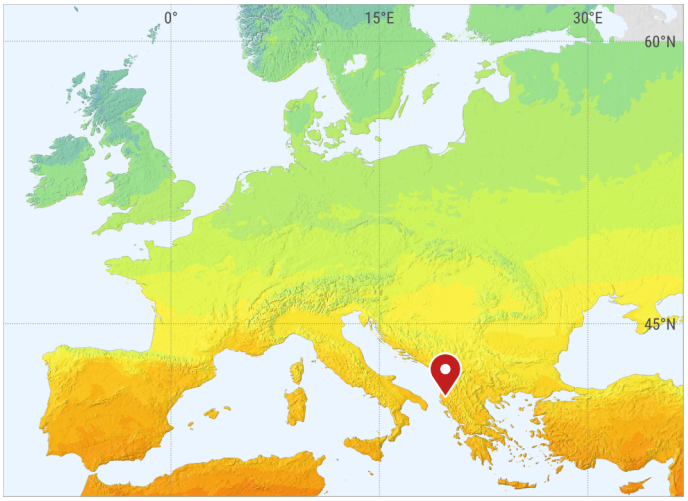
SOLARGIS

Solargis Evaluate Report

Site Assessment of Solar Resource and Climate Conditions

Mallakastër, Fier, ALB

PROJECT LOCATION
Mallakastër, Albania



CUSTOMER
Solargis s.r.o.
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REPORT GENERATED
22 September 2025

DATA
Time series
01/1994 to 08/2025

SOURCE OF DATA
Solargis v2025.09.19-2.2.65

SERVICE PROVIDER
Solargis s.r.o.

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1 Summary

This study analyzes solar resource potential for a prospective photovoltaic (PV) power plant. Climate and environmental conditions, affecting the operation and performance of the project, are also analyzed. This report is based on the analysis of the Solargis time series data (Chapter 3), representing a period from 1 January 1994 to 31 December 2024 (31 continuous years). For the sake of statistical representativeness, the complete years are used for calculation of long-term statistics in this report.

1.1 Solar resource

Global horizontal irradiation (GHI) and Direct normal irradiation (DNI) describe primary solar resource for calculating Global tilted irradiation (GTI, plane-of-array irradiation) received by photovoltaic modules. The long-term average yearly value is often referred to as P50, i.e., 50% probability of exceedance (median). Considering the long-term average to be equal to P50 is a simplification, assuming normal distribution of yearly values of solar resource, but it is widely accepted in the industry.

Table 1.1 summarizes the long-term average (represented by a P50 value). Two versions of solar resource values are presented: with and without consideration of terrain horizon shading.

Table 1.1 Solar resource: Long-term yearly values at P50

	Acronym	Unit	Terrain shading considered	Terrain shading not considered
Global horizontal irradiation	GHI	[kWh/m^2]	1,636.5	1,640.5
Direct normal irradiation	DNI	[kWh/m^2]	1,722.9	1,746.7

Notes: For the sake of simplification, long-term average is considered as equal to P50

In the estimate of future GHI and DNI long-term averages, a combined effect of two sets of uncertainties is calculated:

1. Uncertainty of satellite-based solar model. This uncertainty is quantified by a combination of numerical analysis and an expert estimate.
2. Uncertainty due to interannual (year-by-year) variability, long-term trends and due to occasional events of large-scale volcano eruptions. The uncertainty from interannual variability is calculated from the time series data. Our understanding of the uncertainty due to long-term cycles, man-induced climate change, and likelihood of large-scale volcano eruptions is very limited. Therefore, uncertainty calculated from interannual variability at any single year is used as a proxy for capturing possible deviation of future solar resource due to effects difficult to quantify.

The most often, P90 uncertainty is used in calculating long-term yearly GHI and DNI values at 90% probability of exceedance.

Table 1.2 Solar resource uncertainty at P90

			Satellite-based solar model uncertainty	Uncertainty due to interannual variability at any single year	Combined uncertainty
Global horizontal irradiation	GHI	%	4.5	4.3	6.2
Direct normal irradiation	DNI	%	11.0	9.4	14.5

Table 1.3 summarizes solar resource long-term average yearly values for probability of exceedance scenarios P50 and P90, calculated from Solargis time series, assuming the model uncertainty and interannual variability that can occur at any single year.

Table 1.3 Summary of solar resource long term average values at P50 and P90 (terrain shading considered)

		Value at P50 [kWh/m2]	Combined uncertainty at P90 [%]	Value at P90 [kWh/m2]
Global horizontal irradiation	GHI	1640.5	6.2	1538.6
Direct normal irradiation	DNI	1746.7	14.5	1494.1

1.2 Climate and environment

Besides solar radiation also climate and environmental conditions at the site have impact on PV power plant operation and energy production. This may be a direct impact to quantity of electricity (air temperature, ground surface albedo) or in a form of weather events, affecting the entire operation (wind speed, snow, or precipitation). The long-term average values of the most important parameters are in Table 1.4.

Table 1.4 Meteorological and environmental parameters: Long-term average yearly values

	Acronym	Unit	Yearly average
Air temperature at 2 m	TEMP	[°C]	15.6
Wind speed at 10 m	WS	[m/s]	1.7
Wind gust at 10 m	WG	[m/s]	5.5
Relative humidity at 2 m	RH	[%]	70.4
Atmospheric pressure	AP	[hPa]	987
Precipitation (rainfall)	PREC	[mm]	1,143.6
Ground surface albedo	ALB	[-]	0.15
Precipitable water	PWAT	[kg/m^2]	17.8

2 Project site

Site name	**Mallakastër, Fier, ALB**
Geographical coordinates	40.604252°, 019.756840°
Elevation above sea level	170m
Terrain slope inclination:	2°
Terrain azimuth:	quasi flat

Location on the map (Solargis Prospect):
https://apps.solargis.com/prospect/map?center=40.604252,19.756840,15&layer=mapbox-satellite&location=40.604252,19.756840

Details of this data and report can be accessed from Solargis Evaluate:
https://apps.solargis.com/evaluate

2.1 Geographical context

Figure 2.1 Detailed position of the project site

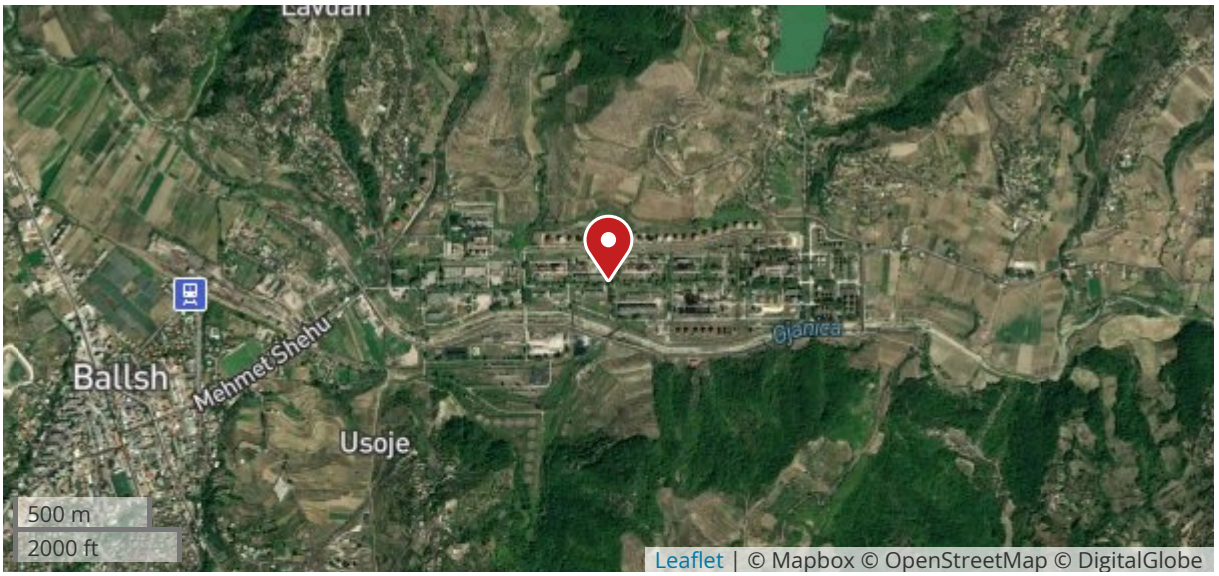
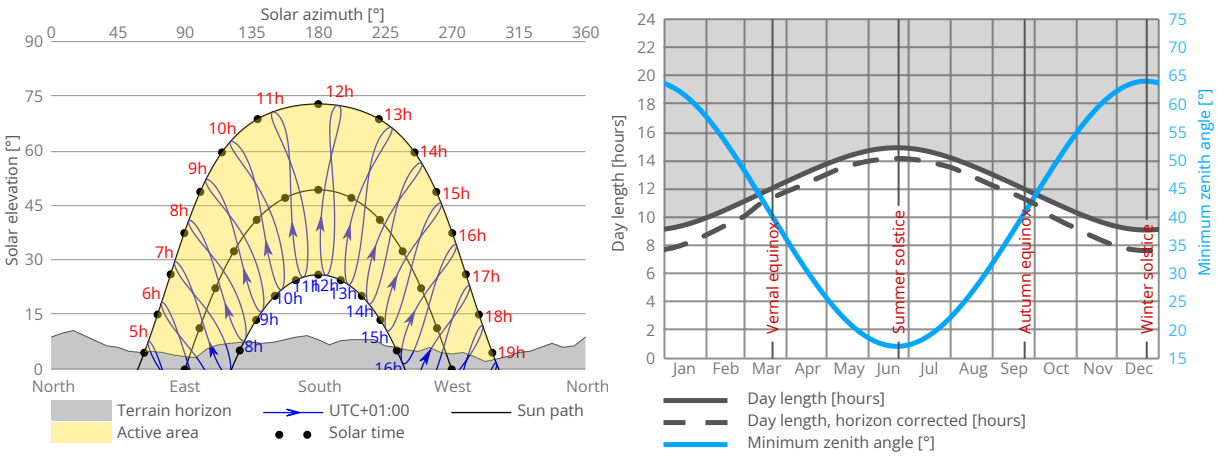


Figure 2.2 Position of the site in the context of a Global horizontal irradiation map

2.2 Terrain and astronomic conditions

Terrain properties (elevation, slope, azimuth, and horizon) are derived from the SRTM3 digital elevation model, unless customized.

Figure 2.3 Project horizon, sunpath, day length, and solar zenith angle



3 Data

This report is based on the analysis of 15-minute time series data derived from Solargis models and processing procedures. The time series used in this study represent a period from to (continuous years). For the sake of statistical representativeness, the complete years are used for calculation of long-term statistics in this report.

The Solargis models are optimized for all geographic regions, with the satellite, atmospheric and geographical input data harmonized to achieve the best possible geographical and temporal representation. The model parameters are validated by ground measurements acquired at meteorological stations worldwide.

3.1 Data properties

Table 3.1 Global characteristics of solar resource parameters

Data originator	Solargis
Version	2.2.65 (19 September 2025)
Type of data	Time series
Geographical representation	Grid resolution depends on the input data and geographical site. Terrain and clouds: between ~2.5 km and 8 km, PWAT and aerosols: ~30 km to 125 km
Time resolution	15-minute
Data aggregation	Long-term yearly, monthly and hourly averages
Period of time represented	1 Jan 1994 to 31 Dec 2024 (complete calendar years are used in this report)
Time zone	UTC+01
Method	Solargis solar models characterizing state of the atmosphere, cloud transmittance, and terrain conditions. Data from geostationary meteorological satellites Meteosat, GOES, Himawari, global meteorological data MACC-II, CAMS, MERRA-2, CFSR, GFS and digital terrain model SRTM3 are used as inputs.
Parameters	GHI, DNI, DIF, SUN_AZIMUTH, SUN_ELEVATION
Terrain shading	Terrain shading is considered in all calculations. Typically calculated from the SRTM3 data set. Depending on a specific data product/format the solar parameters may be provided with or without consideration of the terrain horizon shading.

Table 3.2 Global characteristics of meteorological and environmental parameters

Data originator	Solargis
Version	2.2.65 (19 September 2025)
Type of data	Time series
Geographical representation	Grid resolution depends on the input data and geographical site. TEMP and AP: ~1km, other parameters: between ~9 km and 25 km
Time resolution	15-minute (recalculated from hourly)
Data aggregation	Long-term yearly, monthly and hourly averages
Period of time represented	1 Jan 1994 to 31 Dec 2024 (complete calendar years are used in this report)
Time zone	UTC+01
Method	Processing of ERA5, ERA5-Land and IFS global meteorological model outputs
Parameters	TEMP, RH, TD, WBT, WS, WD, WG, AP, PREC, SDWE, PWAT

Table 3.3 Ground surface albedo

Type of data	Long-term yearly and monthly averages
Geographical representation	Grid resolution ~1km
Time resolution	Long-term averages
Period of time represented	1 Jan 2006 to 31 Dec 2015
Time zone	N/A
Method	Processing based on the input data from MODIS database, global meteorological models, and Solargis time series
Parameters	ALB

3.2 Parameters analyzed in this report

Although the delivered data cover the entire period until the last available calendar month, the calculation of long-term statistics in this report is limited to complete calendar years.

Table 3.4 Data parameters analyzed in this report

Parameter	Acronym	Monthly and yearly	Daily	Hourly	15-minute	Uncertainty
Global horizontal irradiance	GHI	Yes	Yes	Yes	Yes	-
Direct normal irradiance	DNI	Yes	Yes	Yes	Yes	-
Diffuse horizontal irradiance	DIF	Yes	-	-	-	-
Global tilted irradiance	GTI	-	-	-	-	-
Cloud identification quality flag	CI_FLAG	-	-	-	-	N/A
Sun elevation	SUN_ELEVATION	-	-	-	-	N/A
Sun azimuth	SUN_AZIMUTH	-	-	-	-	N/A
Air temperature at 2 meters	TEMP	Yes	-	Yes	-	-
Relative humidity at 2 meters	RH	Yes	-	Yes	-	-
Dew point temperature at 2 meters	TD	Yes	-	Yes	-	-
Wet bulb temperature at 2 meters	WBT	Yes	-	Yes	-	-
Wind speed at 10 meters	WS	Yes	-	Yes	-	-
Wind direction at 10 meters	WD	-	-	Yes	-	-
Wind gust at 10 meters	WG	-	-	Yes	-	-
Atmospheric pressure	AP	Yes	-	-	-	-
Precipitation rate/total	PREC	Yes	Yes	Yes	-	-
Precipitable water	PWAT	Yes	-	-	-	-
Snow depth water equivalent	SDWE	Yes	-	-	-	-
Snowfall rate water equivalent	SFWE	-	-	-	-	-
Ground surface albedo	ALB	Yes	-	-	-	-

4 Global and diffuse horizontal irradiation/irradiance

Global horizontal irradiation (GHI) represents the total amount of direct and diffuse radiation received on a horizontal surface. GHI is used to compare solar energy potential of different sites, as it is independent of any solar technology.

4.1 Monthly and yearly GHI

Figure 4.1 and Table 4.2 show monthly and yearly long-term averages of Global horizontal irradiation (GHI) and Diffuse horizontal irradiation (DIF). A ratio of diffuse to global irradiation (DIF/GHI, or D2G) is important for understanding the efficiency of solar modules and trackers. Table 4.2 shows also GHI and DIF/GHI minimum and maximum monthly sums as seen in the time series data. Note that the monthly extremes do not sum to the annual extremes.

The time series of monthly and yearly GHI sums are shown in Figure 4.2, Figure 4.3 and Table 4.3

All data shown here do consider solar irradiation losses due to terrain shading (far shading) calculated from SRTM3. The only exception is Table 4.4, which shows theoretical GHI, DNI and DIF values without consideration of terrain shading. While these values have no practical use, they are often used as an input into some PV simulation software, which are designed to calculate terrain shading internally.

