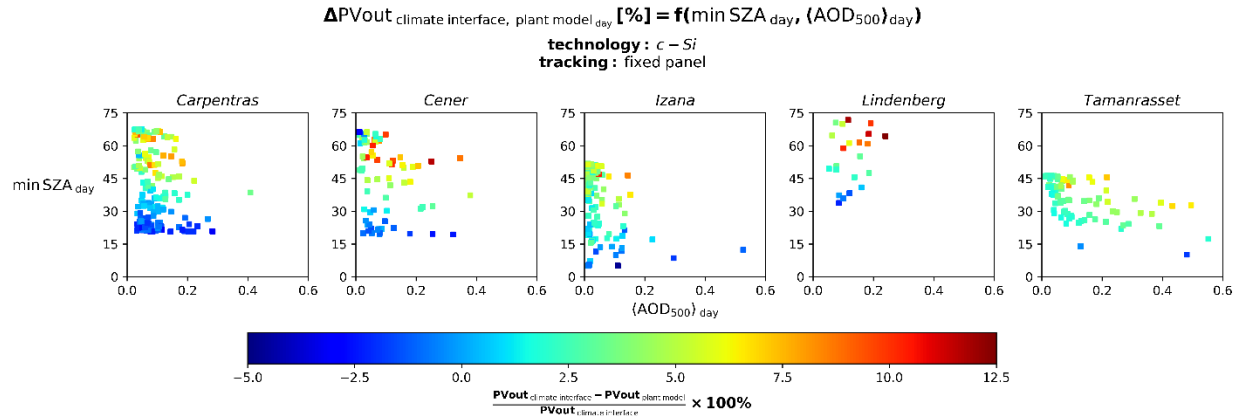


Figure S4. Percentage differences between the daily PV output estimated using the climate interface and the corresponding daily sums from hourly simulations as function of minimum daily SZA and mean daily aerosol load for fixed panels

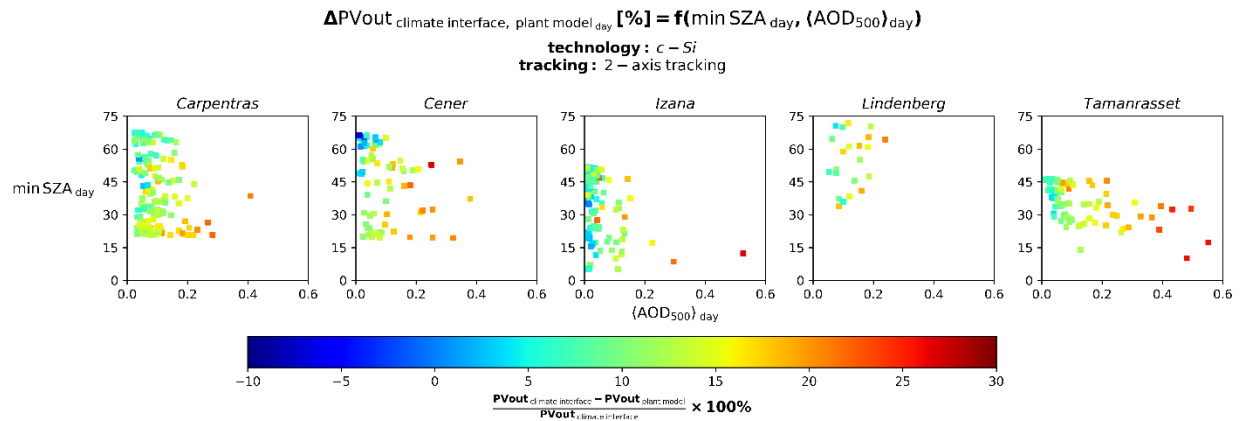


Figure S5. Percentage differences between the daily PV output estimated using the climate interface and the corresponding daily sums from hourly simulations as function of minimum daily SZA and mean daily aerosol load for panels with 2-axis tracking