Figure 4.1 Global horizontal irradiation (left) and Ratio of diffuse to global horizontal irradiation (right). Long-term averages of monthly sums and minimum/maximum sums

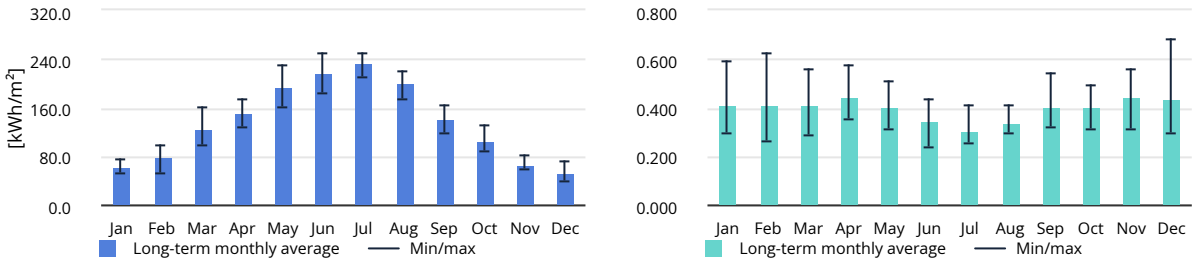


Figure 4.2 Global horizontal irradiation - interannual variability: monthly sums (left) and yearly sums (right)

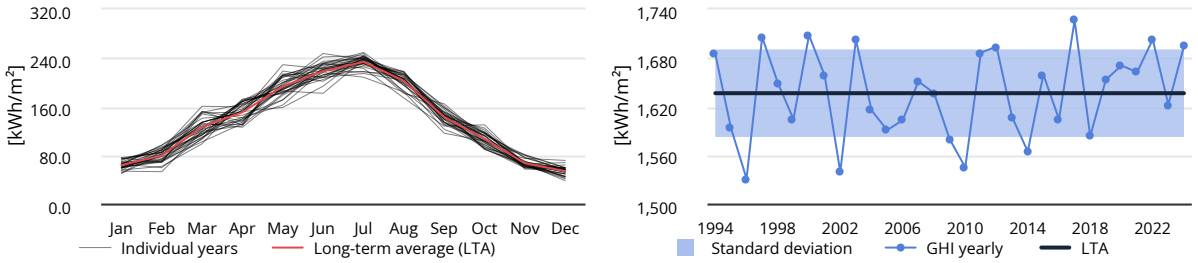


Table 4.1 Global horizontal irradiation: Long-term averages and extremes of monthly and yearly sums. Monthly share of GHI

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average	kWh/m²	63.3	79.2	126.6	150.5	193.4	218.3	233.6	202.5	142.6	106.5	66.4	53.4	1,636.5
Yearly share	%	3.9	4.8	7.7	9.2	11.8	13.3	14.3	12.4	8.7	6.5	4.1	3.3	100.0
Min	kWh/m²	49.7	52.6	98.6	125.8	158.5	181.8	208.3	174.0	116.0	89.0	56.6	37.6	1,530.7
Min	%	-21.4	-33.6	-22.1	-16.4	-18.0	-16.7	-10.8	-14.1	-18.7	-16.5	-14.8	-29.6	-6.5
Max	kWh/m²	75.7	96.4	160.4	172.3	229.0	247.4	249.2	218.1	164.5	129.8	80.7	71.1	1,726.4
Max	%	+19.6	+21.7	+26.7	+14.4	+18.4	+13.3	+6.7	+7.7	+15.3	+21.9	+21.5	+33.1	+5.5
Standard deviation	kWh/m²	-	-	-	-	-	-	-	-	-	-	-	-	54.1
Standard deviation	%	-	-	-	-	-	-	-	-	-	-	-	-	3.3

Figure 4.3 Global horizontal irradiation: Time series of monthly sums

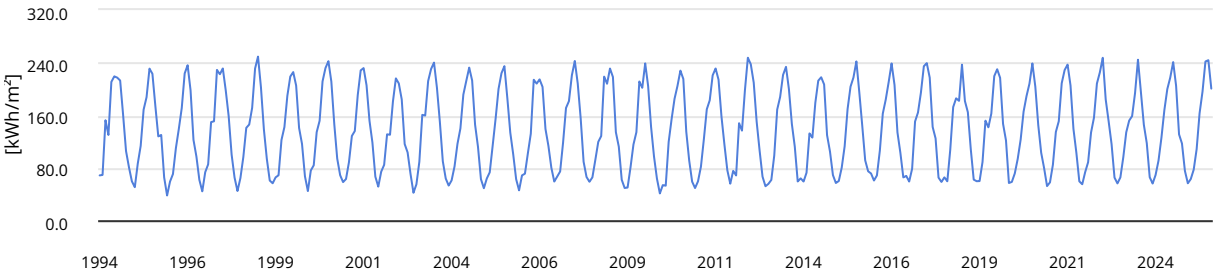


Table 4.2 Global horizontal irradiation (GHI) and Diffuse horizontal irradiation (DIF): Long-term averages and extremes of monthly sums. D2G ratio

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
GHI	kWh/m²	Average	63.3	79.2	126.6	150.5	193.4	218.3	233.6	202.5	142.6	106.5	66.4	53.4	1,636.5
		Min	49.7	52.6	98.6	125.8	158.5	181.8	208.3	174.0	116.0	89.0	56.6	37.6	1,530.7
		Max	75.7	96.4	160.4	172.3	229.0	247.4	249.2	218.1	164.5	129.8	80.7	71.1	1,726.4
DIF	kWh/m²	Average	25.9	32.8	52.1	66.7	78.7	76.2	71.8	68.8	57.3	42.8	29.6	23.5	626.3
		Min	22.0	25.4	42.8	57.7	70.2	57.9	62.8	62.2	52.0	35.7	24.5	19.8	585.9
		Max	31.4	37.4	59.4	74.6	85.2	86.3	85.4	80.4	64.7	48.2	33.1	26.3	668.6
D2G		Average	0.410	0.414	0.412	0.443	0.407	0.349	0.307	0.340	0.402	0.401	0.446	0.441	0.383

Table 4.3 Global horizontal irradiation: Monthly and yearly sums and long-term averages (LTA) [kWh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1994	68.2	69.0	152.3	129.8	210.6	219.1	217.1	212.7	160.7	105.4	80.7	59.2	1,684.9
1995	50.3	86.0	113.2	168.4	187.3	230.9	223.0	174.0	127.6	129.8	65.2	37.6	1,593.5
1996	58.8	70.3	109.7	139.0	170.9	223.6	236.0	197.9	122.3	96.9	61.5	44.0	1,530.7
1997	73.1	85.0	149.4	150.7	228.9	222.3	231.1	197.6	158.3	99.9	65.0	44.5	1,705.8
1998	64.2	96.4	140.7	145.7	171.1	231.0	249.2	202.4	138.4	93.5	60.4	56.2	1,649.3
1999	65.2	68.5	122.2	141.9	189.4	218.7	225.6	205.0	140.5	116.2	66.8	44.3	1,604.4
2000	75.7	83.6	134.1	151.4	211.4	231.8	242.2	211.1	146.4	93.9	68.6	58.0	1,708.2
2001	62.8	88.2	128.3	135.8	190.5	228.2	231.7	205.4	151.6	118.3	66.3	51.1	1,658.3
2002	73.9	84.3	130.8	130.1	180.8	216.0	208.3	183.9	116.0	103.2	70.2	41.8	1,539.3
2003	54.6	88.9	160.4	159.4	211.9	230.3	240.1	201.7	149.5	89.7	63.5	52.7	1,702.7
2004	60.6	81.9	116.2	139.8	191.3	212.1	232.4	212.8	145.6	111.4	62.5	48.7	1,615.3
2005	63.5	72.9	113.5	154.6	199.9	223.9	234.6	185.9	133.5	100.4	62.5	45.5	1,590.8
2006	68.2	70.8	101.9	131.8	213.9	208.1	214.5	203.0	138.9	113.3	80.0	58.9	1,603.3
2007	66.5	74.2	118.1	170.9	181.4	220.6	242.5	208.2	155.3	89.0	65.8	58.5	1,651.0
2008	65.3	91.9	119.3	128.2	218.7	207.8	231.0	218.1	134.1	112.0	61.5	49.0	1,636.7
2009	49.7	80.7	115.4	134.1	211.3	201.7	238.9	204.3	142.3	97.2	63.4	40.8	1,579.6
2010	53.4	52.6	119.2	153.9	184.9	204.5	227.8	215.1	134.9	90.9	58.7	48.9	1,544.9
2011	59.1	81.5	123.3	169.0	182.6	220.6	231.1	214.0	158.1	115.5	76.1	55.6	1,686.6
2012	75.1	68.2	147.7	136.4	198.0	247.4	237.5	209.5	150.0	106.2	66.4	51.7	1,694.1
2013	55.3	61.3	98.6	168.5	187.6	221.3	233.6	199.5	146.6	111.9	59.0	63.7	1,606.8
2014	58.9	72.3	132.2	125.8	178.8	212.5	217.7	206.7	129.6	104.5	68.8	56.6	1,564.5
2015	59.7	80.0	112.7	169.4	203.4	217.3	241.9	194.5	143.8	91.2	74.5	71.1	1,659.5
2016	60.4	68.2	106.1	162.3	183.6	210.2	238.8	206.0	133.7	102.5	65.2	67.5	1,604.3
2017	58.9	78.3	150.3	164.0	194.3	234.5	239.2	217.1	142.1	124.5	64.9	58.2	1,726.4
2018	65.2	59.2	107.3	172.3	185.6	181.8	236.9	181.5	164.5	108.0	61.8	59.4	1,583.5
2019	59.6	88.6	151.6	141.5	162.4	219.4	229.9	216.8	146.8	121.5	56.6	58.3	1,653.1
2020	71.2	93.4	122.7	165.3	189.0	207.9	238.8	203.5	145.0	102.7	79.2	51.9	1,670.7
2021	57.6	84.6	134.4	150.8	208.6	228.7	237.0	205.2	139.1	102.5	59.2	54.7	1,662.4
2022	73.3	88.3	133.5	156.2	208.1	225.1	247.4	183.8	150.5	115.8	64.9	56.0	1,702.9
2023	65.2	96.1	133.9	151.7	158.5	193.6	244.4	195.1	145.4	117.3	65.5	55.8	1,622.4
2024	68.8	90.7	125.8	167.8	199.7	217.2	240.8	204.6	130.8	116.8	75.2	56.2	1,694.4
2025	62.7	77.0	108.2	162.8	195.8	241.8	243.7	200.4					
	63.3	79.2	126.6	150.5	193.4	218.3	233.6	202.5	142.6	106.5	66.4	53.4	1,636.5

Table 4.4 Global horizontal irradiation (GHI) and Diffuse horizontal irradiation (DIF): Long-term averages of monthly and yearly sums. Terrain shading not considered

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
GHI	kWh/m²	Average	64.0	79.7	126.9	150.8	193.6	218.4	233.6	202.6	142.9	106.9	66.9	54.1	1,640.5
DIF	kWh/m²	Average	26.2	33.1	52.4	66.9	78.9	76.2	71.7	68.9	57.6	43.0	29.9	23.8	628.6
D2G		Average	0.409	0.415	0.413	0.444	0.408	0.349	0.307	0.340	0.403	0.402	0.446	0.439	0.383

4.2 Daily and hourly GHI

Figure 4.4 shows histograms of daily GHI sums for each month. The distribution of daily values is not symmetric: median is drawn by the vertical line. The area between percentiles p10 and p90 shows 80% occurrence of daily values within each month and the area between percentiles p25 and p75 shows 50% occurrence. GHI is variable throughout a year: narrower groups indicate more stable weather with lower influence of clouds. Table 4.5 shows occurrence statistics of daily sums per month.

Figure 4.4 Global horizontal irradiation, daily sums [kWh/m²]: Relative occurrence and percentiles p10, p25, p50, p75 and p90. Description of figure Y-axes: left - occurrence, right - cumulative distribution

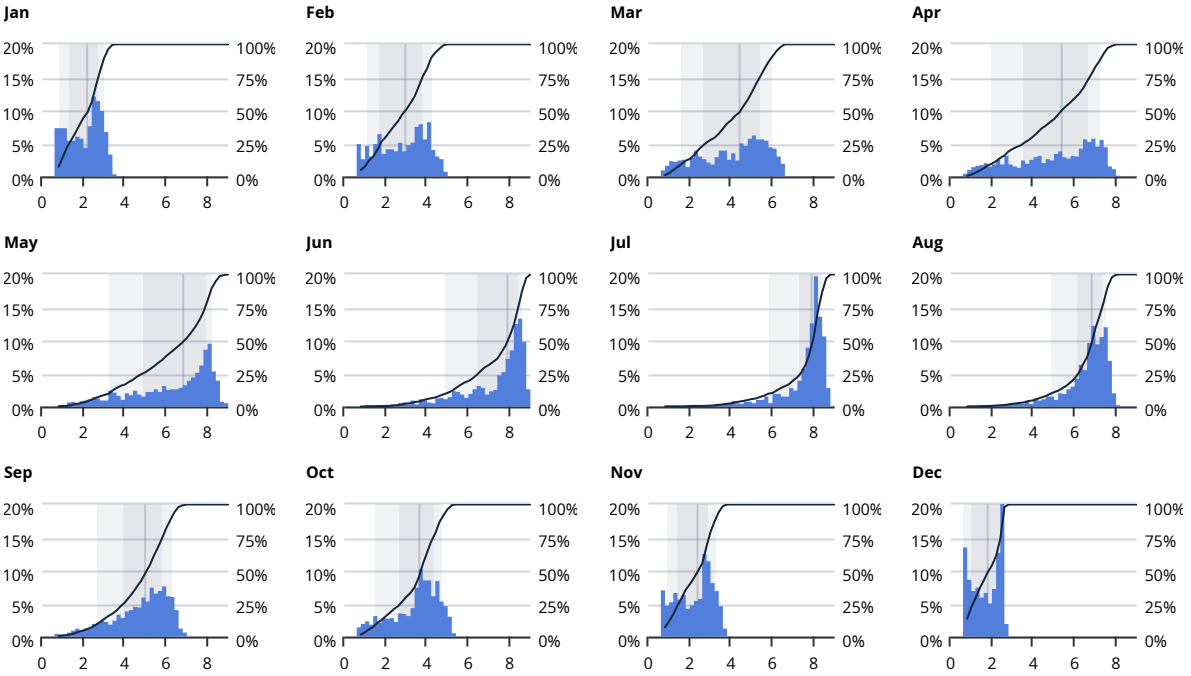


Table 4.5 Global horizontal irradiation, daily sums: Long-term monthly averages, minimum/maximum value and percentiles p01, p05, p10, p25, p50, p75, p90, p95, and p99 [kWh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	2.042	2.804	4.084	5.018	6.238	7.278	7.535	6.532	4.755	3.436	2.215	1.724
Min	0.375	0.399	0.457	0.477	0.747	1.095	0.900	0.992	0.547	0.608	0.305	0.229
Max	3.411	4.918	6.579	8.058	8.879	9.002	8.849	8.162	6.910	5.314	3.737	2.738
p01	0.524	0.590	0.824	0.839	1.403	2.637	3.268	2.471	1.204	0.779	0.443	0.415
p05	0.729	0.821	1.239	1.491	2.390	3.838	4.833	4.042	2.050	1.190	0.744	0.552
p10	0.880	1.132	1.658	2.049	3.243	4.958	5.943	4.933	2.704	1.561	0.945	0.693
p25	1.313	1.742	2.757	3.561	4.916	6.466	7.378	6.189	3.930	2.714	1.470	1.055
p50	2.232	2.974	4.453	5.387	6.866	7.906	7.950	6.844	5.060	3.703	2.409	1.857
p75	2.698	3.778	5.382	6.703	7.890	8.412	8.229	7.326	5.832	4.314	2.930	2.415
p90	3.004	4.223	5.953	7.304	8.208	8.626	8.461	7.581	6.285	4.736	3.281	2.494
p95	3.150	4.468	6.190	7.485	8.404	8.728	8.540	7.714	6.434	4.923	3.423	2.540
p99	3.344	4.781	6.455	7.820	8.649	8.853	8.683	7.882	6.725	5.124	3.614	2.623

Figure 4.5 shows distribution of hourly GHI statistics for each month and it identifies variability of the GHI profiles. The graphs show average, and percentiles p10 - p90 and p01 - p99 as calculated from GHI time series. Table 4.6 is complementary, and it shows distribution of hourly GHI averages per month.

Figure 4.5 Global horizontal irradiation, hourly profiles: Average values, percentiles p01, p10, p90 and p99 [Wh/m²]

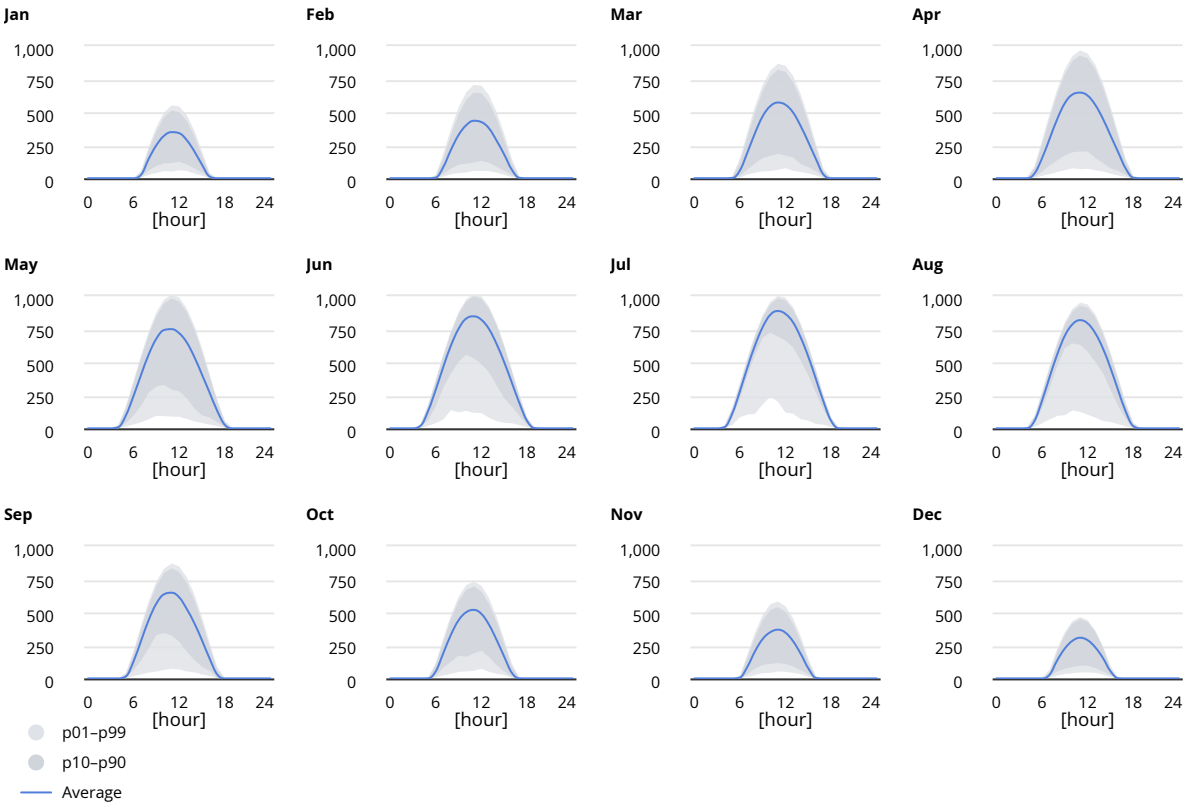


Table 4.6 Global horizontal irradiation, hourly averages per month [Wh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	-	-	-	-	-	-	-	-	-	-	-	-
1 - 2	-	-	-	-	-	-	-	-	-	-	-	-
2 - 3	-	-	-	-	-	-	-	-	-	-	-	-
3 - 4	-	-	-	-	-	-	-	-	-	-	-	-
4 - 5	-	-	-	-	9	19	10	1	-	-	-	-
5 - 6	-	-	2	36	99	132	113	56	16	1	-	-
6 - 7	-	5	59	152	246	292	281	210	130	54	7	-
7 - 8	27	85	197	300	407	466	463	390	287	192	90	29
8 - 9	148	215	344	449	561	627	630	561	444	331	207	138
9 - 10	250	327	470	569	679	753	767	702	567	440	299	227
10 - 11	321	401	546	634	744	831	860	788	637	501	350	285
11 - 12	349	435	573	648	751	848	888	819	649	519	369	308
12 - 13	341	425	556	625	720	822	865	794	614	489	346	289
13 - 14	288	378	497	555	650	752	801	720	525	407	281	235
14 - 15	203	285	394	450	539	639	687	605	417	292	186	155
15 - 16	102	180	273	324	406	501	541	456	288	165	76	54
16 - 17	13	65	145	198	270	347	372	289	150	43	4	2
17 - 18	-	3	27	73	132	191	201	127	30	1	-	-
18 - 19	-	-	-	4	26	57	56	16	-	-	-	-
19 - 20	-	-	-	-	-	2	1	-	-	-	-	-
20 - 21	-	-	-	-	-	-	-	-	-	-	-	-
21 - 22	-	-	-	-	-	-	-	-	-	-	-	-
22 - 23	-	-	-	-	-	-	-	-	-	-	-	-
23 - 24	-	-	-	-	-	-	-	-	-	-	-	-
Sum	2,042	2,804	4,083	5,017	6,239	7,279	7,536	6,534	4,754	3,435	2,215	1,722

4.3 15-minute GHI

Figure 4.6 shows monthly histograms, representing occurrence of daytime 15-minute GHI values. Figure 4.7 shows monthly histograms of 15-minute GHI variability (ramps, signed values).

Figure 4.6 Global horizontal irradiance, 15-minute values: Relative occurrence and percentiles p10, p25, p50, p75 and p90 [W/m²]. Description of figure Y-axes: left - occurrence, right - cumulative distribution

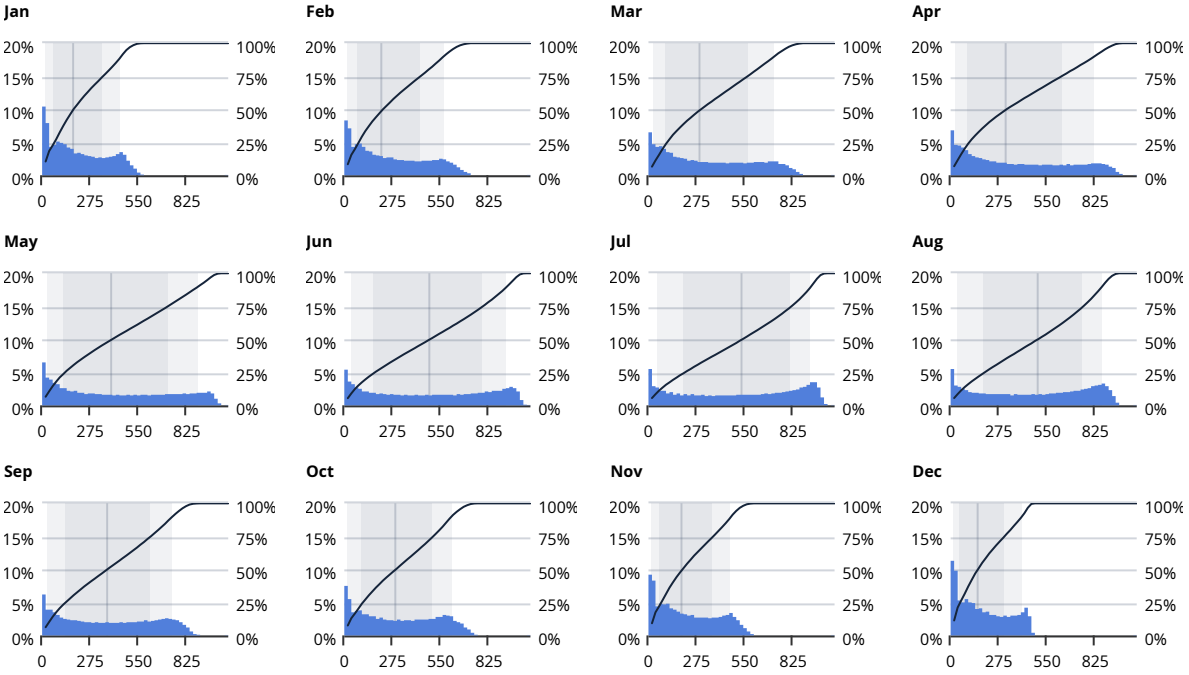
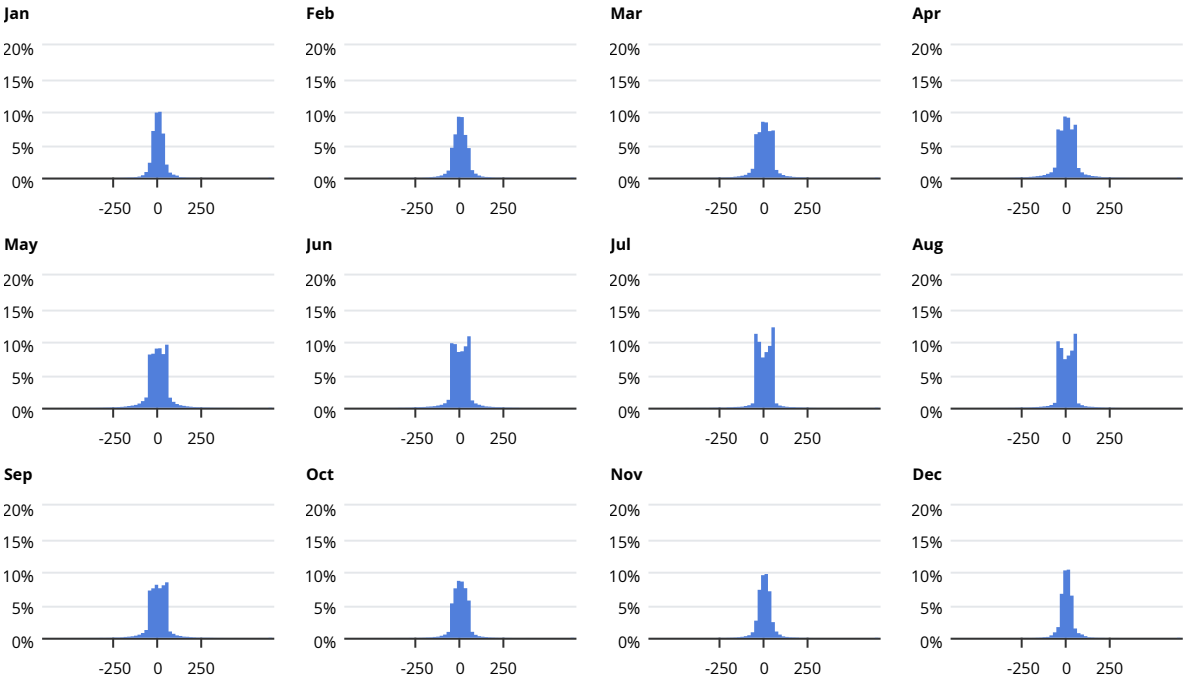


Figure 4.7 Global horizontal irradiance, 15-minute values: Occurrence of signed ramps [W/m²]



5 Direct normal irradiation/irradiance

Understanding DNI helps optimize PV systems' performance, especially those utilizing sun trackers. Accurate DNI is complementary to GHI and helps fine-tune the PV design, enhancing its overall efficiency.

5.1 Monthly and yearly DNI

Figure 5.1 and Table 5.1 show monthly and yearly long-term averages of Direct normal irradiation (DNI). Figure 5.2, Figure 5.3, and Table 5.2 show the time series of monthly and yearly DNI sums.

All data shown here consider solar radiation losses due to terrain shading. The only exception is Table 5.3, which shows theoretical DNI values without consideration of terrain shading (far shading). While these values have no practical use, they are often used as input into some PV simulation software, which calculates terrain shading internally.

Figure 5.1 Direct normal irradiation, monthly sums: Long-term monthly averages and minimum/maximum values of monthly sums

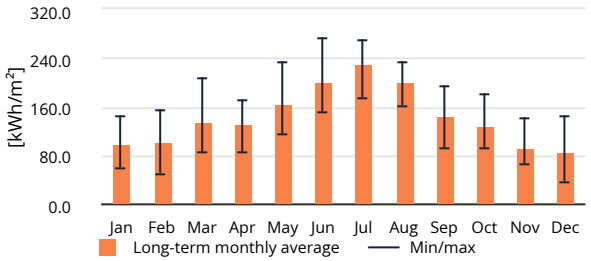


Figure 5.2 Direct normal irradiation, interannual variability: Time series of monthly sums (left). Time series of yearly sums (right)

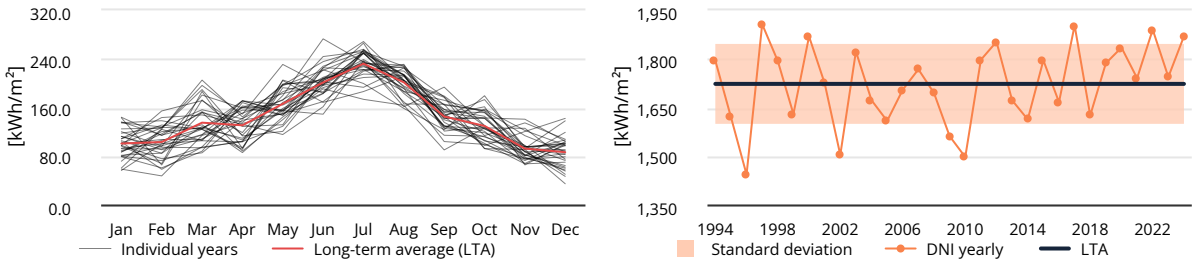


Table 5.1 Direct normal irradiation: Long-term averages and extremes of monthly and yearly sums. Monthly share of DNI. Terrain shading considered

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average	kWh/m²	100.5	103.0	134.9	130.6	166.1	201.2	232.2	201.4	145.1	129.5	92.2	86.2	1,722.9
Yearly share	%	5.8	6.0	7.8	7.6	9.6	11.7	13.5	11.7	8.4	7.5	5.3	5.0	100.0
Min	kWh/m²	56.1	47.2	85.3	85.6	115.4	148.9	173.4	158.4	90.0	92.0	65.2	34.1	1,442.6
Min	%	-44.2	-54.2	-36.8	-34.5	-30.5	-26.0	-25.3	-21.3	-38.0	-28.9	-29.2	-60.4	-16.3
Max	kWh/m²	143.9	154.2	205.1	171.2	230.9	273.2	268.7	231.1	193.5	179.4	140.6	142.0	1,907.5
Max	%	+43.1	+49.7	+52.0	+31.1	+39.1	+35.8	+15.7	+14.7	+33.4	+38.5	+52.6	+64.8	+10.7
Standard deviation	kWh/m²	-	-	-	-	-	-	-	-	-	-	-	-	123.5
Standard deviation	%	-	-	-	-	-	-	-	-	-	-	-	-	7.2

Figure 5.3 Direct normal irradiation: Time series of monthly sums

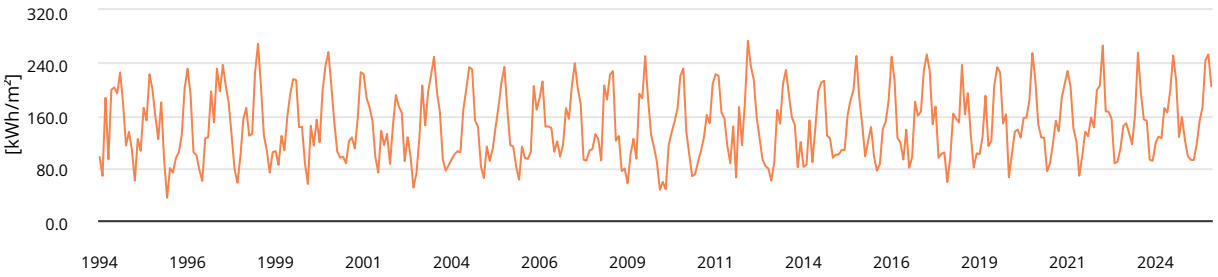


Table 5.2 Direct normal irradiation: Monthly and yearly sums and long-term averages (LTA) [kWh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1994	96.3	67.5	186.4	92.7	198.5	202.4	193.2	225.1	177.3	113.6	134.6	107.6	1,795.2
1995	60.1	123.9	105.4	171.2	152.0	222.3	199.5	158.4	123.3	179.4	90.8	34.1	1,620.3
1996	79.4	72.4	94.6	103.7	129.0	201.7	230.7	191.7	103.8	99.1	76.6	59.8	1,442.6
1997	124.7	126.2	196.3	148.9	230.9	196.4	236.6	204.4	178.8	129.5	77.9	56.9	1,907.5
1998	97.3	154.2	171.2	128.6	131.5	225.4	268.7	205.3	129.3	106.0	72.4	103.7	1,793.5
1999	105.2	84.4	128.6	106.4	158.4	192.7	215.0	213.3	141.9	142.1	86.8	55.1	1,629.8
2000	143.9	113.8	153.1	118.6	197.0	235.5	256.0	204.9	149.8	104.8	95.3	96.7	1,869.5
2001	86.7	120.2	126.1	109.2	155.1	225.4	222.7	186.5	171.9	152.0	96.3	72.6	1,724.7
2002	136.2	114.4	131.4	85.6	144.3	190.8	173.4	163.6	90.0	126.4	97.5	49.8	1,503.3
2003	71.3	124.5	205.1	144.4	195.9	221.1	248.9	195.3	165.0	92.4	75.4	83.9	1,823.1
2004	92.6	100.3	105.1	103.3	168.4	199.6	233.0	229.6	151.9	142.4	82.0	64.2	1,672.3
2005	112.3	90.3	108.1	141.9	172.9	209.7	233.6	169.1	114.1	112.6	82.0	61.6	1,608.3
2006	112.3	94.4	93.5	104.2	204.4	168.4	186.3	211.2	142.6	142.8	140.6	104.2	1,704.9
2007	120.1	96.8	115.2	170.7	154.3	204.2	239.0	201.5	176.8	92.0	90.9	106.4	1,767.9
2008	108.2	131.0	123.8	90.9	205.3	183.8	221.7	227.1	121.0	128.2	74.7	78.7	1,694.4
2009	56.1	99.7	124.1	93.6	192.5	185.7	250.0	183.2	130.4	111.4	88.1	46.3	1,561.2
2010	58.3	47.2	113.9	133.7	149.9	169.7	219.9	231.1	135.5	100.7	67.0	69.8	1,496.6
2011	88.8	105.6	125.6	160.4	147.6	207.4	222.4	220.0	164.0	155.2	113.5	86.8	1,797.3
2012	143.0	65.2	172.5	114.2	179.6	273.2	234.8	214.5	156.8	124.9	92.3	82.3	1,853.2
2013	78.8	60.4	87.8	168.1	146.9	208.4	228.9	191.0	156.8	145.5	80.6	119.0	1,672.1
2014	81.1	84.7	152.0	88.2	140.0	196.5	209.4	212.5	128.9	124.7	94.9	99.9	1,613.0
2015	100.2	107.2	106.9	160.1	182.9	197.8	250.2	186.1	144.7	97.2	120.4	142.0	1,795.7
2016	97.5	75.5	85.3	139.0	149.9	182.8	249.0	213.3	125.4	118.4	92.4	138.0	1,666.4
2017	79.9	95.8	180.4	159.2	165.2	228.0	252.1	227.9	146.0	173.0	95.0	101.0	1,903.5
2018	103.2	58.0	95.0	162.4	154.8	148.9	236.5	161.1	193.5	130.2	80.1	101.8	1,625.6
2019	100.5	126.4	189.5	113.1	120.5	204.8	233.0	225.2	147.3	161.2	65.2	99.9	1,786.6
2020	134.8	138.1	125.8	155.5	156.3	183.4	254.6	213.8	146.4	126.3	125.6	74.6	1,835.2
2021	86.4	116.5	151.6	135.6	186.1	207.3	227.2	204.1	139.7	120.6	67.7	97.8	1,740.6
2022	134.7	127.9	156.2	141.2	198.2	205.3	266.0	165.8	165.3	154.3	86.7	88.9	1,890.6
2023	108.5	143.4	147.7	132.1	115.4	161.2	255.1	193.6	153.5	151.4	92.0	90.4	1,744.3
2024	117.5	127.3	124.7	170.9	163.9	197.5	250.9	213.4	126.7	157.2	122.1	97.7	1,870.0
2025	91.9	91.6	114.9	150.9	171.9	243.9	252.5	204.0					
	100.5	103.0	134.9	130.6	166.1	201.2	232.2	201.4	145.1	129.5	92.2	86.2	1,722.9

Table 5.3 Direct normal irradiation (DNI): Long-term averages of monthly and yearly sums. Terrain shading not considered

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
DNI	kWh/m²	Average	105.5	105.8	136.2	131.2	166.7	202.0	233.0	202.3	146.0	131.6	95.3	91.1	1,746.7

5.2 Daily and hourly DNI

Figure 5.4 shows histograms of daily DNI summaries for each month. The distribution of daily values is not symmetric: the median is drawn by the vertical line. The area between percentiles p10 and p90 shows an 80% occurrence of daily values per month, and the area between percentiles p25 and p75 shows a 50% occurrence. DNI is variable throughout the year. Narrower groups indicate more stable weather with a lower influence of clouds. Table 5.4 shows daily occurrence statistics per month.