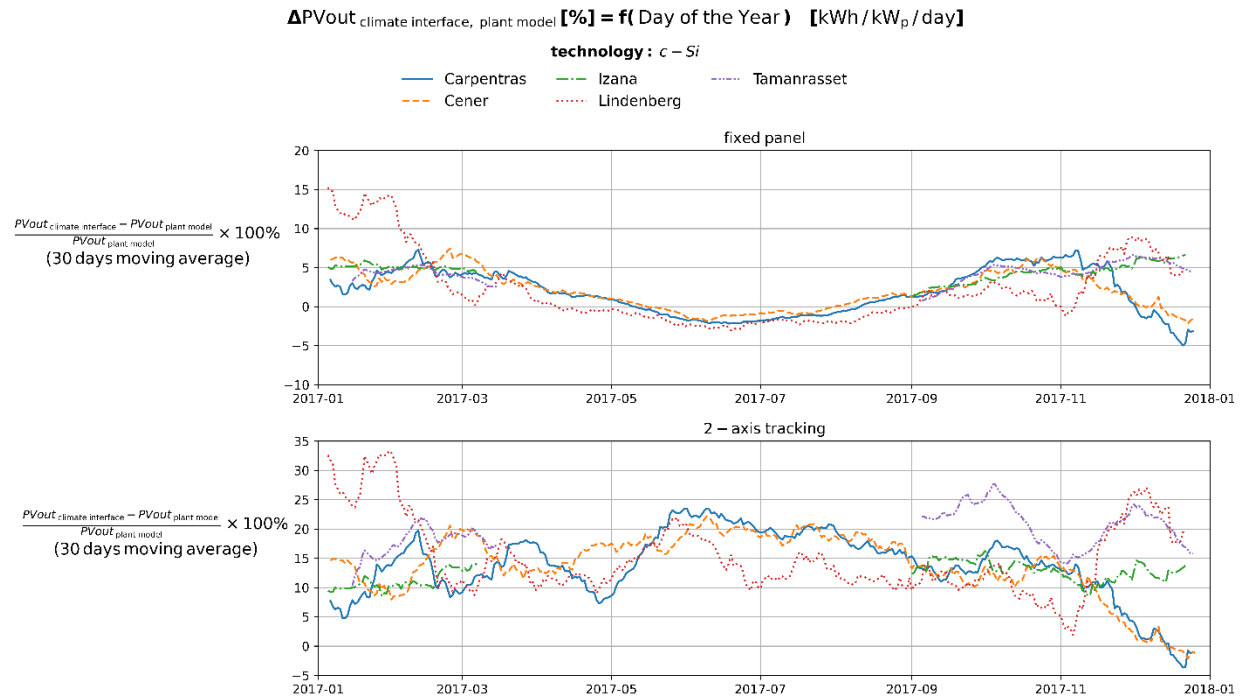


Figure S6. Time-series of the percentage differences between the daily PV output estimated using the climate interface and the corresponding daily sums from hourly simulations

Table S4. Evaluation metrics assessing the reliability of GSEE Climate Data Interface in estimating total daily PV output power in Carpentras

STATION: Carpentras		fixed panels			2-axis tracking		
		RMSE (kWh/kWp/day)	MAE (kWh/kWp/day)	rMBE (%)	RMSE (kWh/kWp/day)	MAE (kWh/kWp/day)	rMBE (%)
All Days		0.22	0.17	1.7	1.24	1.08	15.5
Sunny (cloudless) Days		0.19	0.15	1.8	1.19	1.08	14.1
Sunny Days: average aerosol load	very-low aerosol	0.18	0.15	2.1	0.82	0.72	10.0
	aerosol-laden	0.19	0.16	1.7	1.28	1.20	15.3

Table S5. Evaluation metrics assessing the reliability of GSEE Climate Data Interface in estimating total daily PV output power in Tamanrasset

STATION: Tamanrasset	fixed panels	2-axis tracking
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		RMSE (kWh/kWp/day)	MAE (kWh/kWp/day)	rMBE (%)	RMSE (kWh/kWp/day)	MAE (kWh/kWp/day)	rMBE (%)
All Days		0.24	0.22	3.4	1.45	1.34	19.0
Sunny (cloudless) Days		0.22	0.20	3.4	1.20	1.11	14.4
Sunny Days: average aerosol load	very-low aerosol	0.15	0.14	2.5	0.66	0.62	7.7
	aerosol-laden	0.24	0.22	3.7	1.37	1.31	17.3

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62 **Table S6.** Evaluation metrics assessing the reliability of GSEE Climate Data Interface in estimating
63 total daily PV output power in Cener

STATION: Cener		fixed panels			2-axis tracking		
		RMSE (kWh/kWp/day)	MAE (kWh/kWp/day)	rMBE (%)	RMSE (kWh/kWp/day)	MAE (kWh/kWp/day)	rMBE (%)
All Days		0.24	0.18	2.5	1.28	1.08	16.8
Sunny (cloudless) Days		0.26	0.21	3.3	1.15	1.00	13.6
Sunny Days (average aerosol load)	aerosol-free	0.18	0.15	2.4	0.73	0.60	7.6
	aerosol-laden	0.30	0.24	4.0	1.37	1.28	17.8

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65 **Table S7.** Evaluation metrics assessing the reliability of GSEE Climate Data Interface in estimating
66 total daily PV output power in Lindenberg

STATION: Lindenberg		fixed panels			2-axis tracking		
		RMSE (kWh/kWp/day)	MAE (kWh/kWp/day)	rMBE (%)	RMSE (kWh/kWp/day)	MAE (kWh/kWp/day)	rMBE (%)
All Days		0.24	0.18	2.1	0.99	0.81	15.2
Sunny (cloudless) Days		0.29	0.23	4.4	1.04	0.96	14.6
Sunny Days (average aerosol load)	aerosol-free	NaN	NaN	NaN	NaN	NaN	NaN
	aerosol-laden	NaN	NaN	NaN	NaN	NaN	NaN