Figure 5.4 Direct normal irradiation per month, daily sums: Relative occurrence [%]. Percentiles p10, p25, p50 (vertical line), p75, p90 [kWh/m²]. Description of figure Y-axes: left - occurrence, right - cumulative distribution

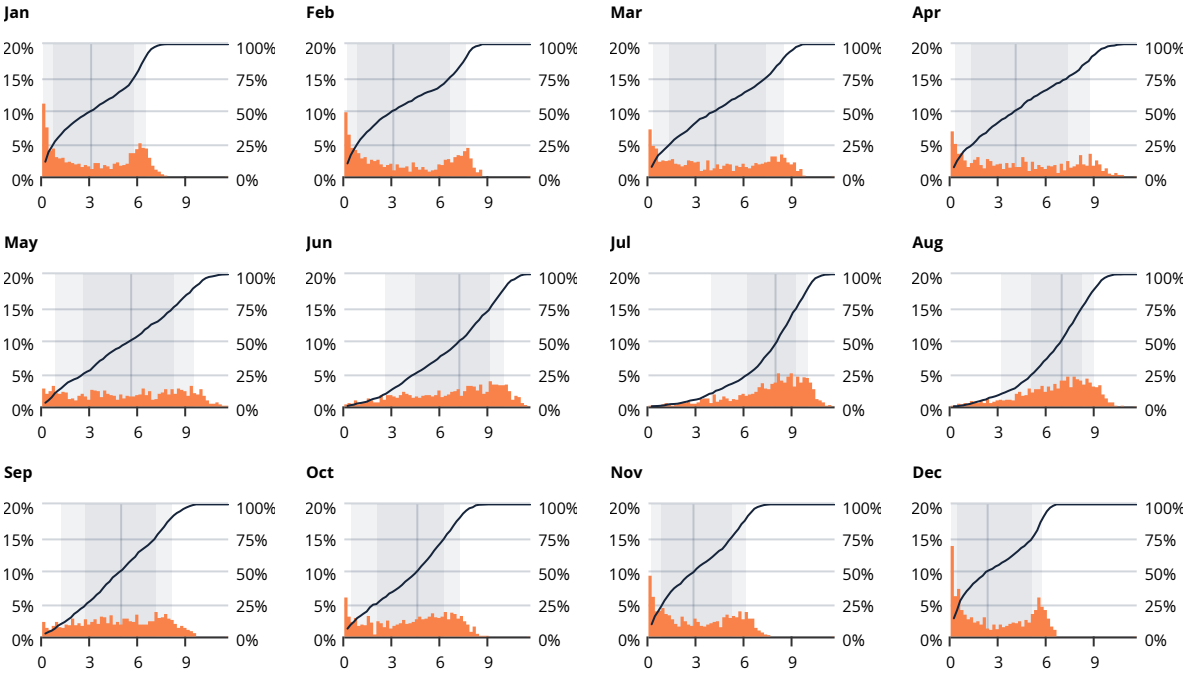


Table 5.4 Direct normal irradiance, daily sums: Long-term monthly averages, minimum/maximum value and percentiles p01, p05, p10, p25, p50, p75, p90, p95, and p99 [kWh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	3.243	3.645	4.353	4.352	5.357	6.707	7.490	6.497	4.837	4.178	3.072	2.780
Min	0.000	0.000	0.002	0.000	0.004	0.070	0.005	0.030	0.014	0.000	0.000	0.000
Max	7.614	8.566	9.800	10.691	11.567	11.326	11.300	10.601	9.545	8.834	7.553	6.571
p01	0.008	0.004	0.015	0.014	0.098	0.540	1.066	0.931	0.110	0.025	0.015	0.002
p05	0.068	0.080	0.127	0.100	0.427	1.656	2.968	2.078	0.666	0.169	0.105	0.045
p10	0.173	0.210	0.332	0.327	0.825	2.648	4.019	3.305	1.289	0.472	0.216	0.122
p25	0.735	0.836	1.380	1.418	2.620	4.460	6.263	5.144	2.793	2.071	0.886	0.521
p50	3.153	3.065	4.234	4.108	5.562	7.235	8.029	6.927	4.952	4.595	2.918	2.362
p75	5.747	6.596	7.379	7.304	8.179	9.118	9.241	8.191	7.066	6.273	5.181	5.106
p90	6.427	7.590	8.447	8.750	9.488	10.012	9.969	9.024	8.054	7.210	6.118	5.766
p95	6.644	7.861	8.926	9.234	9.951	10.361	10.247	9.348	8.627	7.564	6.511	6.005
p99	7.215	8.338	9.420	10.038	10.838	10.981	10.764	9.881	9.219	8.142	7.026	6.405

Figure 5.5 shows the distribution of hourly DNI profiles for each month and identifies the typical variability of the DNI during a day. The graphs show the average and percentiles p10 - p90 and p01 - p99 as calculated from the DNI time series. Table 5.5 is complementary and shows the distribution of hourly DNI averages per month.

Figure 5.5 Direct normal irradiation, hourly profiles: Average values, percentiles p01, p10, p90, p99 [Wh/m²]

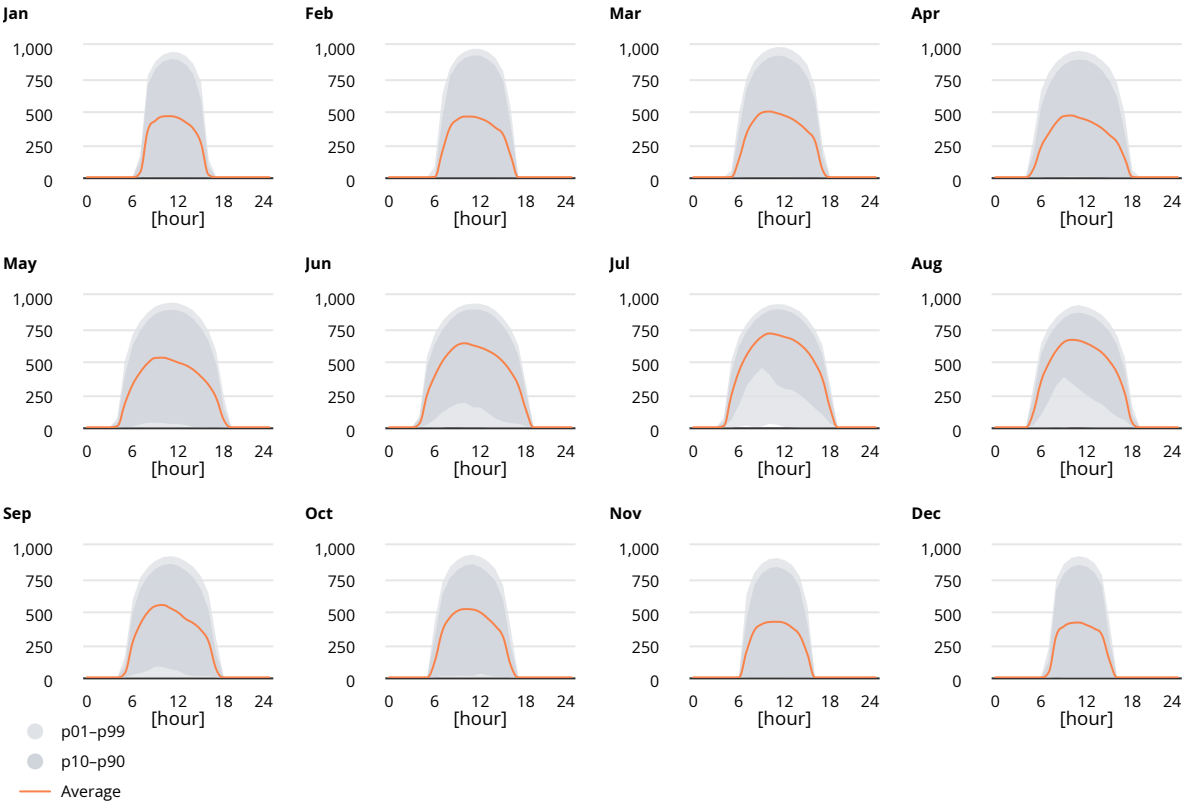


Table 5.5 Direct normal irradiation: Hourly average values per month [Wh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	-	-	-	-	-	-	-	-	-	-	-	-
1 - 2	-	-	-	-	-	-	-	-	-	-	-	-
2 - 3	-	-	-	-	-	-	-	-	-	-	-	-
3 - 4	-	-	-	-	-	-	-	-	-	-	-	-
4 - 5	-	-	-	-	9	30	10	-	-	-	-	-
5 - 6	-	-	2	63	181	247	240	116	34	-	-	-
6 - 7	-	2	134	230	322	388	422	347	263	120	-	-
7 - 8	36	195	329	330	416	498	545	483	402	351	196	38
8 - 9	353	375	432	414	486	573	629	581	493	453	352	315
9 - 10	428	437	488	462	525	623	685	644	540	503	402	386
10 - 11	460	459	497	467	527	636	710	662	548	517	419	412
11 - 12	462	458	485	450	512	621	701	656	523	514	421	415
12 - 13	449	444	466	433	490	604	684	635	491	492	412	396
13 - 14	415	418	441	406	470	580	666	605	442	445	376	369
14 - 15	366	374	401	370	435	546	629	565	410	387	318	321
15 - 16	256	322	348	319	384	495	574	500	358	304	177	129
16 - 17	18	161	274	264	320	420	487	410	270	91	-	-
17 - 18	-	-	56	142	222	315	364	259	62	-	-	-
18 - 19	-	-	-	3	56	132	143	34	-	-	-	-
19 - 20	-	-	-	-	-	-	-	-	-	-	-	-
20 - 21	-	-	-	-	-	-	-	-	-	-	-	-
21 - 22	-	-	-	-	-	-	-	-	-	-	-	-
22 - 23	-	-	-	-	-	-	-	-	-	-	-	-
23 - 24	-	-	-	-	-	-	-	-	-	-	-	-
Sum	3,243	3,645	4,353	4,353	5,355	6,708	7,489	6,497	4,836	4,177	3,073	2,781

5.3 15-minute DNI

Figure 5.6 shows monthly histograms representing occurrence of daytime 15-minute irradiance values and percentiles. Figure 5.7 shows monthly histograms of 15-minute DNI variability (ramps).

Figure 5.6 Direct normal irradiance, 15-minute values: Relative occurrence and percentiles p10, p25, p50, p75 and p90 [W/m²]. Description of figure Y-axes: left - occurrence, right - cumulative distribution

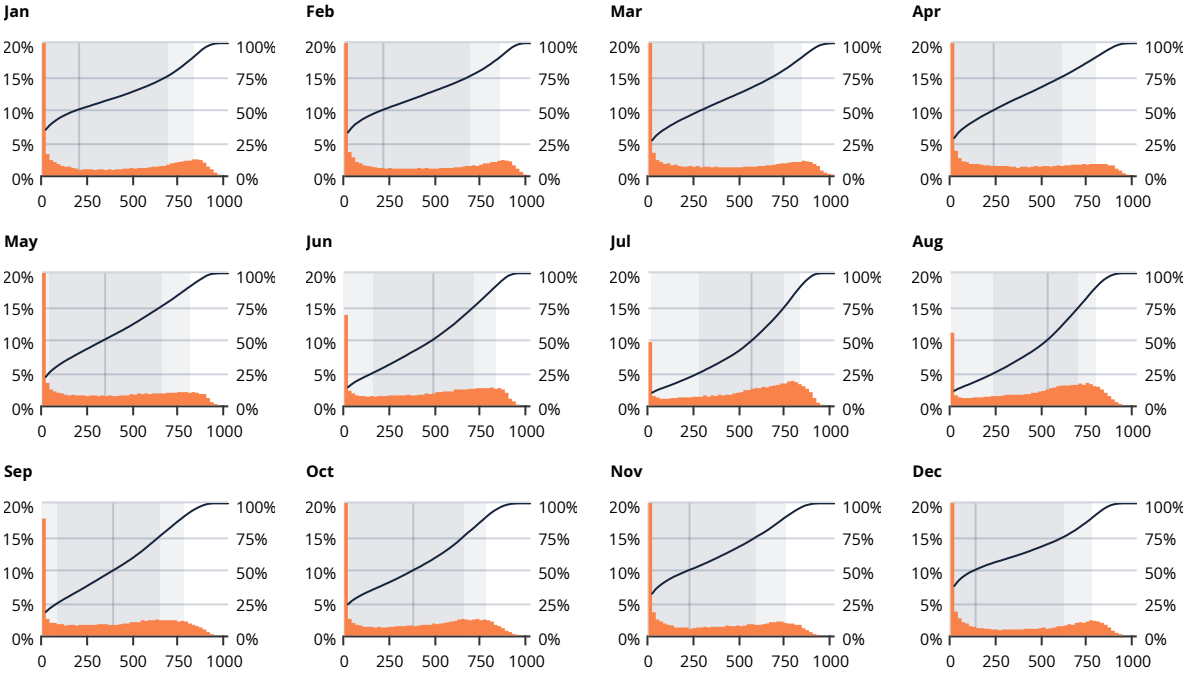
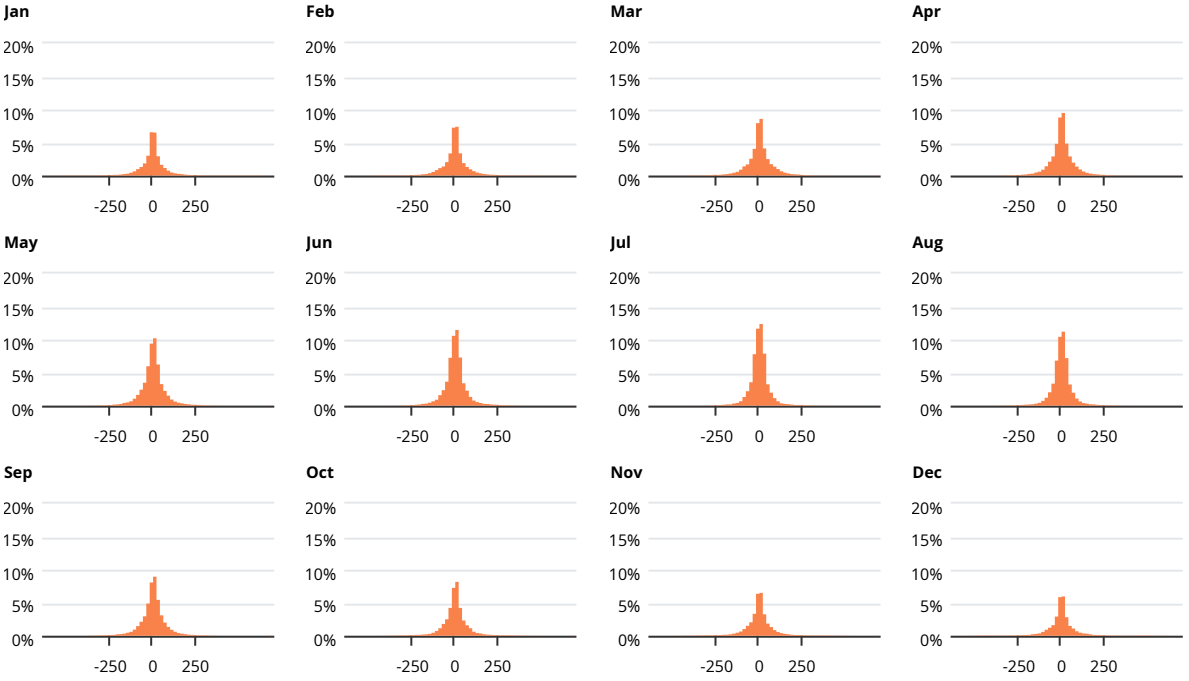


Figure 5.7 Direct normal irradiance, 15-minute values: Occurrence of signed ramps [W/m²]



6 Climate

6.1 Summary monthly statistics

The meteorological parameters are used to optimize PV designs, estimate energy production, and understand operation conditions. The data is derived from the meteorological models and processed by Solargis algorithms. Due to its spatial representation, the data may represent regional climate patterns rather than microclimate of the project location. Especially the extreme values may be smoothed, thus not always representing reliably the local conditions. Table 6.1 summarizes monthly and yearly statistics: long-term averages, and minimum and maximum averages.

Table 6.1 Monthly and yearly statistics of selected meteorological parameters

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
TEMP	°C	Average	6.3	7.4	9.9	13.5	18.3	22.9	25.6	25.6	20.9	16.5	12.0	7.7	15.6
		Min	2.3	3.6	7.1	9.2	15.9	20.9	23.7	22.7	17.8	14.5	8.7	3.4	14.5
		Max	8.8	11.1	13.3	17.2	20.3	25.5	28.2	28.0	23.8	19.6	14.5	11.1	17.0
RH	%	Average	75.4	72.3	69.8	69.8	69.9	66.0	61.9	63.1	70.2	73.9	76.0	77.4	70.4
		Min	67.4	64.1	61.9	62.8	62.9	57.9	52.6	54.7	61.6	68.3	69.3	65.7	66.8
		Max	81.4	79.3	75.3	76.4	76.1	73.5	68.4	73.2	80.4	78.0	80.2	82.3	73.8
TD	°C	Average	2.0	2.3	4.1	7.6	12.1	15.5	16.9	17.2	14.7	11.4	7.6	3.7	9.6
		Min	-2.9	-2.6	-0.4	3.0	10.4	13.6	14.9	15.9	12.6	8.3	3.9	-1.3	8.5
		Max	5.6	5.6	8.0	9.6	14.8	17.9	18.8	18.6	16.4	13.5	10.9	8.0	10.8
WBT	°C	Average	4.9	5.7	7.9	11.4	15.9	19.8	22.0	22.1	18.4	14.6	10.5	6.4	13.3
		Min	0.6	1.5	4.8	7.1	13.9	18.2	20.2	20.1	15.9	12.3	7.1	1.9	12.4
		Max	7.8	9.2	11.4	14.1	17.8	22.2	24.3	23.9	20.4	17.1	13.3	10.1	14.6
WS	m/s	Average	1.8	1.9	1.9	1.7	1.6	1.5	1.6	1.5	1.5	1.6	1.8	1.9	1.7
		Min	1.5	1.6	1.6	1.4	1.4	1.3	1.4	1.2	1.3	1.3	1.5	1.3	1.6
		Max	2.1	2.3	2.5	2.1	1.9	1.8	1.9	1.7	1.8	2.0	2.2	2.2	1.8
AP	hPa	Average	988	988	986	985	986	986	985	985	987	989	988	989	987
		Min	981	979	979	981	983	983	983	983	983	985	984	981	985
		Max	995	996	992	989	988	988	986	987	989	993	994	999	988
PREC	mm	Average	106.8	95.5	112.2	100.2	91.0	61.0	38.0	46.2	112.0	114.8	137.1	128.8	1,143.6
		Min	38.8	20.2	13.9	32.4	27.9	7.0	2.8	5.5	9.2	2.9	11.9	0.4	777.2
		Max	320.2	252.9	267.1	180.0	191.1	174.3	111.9	159.9	320.8	261.9	266.4	252.4	1,704.2
SDWE	kg/m²	Average	0.4	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
		Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Max	3.7	1.6	1.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.2	0.3

6.2 Air temperature and Relative humidity at 2 meters

PV module efficiency is affected by air temperature. Higher temperature reduces its energy conversion efficiency. Extreme temperature increases long-term thermal degradation of PV modules, and this data is important for optimizing the design of PV strings matching to inverters. Relative humidity affects the efficiency, increased degradation and durability of PV installations. High humidity increases the risk of condensation, which can cause electrical failures and reduced lifetime.

Diurnal statistics of Air temperature (TEMP) and Relative humidity (RH) at 2 meters above ground are calculated over the 24-hour daily cycle.

Figure 6.1 summarizes statistics of monthly values: long-term average and average minimum/maximum values. In Figure 6.2 to Figure 6.5, the time series of monthly and yearly averages show year-by-year variability. Table 6.2 shows monthly and yearly long-term averages of Air temperature at 2 meters. Table 6.3 to Table 6.6 show statistics of hourly values per month. Figure 6.6 and Figure 6.7 show statistics of hourly data in the form of daily profiles for each month.

Figure 6.1 Air temperature at 2 m (left) and Relative humidity at 2 m (right): Long-term averages, minimum/maximum monthly average values

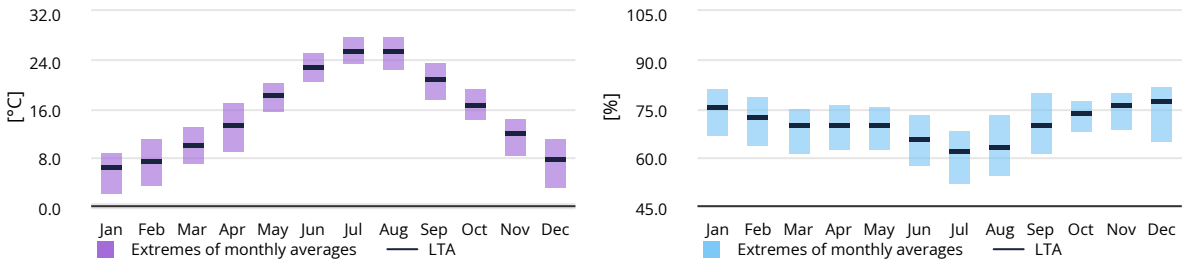


Figure 6.2 Air temperature at 2 m (left) and Relative humidity at 2 m (right): Time series of yearly averages and their standard deviation

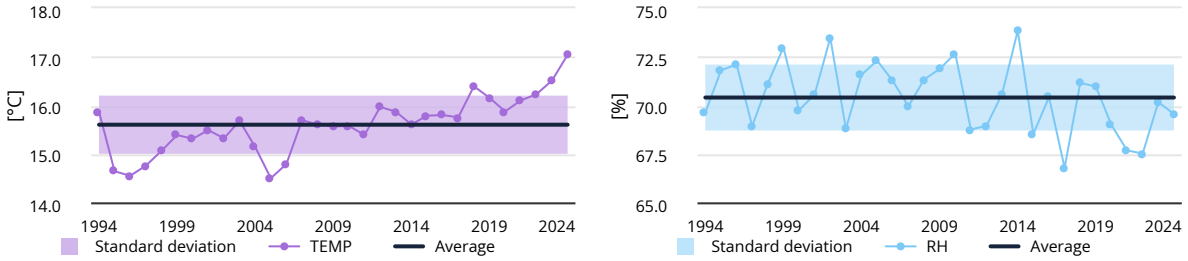


Figure 6.3 Air temperature at 2 m (left) and Relative humidity at 2 m (right) - interannual variability: Long-term monthly averages and time series of monthly average values

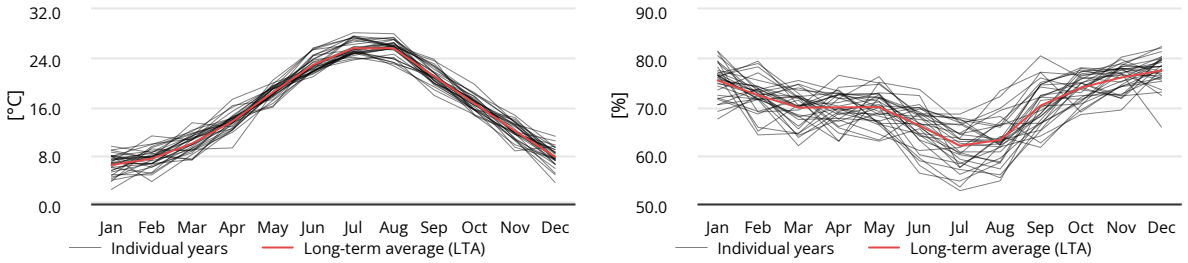


Figure 6.4 Air temperature at 2 m: Time series of monthly average values

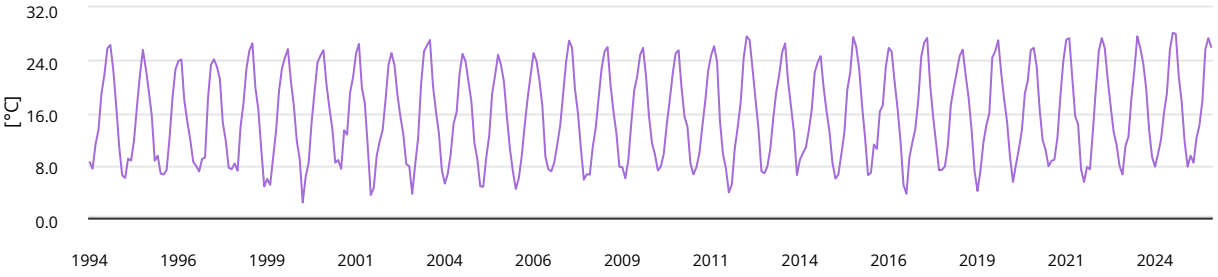


Figure 6.5 Relative humidity at 2 m: Time series of monthly average values

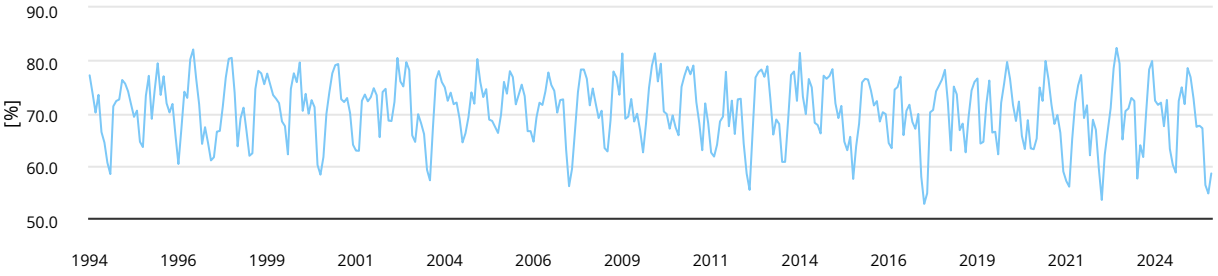


Table 6.2 Air temperature at 2 m: Monthly and yearly long-term averages (LTA) [°C]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1994	8.5	7.5	11.2	13.4	18.9	21.8	25.8	26.3	22.5	16.9	10.8	6.4	15.9
1995	6.0	9.0	8.7	11.7	17.0	21.7	25.5	22.7	19.2	15.5	8.7	9.4	14.6
1996	6.7	6.6	7.2	12.1	18.3	22.6	23.9	24.1	17.8	14.6	11.9	8.5	14.5
1997	7.9	7.0	8.9	9.2	18.2	23.3	24.1	23.0	21.2	14.5	11.7	7.6	14.8
1998	7.4	8.2	7.1	13.9	17.5	22.7	25.5	26.5	19.8	16.5	10.3	4.7	15.1
1999	5.9	5.0	9.1	13.2	19.3	22.8	24.4	25.7	20.9	17.0	11.7	8.9	15.4
2000	2.3	6.3	8.3	14.5	19.2	23.6	24.7	25.5	20.4	16.8	13.6	8.4	15.3
2001	8.8	7.4	13.3	12.6	19.0	21.3	25.0	26.5	19.7	17.4	10.7	3.4	15.5
2002	4.6	9.4	11.6	13.3	18.0	23.4	25.1	23.2	18.7	15.4	12.7	8.1	15.3
2003	7.8	3.6	8.1	12.1	20.3	25.4	26.2	27.1	20.2	16.2	12.9	7.3	15.7
2004	5.2	6.6	9.7	14.4	16.0	21.9	24.9	23.8	20.7	17.7	11.4	8.9	15.1
2005	4.8	4.7	9.1	12.4	18.9	21.7	24.8	23.3	20.7	15.3	10.6	7.1	14.5
2006	4.4	6.0	9.4	14.0	18.2	21.7	25.1	23.8	20.9	16.9	9.3	7.4	14.8
2007	7.0	8.4	11.1	14.1	18.9	23.7	27.0	25.9	19.6	15.9	10.5	5.8	15.7
2008	6.6	6.5	10.8	13.6	18.3	22.7	25.3	26.0	20.2	16.2	12.8	7.7	15.6
2009	7.7	6.0	8.6	14.3	19.3	21.5	24.8	25.9	21.5	15.5	11.4	9.6	15.6
2010	7.2	7.8	9.7	14.2	17.8	21.8	25.0	25.5	19.8	15.4	13.9	8.3	15.6
2011	6.6	7.6	9.7	13.8	17.7	22.4	24.7	26.1	23.8	14.6	9.7	7.5	15.4
2012	3.8	5.1	10.6	13.8	17.7	24.3	27.6	27.1	22.6	18.0	13.5	7.0	16.0
2013	6.8	7.8	10.5	15.2	19.1	21.7	25.2	26.5	20.8	16.9	12.9	6.5	15.9
2014	8.8	9.8	10.7	13.3	16.5	22.1	23.7	24.6	19.9	16.2	13.1	8.3	15.6
2015	6.0	6.6	9.7	12.9	19.4	22.1	27.5	26.1	22.7	17.1	12.3	6.5	15.8
2016	6.8	11.1	10.5	16.2	17.1	22.9	25.9	25.3	20.7	16.6	11.6	5.0	15.8
2017	3.6	9.2	11.5	13.5	17.9	24.5	26.7	27.4	20.3	15.4	11.4	7.2	15.8
2018	7.3	7.8	11.1	17.2	19.9	22.2	24.7	25.6	21.7	18.3	13.4	7.1	16.4
2019	4.0	7.2	11.4	14.1	15.9	24.4	25.4	27.0	22.1	18.1	14.5	9.2	16.2
2020	5.4	8.1	10.5	13.3	18.9	20.9	25.5	25.9	23.0	16.5	11.8	10.3	15.9
2021	7.8	8.6	8.8	12.2	18.5	23.8	27.1	27.3	21.5	15.5	14.2	7.4	16.1
2022	5.4	7.7	7.4	13.2	19.6	25.4	27.4	25.8	21.1	17.0	13.1	11.1	16.2
2023	7.9	6.6	10.9	12.3	18.1	22.5	27.6	25.8	23.5	19.6	13.3	9.2	16.5
2024	7.8	9.7	11.9	15.9	19.0	25.5	28.2	28.0	21.5	17.6	11.5	7.8	17.0
2025	9.4	8.4	12.1	14.1	17.9	25.7	27.3	26.0					
	6.3	7.4	9.9	13.5	18.3	22.9	25.6	25.6	20.9	16.5	12.0	7.7	15.6

Table 6.3 Air temperature at 2 m, hourly values per month: Long-term averages, minimum/maximum value and percentiles p01, p05, p10, p25, p50, p75, p90, p95, and p99 [°C]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	6.3	7.4	9.9	13.5	18.3	22.9	25.6	25.6	20.9	16.5	12.0	7.7
Min	-11.4	-9.4	-3.3	-3.6	6.5	8.9	12.6	13.8	8.4	2.8	-1.5	-6.5
Max	18.8	23.2	25.8	29.9	34.3	39.2	42.1	41.1	36.5	31.3	26.4	20.5
p01	-3.1	-2.0	-0.3	3.6	9.1	12.9	16.6	16.8	11.8	7.0	1.6	-1.4
p05	-0.9	-0.3	2.4	6.3	11.1	15.1	18.3	18.5	14.2	9.5	4.5	0.2
p10	0.3	1.2	4.0	7.6	12.4	16.4	19.5	19.6	15.4	11.0	6.2	1.6
p25	3.3	4.1	6.6	10.1	14.8	19.0	21.8	21.8	17.7	13.5	9.0	4.7
p50	6.6	7.5	9.8	13.3	18.0	22.6	25.2	25.2	20.6	16.3	12.1	8.0
p75	9.6	10.7	13.2	16.9	21.7	26.5	29.3	29.2	23.9	19.6	15.1	10.8
p90	12.0	13.4	16.2	19.9	24.8	29.9	32.3	32.3	27.1	22.3	17.6	13.2
p95	13.1	14.8	17.6	21.6	26.5	31.7	34.0	34.0	28.8	23.7	18.9	14.4
p99	15.0	17.3	20.2	25.0	29.3	34.2	36.4	36.6	31.9	26.0	21.5	16.4

Table 6.4 Relative humidity at 2 m, hourly values per month: Long-term averages, minimum/maximum value and percentiles p01, p05, p10, p25, p50, p75, p90, p95, and p99 [%]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	75.4	72.3	69.8	69.8	69.9	66.0	61.9	63.1	70.2	73.9	76.0	77.4
Min	22.9	14.3	15.9	17.9	17.9	19.4	18.8	20.7	19.2	19.4	22.8	23.7
Max	99.5	99.4	99.3	99.3	99.4	99.4	99.3	99.3	99.4	99.4	99.3	99.4
p01	36.1	31.6	29.6	31.3	33.2	31.4	27.3	27.3	31.2	35.0	38.1	41.0
p05	46.5	41.5	38.7	38.7	40.4	37.7	33.3	33.2	38.7	43.7	48.7	52.0
p10	53.9	48.1	44.6	43.9	45.1	41.6	37.3	37.5	44.1	49.5	55.2	58.5
p25	66.0	61.0	56.4	56.2	55.9	51.4	46.7	47.8	57.0	62.5	67.0	69.4
p50	78.2	75.4	72.9	72.8	72.3	67.3	62.6	64.5	73.3	77.1	79.0	79.9
p75	87.0	85.8	84.2	84.5	84.5	81.0	77.0	78.4	84.6	87.0	86.9	87.6
p90	92.3	91.3	90.2	90.7	91.1	88.9	86.0	86.9	90.8	92.6	91.9	92.3
p95	94.6	93.9	92.6	93.3	93.7	91.9	89.8	90.5	93.6	94.8	94.4	94.5
p99	98.0	97.5	96.4	96.9	97.2	96.2	94.8	95.5	97.0	98.1	97.5	97.5

Figure 6.6 Air temperature at 2 m: daily profiles of hourly values per month: Average (color line), percentile values p01, p10, p90, p99 (grey bands) [°C]