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68 **Table S8.** Evaluation metrics assessing the reliability of GSEE Climate Data Interface in estimating
69 total daily PV output power in Izana

STATION: Izana		fixed panels			2-axis tracking		
		RMSE (kWh/kWp/day)	MAE (kWh/kWp/day)	rMBE (%)	RMSE (kWh/kWp/day)	MAE (kWh/kWp/day)	rMBE (%)
All Days		0.28	0.23	3.4	1.12	0.94	11.2
Sunny (cloudless) Days		0.25	0.21	3.1	0.92	0.80	8.9
Sunny Days (average aerosol load)	aerosol-free	0.25	0.22	3.3	0.75	0.65	7.2
	aerosol-laden	0.24	0.19	2.3	1.38	1.31	15.3

Table S9. Evaluations metrics accessing the reliability of using CAMS solar radiation time-series for modelling PV output power in Carpentras

STATION: Carpentras		fixed panels			2-axis tracking		
		RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)	RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)
All-Sky scenes		49.7	36.6	3.9	60.7	43.0	3.8
All-Sky scenes (cloudiness)	cloud-free	35.9	28.4	3.2	41.7	32.5	2.7
	partly cloudy	74.1	56.7	5.7	94.2	70.3	7.1
	cloudy (overcast)	46.7	37.4	11.4	49.2	38.3	13.9
Cloudless- Sky scenes (aerosol load)	low	25.0	20.0	2.1	28.8	22.3	1.5
	moderate	32.5	25.9	3.4	36.7	29.1	2.9
	high	41.8	36.0	5.0	49.0	41.3	4.7
	very high	42.3	36.9	6.1	49.9	44.1	6.3

Table S10. Evaluations metrics accessing the reliability of using CAMS solar radiation time-series for modelling PV output power in Tamanrasset

STATION: Tamanrasset		fixed panels			2-axis tracking		
		RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)	RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)
All-Sky scenes		55.9	33.7	-1.0	75.2	46.1	-0.6
All-Sky scenes (cloudiness)	cloud-free	32.4	20.8	-0.7	45.2	29.8	-0.7
	partly cloudy	87.3	67.5	-4.4	111.8	86.9	-3.0
	cloudy (overcast)	124.9	89.2	23.3	210.7	151.6	48.1
Cloudless- Sky scenes (aerosol load)	low	16.6	11.9	0.3	20.8	15.3	-0.6
	moderate	19.7	14.9	-0.4	28.2	20.9	-1.2
	high	29.8	18.9	-0.9	34.9	23.2	-1.0
	very high	31.0	22.9	0.7	48.0	35.5	2.4

Table S11. Evaluations metrics accessing the reliability of using CAMS solar radiation time-series for modelling PV output power in Cener

STATION: Cener		fixed panels			2-axis tracking		
		RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)	RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)
All-Sky scenes		63.1	43.0	2.0	75.3	51.2	2.1
All-Sky scenes (cloudiness)	cloud-free	35.6	27.0	0.9	45.6	33.5	0.4
	partly cloudy	82.7	61.1	2.1	99.6	73.4	3.4
	cloudy (overcast)	77.3	50.8	20.7	83.5	53.4	24.8
Cloudless- Sky scenes (aerosol load)	clear sky / low	28.0	21.5	1.7	32.1	25.0	1.1
	moderate	38.5	30.4	2.8	48.3	38.8	2.3
	high	34.3	28.4	2.9	41.7	35.1	2.3
	very high	NaN	NaN	NaN	NaN	NaN	NaN

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84 **Table S12.** Evaluations metrics accessing the reliability of using CAMS solar radiation time-series
85 for modelling PV output power in Lindenberg

STATION: Lindenberg		fixed panels			2-axis tracking		
		RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)	RMSE (Wh/kWp/hour)	MAE (Wh/kWp/hour)	rMBE (%)
All-Sky scenes		66.1	46.7	-1.2	76.2	53.8	-1.4
All-Sky scenes (cloudiness)	cloud-free	37.9	24.9	-1.7	50.7	33.4	-2.5
	partly cloudy	76.4	57.5	-2.6	88.9	67.0	-2.3
	cloudy (overcast)	60.9	42.3	8.0	63.9	43.2	9.5
Cloudless- Sky scenes (aerosol load)	clear sky / low	NaN	NaN	NaN	NaN	NaN	NaN
	moderate	42.3	28.7	-2.5	53.4	24.7	-3.0
	high	40.9	26.4	-2.4	52.6	32.0	-2.8
	very high	NaN	NaN	NaN	NaN	NaN	NaN

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