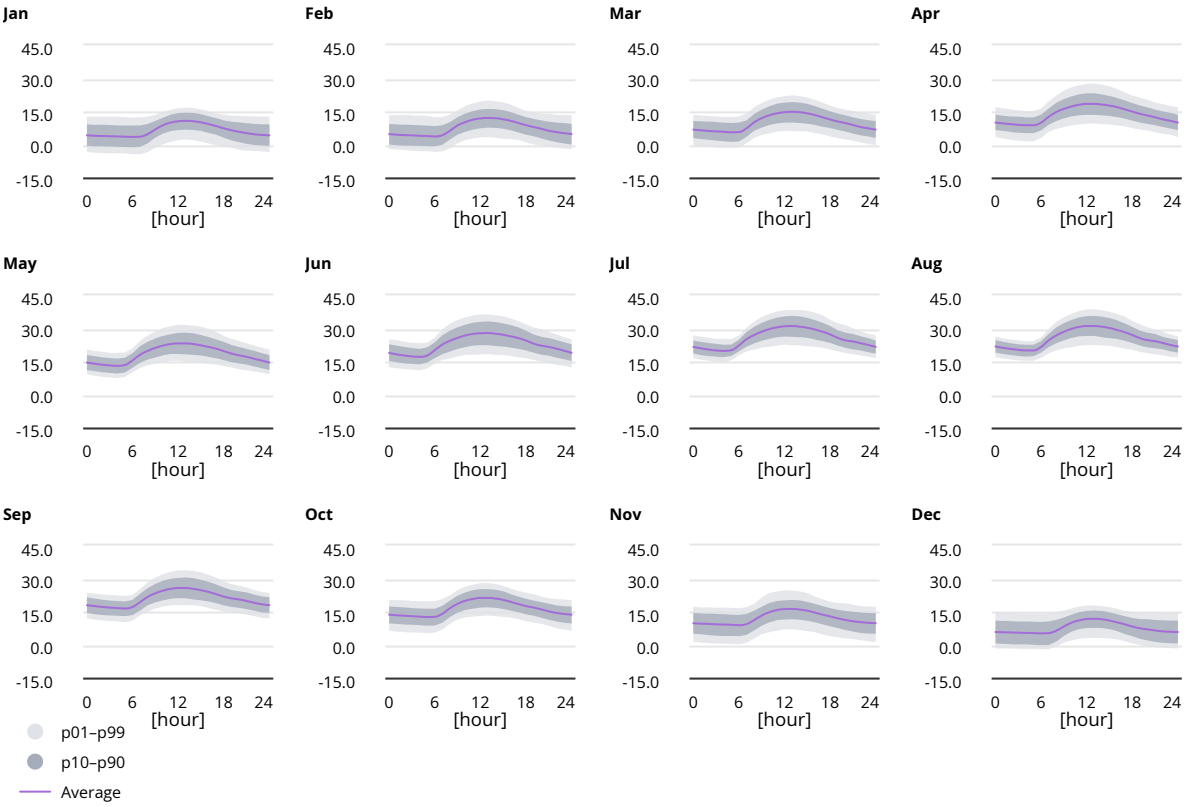


Table 6.5 Air temperature at 2 m: Hourly average values per month [°C]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	4.1	4.7	6.7	9.9	14.5	18.9	21.6	21.8	17.9	13.6	9.7	5.7
1 - 2	3.9	4.4	6.4	9.5	14.0	18.2	21.0	21.2	17.5	13.3	9.5	5.6
2 - 3	3.8	4.2	6.1	9.2	13.5	17.7	20.4	20.7	17.1	13.1	9.4	5.5
3 - 4	3.7	4.1	5.9	8.9	13.2	17.3	20.0	20.3	16.8	12.9	9.2	5.4
4 - 5	3.6	3.9	5.7	8.7	13.0	17.1	19.8	20.0	16.6	12.7	9.1	5.3
5 - 6	3.5	3.8	5.5	8.7	13.4	17.7	20.1	20.0	16.4	12.5	9.0	5.2
6 - 7	3.4	3.6	5.6	9.9	15.5	20.1	22.3	21.6	17.1	12.6	8.8	5.1
7 - 8	3.5	4.2	7.3	12.5	18.1	22.7	25.1	24.6	19.3	14.0	9.3	5.2
8 - 9	4.7	6.2	10.0	14.7	19.8	24.4	27.0	26.8	21.7	16.5	11.1	6.3
9 - 10	6.8	8.6	11.9	16.1	21.2	25.7	28.5	28.5	23.3	18.5	13.2	8.2
10 - 11	8.7	10.1	13.2	17.2	22.2	26.8	29.7	29.8	24.5	19.9	14.7	9.9
11 - 12	9.9	11.2	14.1	18.0	22.9	27.5	30.5	30.7	25.3	20.7	15.7	11.0
12 - 13	10.5	11.8	14.6	18.4	23.2	27.8	31.0	31.1	25.7	21.2	16.1	11.6
13 - 14	10.7	12.0	14.8	18.4	23.2	27.9	31.1	31.1	25.7	21.2	16.2	11.7
14 - 15	10.5	11.9	14.6	18.1	22.9	27.6	30.8	30.8	25.3	20.9	15.9	11.5
15 - 16	10.0	11.4	14.1	17.6	22.3	27.1	30.3	30.2	24.7	20.3	15.4	10.9
16 - 17	9.2	10.7	13.3	16.9	21.6	26.4	29.5	29.3	23.9	19.4	14.5	10.1
17 - 18	8.3	9.7	12.3	15.9	20.8	25.6	28.5	28.3	22.9	18.4	13.6	9.2
18 - 19	7.3	8.7	11.3	14.9	19.7	24.5	27.3	27.0	21.8	17.5	12.8	8.2
19 - 20	6.4	7.9	10.4	13.9	18.6	23.1	25.7	25.6	21.0	16.8	11.9	7.4
20 - 21	5.7	7.1	9.7	13.1	17.8	22.2	24.6	24.7	20.5	16.0	11.2	6.9
21 - 22	5.1	6.2	8.8	12.3	17.1	21.6	24.1	24.2	19.8	15.1	10.6	6.4
22 - 23	4.6	5.6	7.9	11.4	16.2	20.8	23.3	23.4	19.0	14.4	10.2	6.0
23 - 24	4.3	5.1	7.3	10.7	15.4	19.9	22.5	22.5	18.3	13.9	9.9	5.8
LTA	6.3	7.4	9.9	13.5	18.3	22.9	25.6	25.6	20.9	16.5	12.0	7.7

Figure 6.7 Relative humidity at 2 m: daily profiles of hourly values per month: Average (color line), percentile values p01, p10, p90, p99 (grey bands) [%]

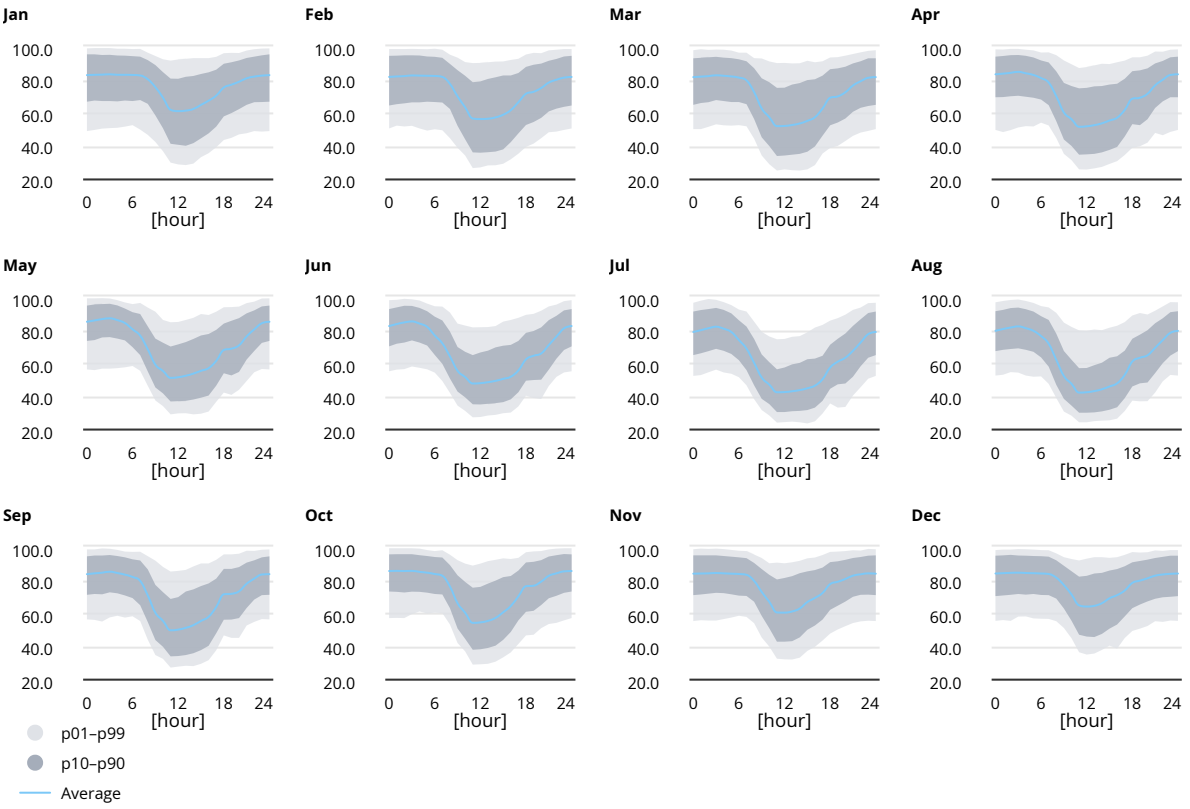


Table 6.6 Relative humidity at 2 m: Hourly averages per month [%]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	82.6	81.5	81.4	83.1	84.7	82.1	78.5	79.2	83.3	85.2	83.6	83.7
1 - 2	82.8	81.8	81.7	83.5	85.5	83.3	79.6	80.3	83.8	85.3	83.7	83.9
2 - 3	82.9	82.0	82.0	84.0	86.3	84.3	80.8	81.2	84.2	85.2	83.8	84.1
3 - 4	83.1	82.4	82.5	84.6	86.8	84.9	81.7	81.9	84.8	85.3	84.0	84.2
4 - 5	82.8	82.3	82.2	83.7	85.7	83.6	80.5	80.8	84.0	84.7	83.8	84.0
5 - 6	82.8	82.2	81.8	82.7	83.9	81.6	78.5	79.2	83.0	84.2	83.6	83.9
6 - 7	82.7	82.1	81.1	80.8	80.1	76.4	73.6	76.0	81.6	83.4	83.4	83.7
7 - 8	82.4	81.5	79.4	78.1	76.3	71.6	68.4	71.4	79.2	82.3	82.9	83.4
8 - 9	80.1	77.3	72.3	69.8	68.0	63.7	59.8	61.6	70.4	75.8	79.2	81.2
9 - 10	75.3	69.7	62.4	60.0	58.7	55.0	50.9	51.8	59.9	65.7	72.5	76.7
10 - 11	68.9	63.1	57.1	55.9	54.9	51.2	46.6	47.1	55.0	59.9	66.5	71.0
11 - 12	61.6	56.3	51.7	51.3	50.7	47.3	42.0	41.8	49.3	53.8	60.1	64.4
12 - 13	60.8	56.0	51.8	51.6	51.1	47.5	42.1	42.0	49.7	54.1	60.0	63.7
13 - 14	61.1	56.2	52.4	52.3	52.0	48.1	42.6	42.7	50.8	55.0	60.7	64.1
14 - 15	62.1	57.0	53.3	53.4	53.3	48.9	43.3	43.8	52.4	56.8	62.5	65.7
15 - 16	64.6	58.6	54.9	55.1	55.0	50.1	44.4	45.5	55.0	60.2	66.4	68.7
16 - 17	67.1	61.4	57.1	56.8	56.6	51.4	46.0	47.4	57.5	64.0	68.9	70.6
17 - 18	70.2	66.2	62.4	61.5	61.0	55.2	49.9	52.5	63.4	69.9	71.9	73.4
18 - 19	75.1	71.3	68.9	68.3	67.6	61.9	57.0	60.6	71.1	76.0	77.3	78.0
19 - 20	76.8	72.5	69.7	68.9	68.4	64.1	60.5	62.9	71.4	76.3	78.7	79.4
20 - 21	78.6	74.8	72.2	71.3	70.4	65.5	62.9	64.4	72.9	78.8	80.4	80.8
21 - 22	80.7	78.1	76.3	76.4	75.8	70.6	67.1	68.9	77.5	82.3	82.4	82.4
22 - 23	81.7	79.8	78.9	79.8	80.1	75.7	72.1	73.6	80.6	83.8	83.2	83.1
23 - 24	82.3	81.1	81.0	82.7	83.8	80.7	77.2	78.0	83.1	85.0	83.8	83.5
LTA	75.4	72.3	69.8	69.8	69.9	66.0	61.9	63.1	70.2	73.9	76.0	77.4

6.3 Dew point temperature and Wet bulb temperature at 2 meters

Both parameters represent values at 2 meters above ground, and they provide insights into atmospheric moisture conditions, which are crucial for the design and energy performance estimation of PV power plants.

Dew point temperature (TD) is the temperature at which air becomes saturated with moisture and dew begins to form. TD is used to assess the risk of condensation, accelerated corrosion, and degradation of PV components. Wet bulb temperature (WBT) is the lowest temperature achieved by evaporative cooling of a water-soaked surface. In areas with low wet bulb temperature, ambient cooling might enhance the performance of PV modules due to the lower operating temperature. High wet bulb temperatures can signify high humidity.

Figure 6.8 summarizes monthly statistics: long-term average and average minimum/maximum values. Table 6.7 and Table 6.8 show statistics of hourly values per month.

Figure 6.8 Dew point temperature at 2 m (left) and Wet bulb temperature at 2 m (right): Long-term monthly averages, minimum and maximum monthly average values

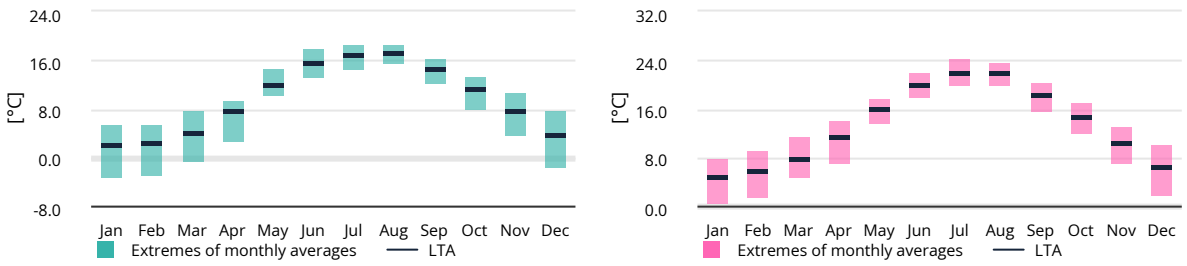


Table 6.7 Dew point temperature at 2 m, hourly values per month: Long-term averages, minimum/maximum value and percentiles p01, p05, p10, p25, p50, p75, p90, p95, and p99 [°C]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	2.0	2.3	4.1	7.6	12.1	15.5	16.9	17.2	14.7	11.4	7.6	3.7
Min	-17.7	-22.0	-12.2	-9.0	-1.0	2.2	5.8	7.0	-2.6	-7.1	-13.0	-13.0
Max	14.7	13.0	14.9	17.3	21.6	24.7	25.6	25.1	23.1	20.7	17.7	14.5
p01	-11.9	-10.3	-7.3	-3.2	5.4	8.2	10.7	11.2	5.6	0.6	-4.7	-8.0
p05	-7.3	-6.4	-3.8	1.5	7.4	10.8	12.6	13.1	8.7	4.3	-0.6	-4.8
p10	-5.1	-4.5	-1.6	3.3	8.5	12.0	13.6	14.0	10.3	6.2	1.7	-3.0
p25	-1.1	-0.6	1.8	5.7	10.3	13.7	15.3	15.6	12.9	9.2	5.2	0.7
p50	2.9	3.2	4.8	7.8	12.3	15.6	17.1	17.4	15.1	11.9	8.2	4.5
p75	5.8	5.7	7.0	9.9	14.1	17.4	18.7	18.9	17.0	14.1	10.7	7.3
p90	7.7	7.5	8.7	11.7	15.6	19.0	20.1	20.2	18.4	15.8	12.4	9.3
p95	8.7	8.3	9.6	12.6	16.5	19.9	20.9	20.9	19.2	16.7	13.4	10.4
p99	10.3	10.0	11.1	14.3	18.0	21.5	22.4	22.4	20.6	18.3	15.0	12.1

Table 6.8 Wet bulb temperature at 2 m, hourly values per month: Long-term averages, minimum/maximum value and percentiles p01, p05, p10, p25, p50, p75, p90, p95, and p99 [°C]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	4.9	5.7	7.9	11.4	15.9	19.8	22.0	22.1	18.4	14.6	10.5	6.4
Min	-12.3	-11.2	-4.7	-5.3	5.1	7.5	11.7	13.1	5.3	0.5	-3.7	-8.6
Max	17.2	17.4	19.0	22.1	26.2	29.5	31.1	31.4	27.3	25.1	21.7	17.1
p01	-5.7	-4.2	-1.8	2.3	8.4	12.0	15.5	15.7	10.5	5.6	0.1	-2.9
p05	-2.6	-1.8	1.1	5.3	10.4	14.2	17.0	17.3	13.0	8.3	3.1	-1.2
p10	-1.2	-0.3	2.7	6.6	11.6	15.3	18.0	18.2	14.3	9.8	5.0	0.3
p25	2.0	2.9	5.3	8.9	13.7	17.4	19.8	20.0	16.3	12.3	7.9	3.5
p50	5.3	6.0	8.2	11.6	15.9	19.8	22.0	22.1	18.5	14.8	10.9	6.7
p75	8.1	8.9	10.9	14.0	18.2	22.3	24.3	24.3	20.7	17.1	13.5	9.5
p90	10.3	11.0	12.9	15.8	20.4	24.6	26.2	25.9	22.6	18.9	15.3	11.7
p95	11.4	12.1	13.8	17.0	21.4	25.7	27.1	26.9	23.7	19.8	16.2	12.8
p99	13.0	13.7	15.4	19.2	23.3	27.4	28.4	28.6	25.4	21.6	17.8	14.7

6.4 Wind speed and Wind direction at 10 meters

Wind helps cool the PV modules. Strong wind loads pose a risk of damage to the mounting structures and PV modules. Understanding wind risk ensures the safety, stability, and sustainable operation of PV systems, especially trackers. The prevailing wind direction and wind speed can influence the orientation of the PV structures and modules, especially in a complex terrain.

Figure 6.9 summarizes monthly and yearly statistics: long-term average and average minimum/maximum values. Table 6.9 and Figure 6.10 to Figure 6.12 show statistics of hourly values per month.

Figure 6.9 Wind speed at 10 m: Long-term monthly averages, minimum/maximum average values (left). Yearly average values (right)

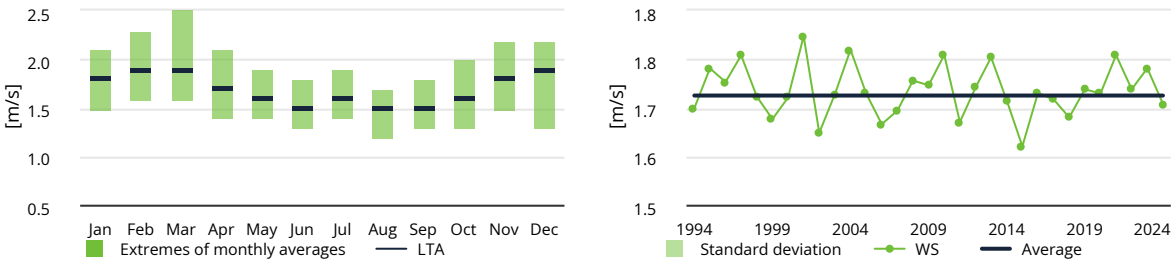


Table 6.9 Wind speed at 10 m, hourly values per month: Long-term averages, minimum/maximum values and percentiles p01, p05, p10, p25, p50, p75, p90, p95, and p99 [m/s]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	1.8	1.9	1.9	1.7	1.6	1.5	1.6	1.5	1.5	1.6	1.8	1.9
Min	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.0
Max	6.2	6.6	8.0	7.0	6.9	5.9	6.2	5.1	6.3	6.4	6.5	5.8
p01	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.3	0.3
p05	0.6	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.5	0.6	0.6
p10	0.8	0.8	0.8	0.7	0.6	0.6	0.6	0.6	0.6	0.7	0.8	0.8
p25	1.2	1.2	1.2	1.1	1.0	0.9	0.9	0.9	0.9	1.0	1.2	1.2
p50	1.8	1.8	1.8	1.6	1.4	1.4	1.3	1.3	1.4	1.5	1.8	1.8
p75	2.4	2.4	2.5	2.3	2.1	2.1	2.3	2.1	2.0	2.1	2.4	2.5
p90	2.9	3.2	3.2	3.0	2.8	2.8	3.1	2.8	2.7	2.7	3.0	3.1
p95	3.4	3.8	3.8	3.5	3.3	3.2	3.5	3.2	3.1	3.2	3.5	3.6
p99	4.3	4.8	4.9	4.6	4.3	4.0	4.2	3.9	4.0	4.2	4.6	4.5

Figure 6.10 Wind speed at 10 meters: Daily profiles of hourly values per month: Average (color line), percentile values p01, p10, p90, p99 (grey bands) [m/s]

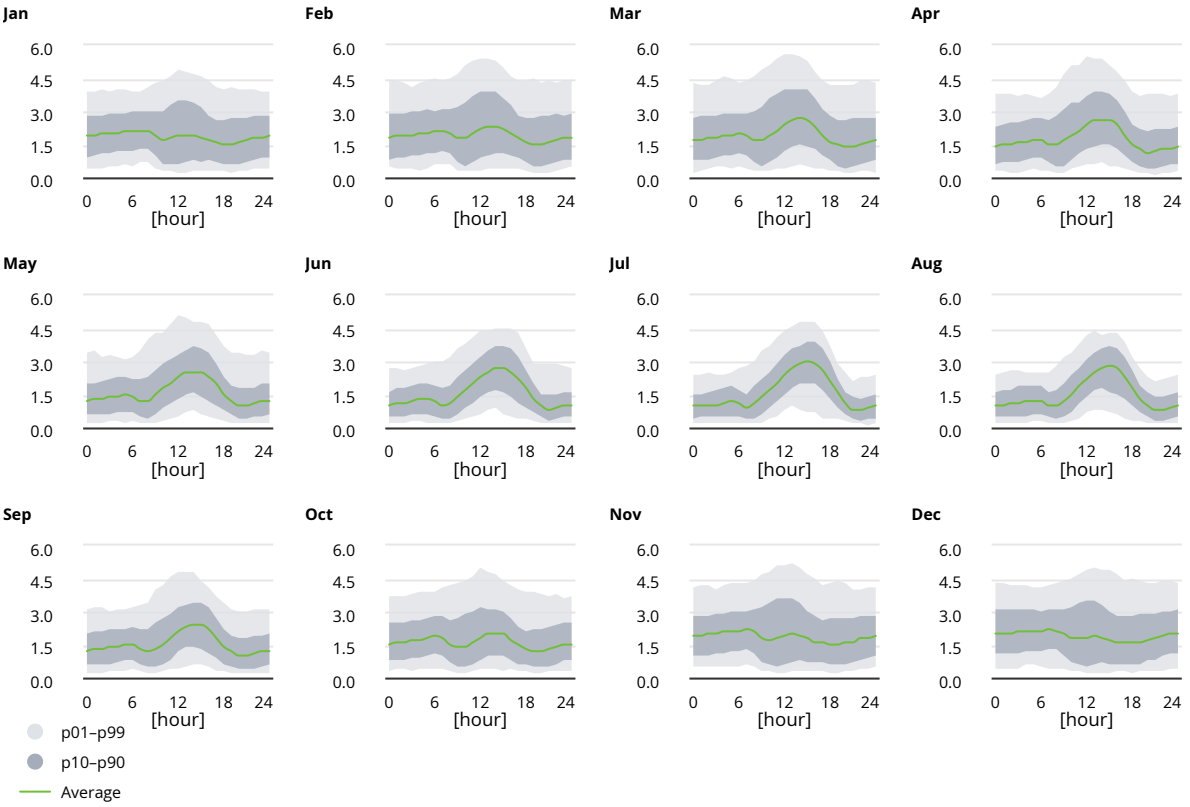


Figure 6.11 Wind speed at 10 m [m/s]: Occurrence statistics of hourly values per month

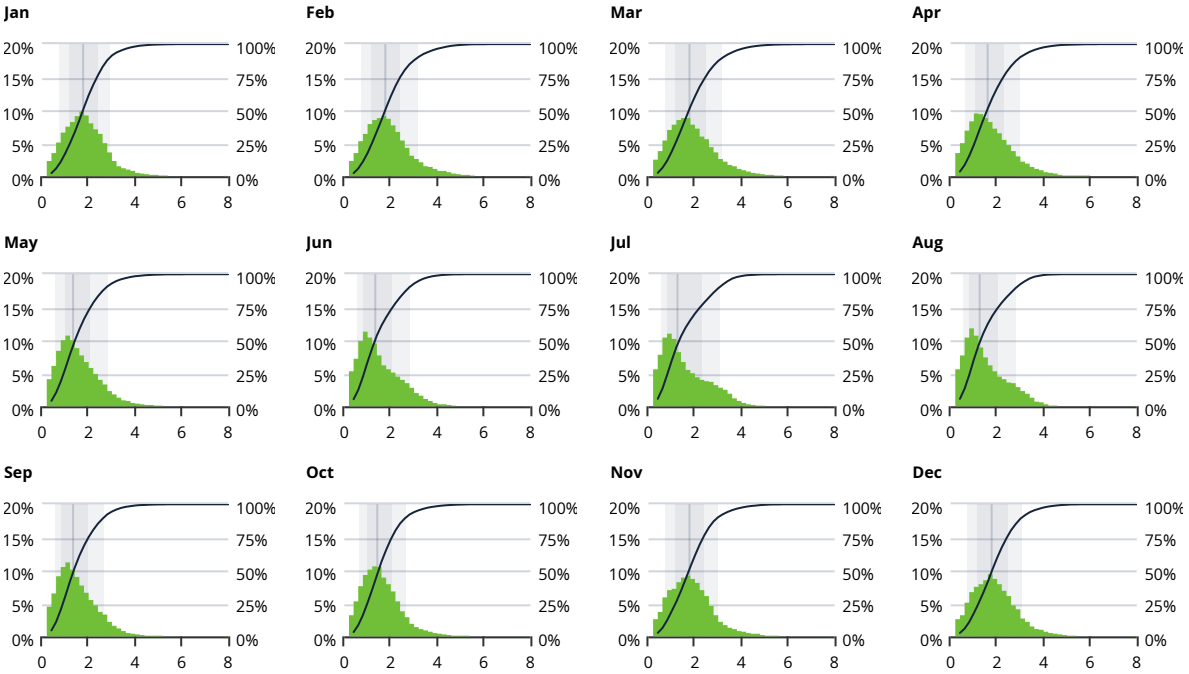
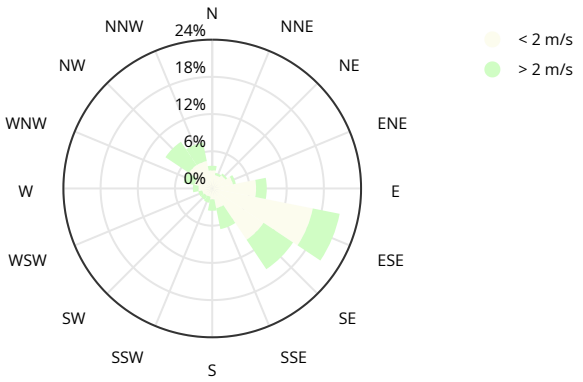


Figure 6.12 Wind speed and Wind direction at 10 meters: Statistics of hourly values [m/s]



The length of the segments in the wind rose above represents the relative frequency [%] of wind blowing from the respective direction. Colors represent wind speed categories.

6.5 Wind gust at 10 meters

Wind gusts are short, intense bursts over a short period (20 seconds). Wind gust significantly exceeds the average wind speed and can impact the design, stability, performance, and operation of PV systems, especially those including large PV modules and trackers.

Table 6.10 show statistics of hourly values per month.

Table 6.10 Wind gust at 10 m, hourly values per month: Long-term averages, minimum/maximum value and percentiles p01, p05, p10, p25, p50, p75, p90, p95, and p99 [m/s]

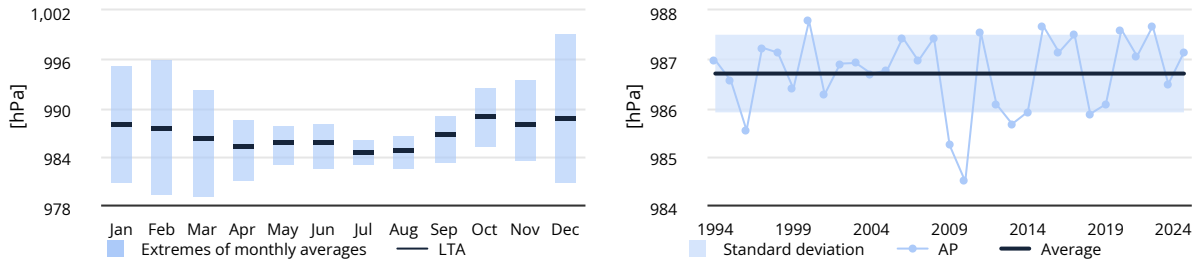
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	5.9	6.2	6.1	5.8	5.2	5.0	5.1	4.8	5.0	5.1	6.0	6.0
Min	1.2	1.0	1.2	1.0	1.0	1.2	1.1	1.2	1.1	0.9	1.2	1.1
Max	24.2	22.4	23.8	22.2	21.8	16.1	20.9	16.1	21.0	20.8	23.0	25.0
p01	2.1	2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.8	1.9	2.0	2.0
p05	2.8	2.8	2.7	2.5	2.4	2.4	2.4	2.3	2.3	2.5	2.6	2.7
p10	3.2	3.2	3.2	2.9	2.7	2.7	2.7	2.6	2.6	2.8	3.0	3.1
p25	4.0	4.1	4.0	3.7	3.4	3.3	3.3	3.2	3.3	3.5	3.8	4.0
p50	5.2	5.4	5.4	5.1	4.6	4.4	4.4	4.1	4.4	4.5	5.1	5.2
p75	7.1	7.5	7.6	7.2	6.7	6.5	6.7	6.2	6.2	6.0	7.3	7.4
p90	9.8	10.4	10.2	9.5	8.6	8.2	8.7	8.2	8.0	8.3	10.3	10.3
p95	11.6	12.5	12.0	11.2	9.9	9.2	9.6	9.1	9.3	10.1	12.3	12.0
p99	15.1	15.7	15.9	14.6	13.3	11.3	11.4	10.6	12.4	13.7	15.9	15.3

6.6 Atmospheric pressure

In general, atmospheric pressure has a low impact on PV systems. Changes in atmospheric pressure can affect the structural components of solar systems, especially in regions where pressure changes are abrupt and frequent.

Figure 6.13 summarizes monthly and yearly statistics: long-term average and average minimum/maximum values. shows statistics of hourly values per month.

Figure 6.13 Atmospheric pressure: Monthly average, minimum/maximum monthly average values (left). Yearly averages (right)



6.7 Precipitation

Precipitation (rainfall) impacts the soiling of PV modules and may affect the design of solar structures. Rain can clean PV modules but little rain can also make them dirtier. In a season of low rainfall, dust and soiling can reduce the efficiency of converting solar radiation into electricity. The PV modules and their supporting structures need to be designed to withstand the impact of water from heavy rainfall events.

Figure 6.14 and Table 6.11 show monthly and yearly totals. Figure 6.15 and Table 6.12 and Table 6.13 show statistics of daily and hourly totals.

Figure 6.14 Precipitation: Totals for individual months (black lines) and long-term monthly averages (red line) (left). Yearly totals and long-term average (LTA) (right)

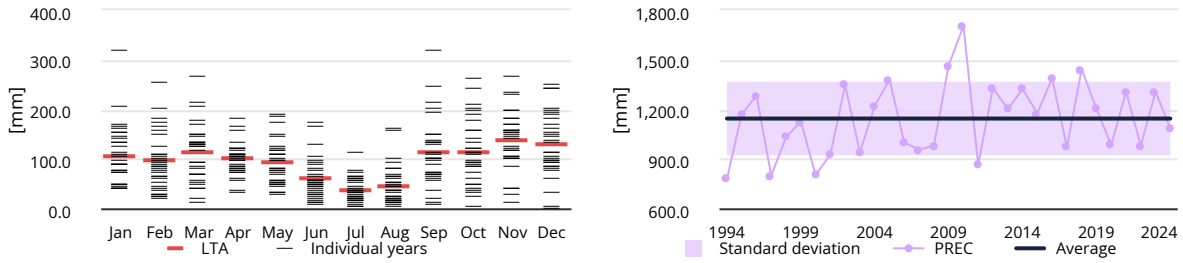


Table 6.11 Precipitation: Monthly and yearly totals, including long-term averages (LTA) [mm]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1994	71.2	83.3	13.9	109.2	54.3	27.4	31.0	44.6	72.5	61.8	122.3	85.7	777.2
1995	114.1	63.9	131.2	81.4	99.8	11.4	52.9	158.6	151.3	2.9	101.5	199.4	1,168.3
1996	46.7	171.8	132.1	104.2	75.2	49.6	27.1	19.6	247.7	92.5	167.7	149.7	1,283.8
1997	39.4	28.9	70.4	84.1	27.9	7.0	12.0	51.5	13.6	209.2	117.7	137.2	798.9
1998	48.4	83.3	47.9	84.6	97.4	38.4	31.5	37.7	131.5	197.1	140.8	92.0	1,030.5
1999	88.7	125.9	127.3	105.9	32.7	56.7	57.5	44.9	70.4	73.0	198.5	144.7	1,126.2
2000	48.8	104.7	92.8	102.9	49.0	22.8	24.8	23.3	68.9	50.2	127.0	86.8	802.0
2001	106.0	74.1	70.3	165.0	95.6	43.1	17.0	17.1	88.5	32.9	103.9	111.5	925.0
2002	41.0	29.5	67.3	119.2	117.3	47.2	111.9	159.9	320.8	121.2	40.5	169.9	1,345.6
2003	161.3	51.5	20.2	76.7	49.8	37.3	8.5	32.6	62.0	261.9	85.5	91.9	939.2
2004	141.1	97.0	124.8	132.1	109.1	70.1	77.2	37.0	134.2	90.1	101.8	106.7	1,221.1
2005	126.0	167.1	131.0	90.7	51.0	89.1	58.7	66.0	98.9	114.2	146.4	240.5	1,379.6
2006	90.1	102.7	178.0	110.4	49.2	91.0	74.7	91.3	70.5	23.1	41.8	75.3	998.0
2007	90.5	75.1	125.0	78.2	69.2	56.9	2.8	13.3	65.1	109.5	168.5	101.4	955.4
2008	42.3	20.2	134.9	80.1	55.6	107.0	36.2	15.1	107.2	85.3	101.4	192.7	978.0
2009	171.6	79.7	205.6	108.3	72.6	167.3	32.7	15.6	55.8	120.5	182.5	252.4	1,464.6
2010	152.2	201.3	146.1	104.3	78.5	97.6	39.4	16.3	202.8	244.1	230.1	191.5	1,704.2
2011	89.6	60.2	80.7	37.7	145.6	51.3	36.6	5.5	133.7	97.3	28.4	98.1	864.6
2012	77.2	149.8	39.3	180.0	147.6	20.9	18.7	10.9	128.7	200.1	153.3	204.0	1,330.4
2013	144.0	182.7	213.6	55.1	120.7	58.4	17.9	35.1	100.0	83.8	156.2	33.0	1,200.5
2014	131.6	62.9	82.9	157.2	173.5	53.5	65.5	20.3	150.5	178.2	148.0	98.8	1,322.8
2015	108.9	158.3	149.1	72.8	30.7	77.8	16.6	48.6	215.0	189.7	107.0	0.4	1,174.9
2016	155.5	110.4	148.9	109.6	109.7	78.9	58.5	62.9	195.5	157.5	199.0	2.2	1,388.5
2017	74.7	43.1	52.3	60.1	109.5	13.4	22.9	12.1	138.5	47.3	155.8	240.5	970.2
2018	76.8	252.9	267.1	32.4	191.1	174.3	60.1	80.9	9.2	35.8	181.2	80.6	1,442.3
2019	164.6	23.9	39.7	120.5	184.5	46.6	66.6	9.6	111.2	39.1	235.4	160.9	1,202.6
2020	38.8	91.2	171.6	97.8	58.0	63.6	16.9	67.2	71.8	158.4	11.9	135.1	982.3
2021	320.2	110.5	94.0	98.0	44.4	32.7	44.5	50.9	35.1	139.7	152.6	183.2	1,305.8
2022	45.8	89.2	58.2	122.1	79.2	42.7	18.9	59.9	100.4	93.4	159.2	111.6	980.5
2023	204.5	24.8	130.8	118.7	116.7	127.7	19.3	101.5	20.2	113.8	266.4	62.4	1,306.8
2024	98.1	41.4	131.9	108.5	124.7	28.2	20.1	23.7	100.6	135.1	117.0	154.1	1,083.3
2025	131.8	35.9	115.8	74.1	82.1	16.1	5.5	81.1					
	106.8	95.5	112.2	100.2	91.0	61.0	38.0	46.2	112.0	114.8	137.1	128.8	1,143.6

Figure 6.15 Precipitation: Occurrence statistics of daily totals per month [mm]

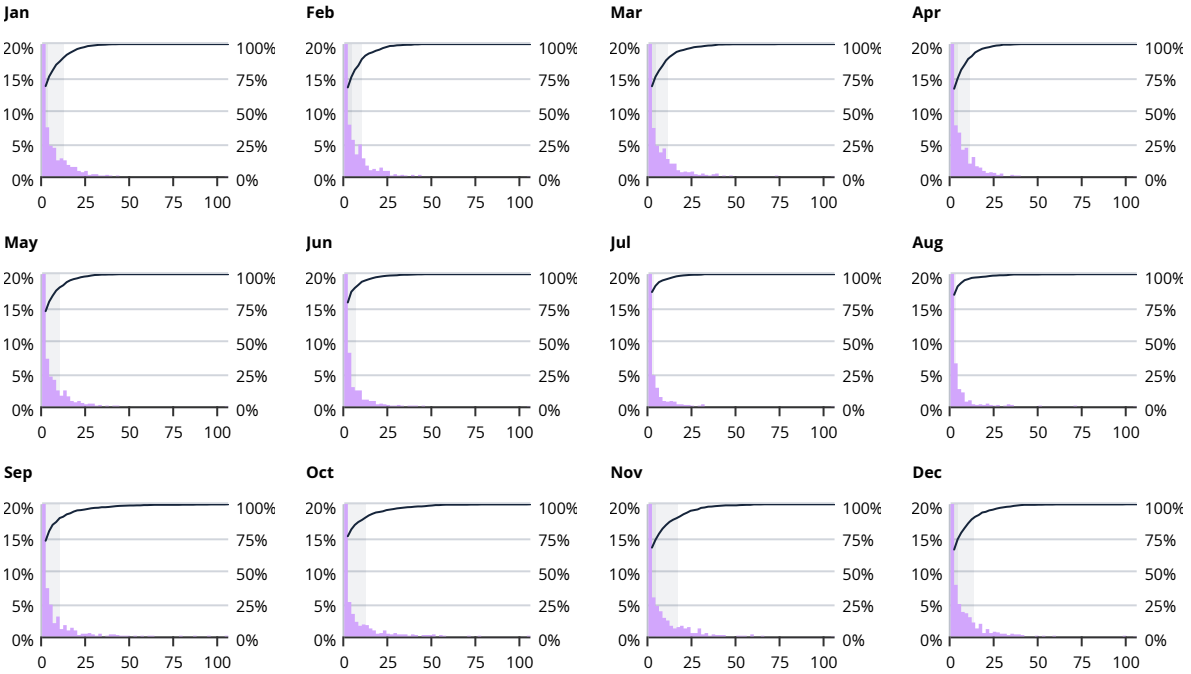


Table 6.12 Precipitation, daily totals per month: Long-term averages, minimum/maximum value and percentiles p01, p05, p10, p25, p50, p75, p90, p95, and p99 [mm]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	3.4	3.4	3.6	3.3	2.9	2.0	1.2	1.5	3.7	3.7	4.6	4.2
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	42.1	42.8	73.8	39.7	42.4	45.4	32.0	70.3	105.8	106.3	65.8	99.8
p01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p50	0.0	0.0	0.2	0.5	0.3	0.0	0.0	0.0	0.1	0.0	0.1	0.1
p75	3.8	4.0	4.0	4.4	2.7	1.5	0.4	0.5	2.6	1.8	4.7	4.6
p90	12.8	10.8	11.6	11.2	9.9	6.3	3.4	3.7	10.7	12.1	16.6	13.5
p95	18.1	18.0	18.0	15.9	15.2	11.7	7.0	7.4	18.7	22.4	24.0	21.0
p99	29.0	28.8	35.9	25.9	27.9	25.3	18.9	25.6	46.0	48.7	40.8	37.7

Table 6.13 Precipitation: Statistics of hourly totals per month [mm]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	5.4	5.8	8.1	7.5	6.6	7.8	7.3	13.2	12.6	13.5	9.0	8.4
p01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
p75	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
p90	0.5	0.4	0.4	0.4	0.3	0.1	0.0	0.0	0.3	0.3	0.5	0.5
p95	0.9	0.9	0.9	0.9	0.8	0.4	0.2	0.2	0.8	0.9	1.2	1.1
p99	2.1	2.1	2.4	2.2	2.3	2.1	1.4	1.6	3.4	3.2	3.1	2.7

6.8 Snow

Snow cover on PV modules blocks solar radiation, reducing their conversion efficiency and energy yield. In heavy snowfall, the mounting and PV modules have to withstand the weight of the accumulated snow and make it possible to slide off. Snow in a combination with freezing and thawing exposes materials and connections to extra stress. On the other hand, snow on the ground increases albedo.

Figure 6.16 and Figure 6.17 show monthly values of Snow depth water equivalent (SDWE).

Figure 6.16 Snow depth water equivalent: Averages for individual months (black lines) and long-term monthly averages (red line)

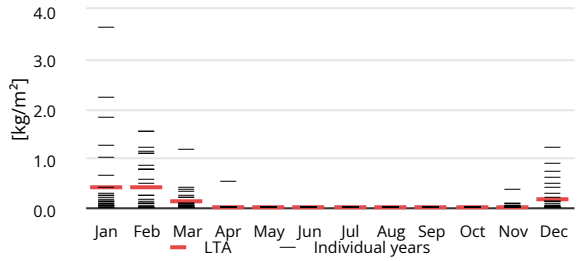
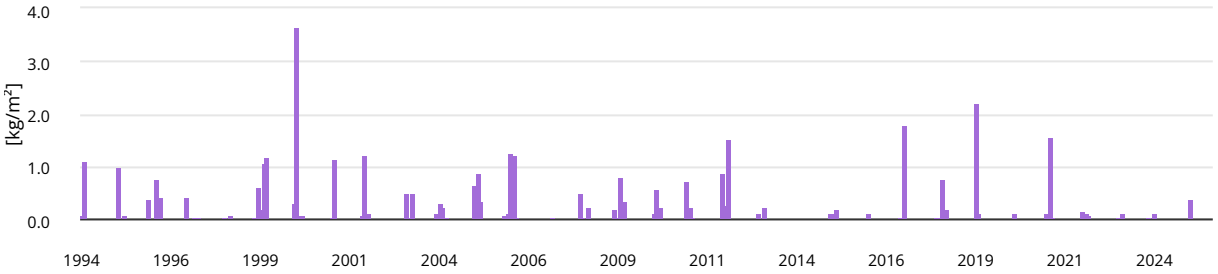


Figure 6.17 Snow depth water equivalent: Monthly time series



7 Atmospheric and environmental conditions

7.1 Precipitable water

Precipitable water (PWAT) refers to the total amount of water in a column from the Earth's surface to the top of the atmosphere, and this parameter is used to model PV module spectral losses.

Figure 7.1 and Table 7.1 show long-term average values.

Figure 7.1 Precipitable water: Long-term monthly averages

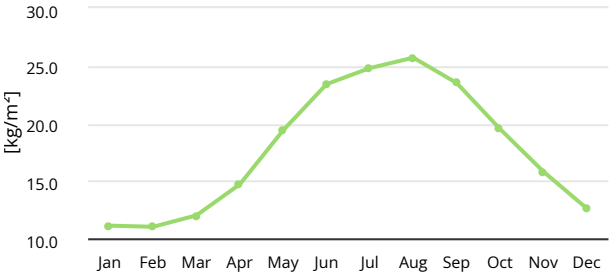


Table 7.1 Precipitable water: Long-term average values

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average	kg/m²	11.1	11.0	12.0	14.7	19.4	23.4	24.8	25.7	23.5	19.5	15.8	12.6	17.8

7.2 Ground surface albedo

Ground surface albedo (ALB) refers to the fraction of solar radiation that is reflected off the ground, and it is important for modelling energy output from bifacial PV modules.

Figure 7.2 and Table 7.2 show long-term average values.

Figure 7.2 Ground surface albedo: Long-term monthly averages

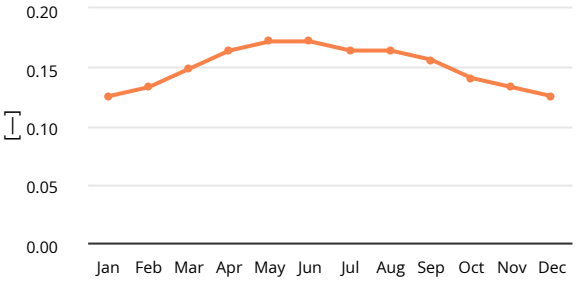


Table 7.2 Ground surface albedo: Long-term average values

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average	0.13	0.13	0.15	0.16	0.17	0.17	0.16	0.16	0.16	0.14	0.13	0.13	0.15

8 GHI and DNI uncertainty, probabilities of exceedance

The uncertainty has probabilistic nature, and it is considered at different confidence levels and converted into probability of exceedance of solar resource values (Pxx). The Pxx values are used in financial calculations. Due to limited length of the data archives and limited availability of ground measurements, in all uncertainty calculations a simplified assumption of normal distribution of values is accepted.

The long-term average yearly GHI and DNI values are considered to be equal to P50, and they represent 50% probability of exceedance (median), often referred to as the “best estimate”.

In the estimate of future GHI and DNI long-term averages, a combined effect of two sets of uncertainties is calculated, at different scenarios, given by different probabilities of exceedance. The most typical is 90% probability of exceedance (P90):

1. Uncertainty of satellite-based solar model,
2. Uncertainty due to year-by-year interannual variability, long-term trends and occasional large-scale volcano eruptions.

8.1 Satellite-based solar model uncertainty

This uncertainty depends on:

i. Accuracy of **solar radiation models** and their input data

ii. Accuracy and reliability of **solar measurements.** Therefore, only high-quality measurements are used for the uncertainty evaluation of the solar model.

1. The model uncertainty is quantified by a combination of numerical analysis and expert estimate.

Table 8.1 GHI and DNI model uncertainty at P90: long-term average values ($U_{GHI\text{-}model}$ and $U_{DNI\text{-}model}$)

			Standard deviation (68.3% occurrence)	80% occurrence	Uncertainty at P90 (90% exceedance)
Global horizontal irradiation	GHI	%	3.5	± 4.5	4.5
Direct normal irradiation	DNI	%	8.6	± 11.0	11.0

8.2 Uncertainty due to interannual variability, volcano eruptions and climate change

For estimating long-term GHI and DNI yearly values for years and decades ahead, three factors of uncertainty have to be considered:

i. Short-term and medium-term solar resource cycles. The **interannual** (year-by year) **variability** is calculated from the historical time series data with a great deal of confidence. Typically, the uncertainty due to interannual variability at any single year or over the lifetime of a power plant (25 or 30 years) are considered. While yearly values in the first years may deviate from the long-term estimate substantially, an extrapolation into two or three decades ahead shows much lower uncertainty.

ii. **Long-term climate cycles** and man-induced **climate change**. An indicative quantitative analysis is possible in regions with sufficient availability of solar measurements and satellite-based model data.

iii. Occasional major **volcano eruptions** injecting large amount of aerosols into stratosphere. Such events may happen about once in a century. They are known to affect solar resource and weather for several month to years. Due to a limited availability of historical data, it is not straightforward to quantify these effects in future with sufficient level of confidence.

The short- and medium-term solar resource variability (i) can be reasonably estimated from the historical data archives: the longer history, the more robust estimates.

Yet, our ability to characterize the longer-term cycles, modified by climate change (ii) and reduced solar resource due to stratospheric aerosols (iii) is very limited. To compensate for insufficient understanding of these elements of uncertainty, it is accepted to apply interannual variability for any single year as a proxy for capturing the risk of possible deviation of solar resource in future. Also, in calculation of Pxx scenarios and in estimating the respective minimum yearly GHI and DNI, a conservative approach has been adopted where uncertainty at any single year (Year 1) is used (blue color numbers in Table 8.2 to Table 8.5).

Table 8.2 Uncertainty of GHI long-term average due to interannual variability ($U_{GHI\text{-}years}$)

Years ahead		1	2	3	4	5	6	7	8	9	10	20	25	30
Possible deviation due to interannual variability	%	± 3.3	± 2.4	± 1.9	± 1.7	± 1.5	± 1.4	± 1.3	± 1.2	± 1.1	± 1.1	± 0.7	± 0.7	± 0.6
Uncertainty at P90	%	4.3	3.0	2.5	2.1	1.9	1.7	1.6	1.5	1.4	1.4	1.0	0.9	0.8

Table 8.3 Uncertainty of DNI long term-average due to interannual variability ($U_{DNI\text{-}years}$)

Years ahead		1	2	3	4	5	6	7	8	9	10	20	25	30
Possible deviation due to interannual variability	%	± 7.3	± 5.2	± 4.2	± 3.7	± 3.3	± 3.0	± 2.8	± 2.6	± 2.4	± 2.3	± 1.6	± 1.5	± 1.3
Uncertainty at P90	%	9.4	6.6	5.4	4.7	4.2	3.8	3.5	3.3	3.1	3.0	2.1	1.9	1.7

8.3 Combined uncertainty

Combined uncertainty of the long-term average GHI and DNI values is calculated as follows:

- $U_{GHI\text{-}combined} = SQRT\ (U_{GHI\text{-}model}^2 + U_{GHI\text{-}years}^2)$
- $U_{DNI\text{-}combined} = SQRT\ (U_{DNI\text{-}model}^2 + U_{DNI\text{-}years}^2)$

Table 8.4 GHI long-term yearly average - combined uncertainty at 90% probability of exceedance ($U_{GHI\text{-}combined}$)

Years	Model uncertainty (Standard deviation)	Uncertainty due to interannual variability (Standard deviation)	Combined uncertainty at P90 (Standard deviation)
N	$U_{GHI\text{-}model}$ [%]	$U_{GHI\text{-}long}$ [%]	$U_{GHI\text{-}combined}$ [%]
1	4.5 (3.5)	4.3 (3.3)	6.2 (4.8)
20	4.5 (3.5)	1.0 (0.7)	4.6 (3.6)
25	4.5 (3.5)	0.9 (0.7)	4.6 (3.6)
30	4.5 (3.5)	0.8 (0.6)	4.6 (3.6)

Table 8.5 DNI long-term yearly average - combined uncertainty at 90% probability of exceedance ($U_{DNI\text{-}combined}$)

Years	Model uncertainty (Standard deviation)	Uncertainty due to interannual variability (Standard deviation)	Combined uncertainty at P90 (Standard deviation)
N	$U_{DNI\text{-}model}$ [%]	$U_{DNI\text{-}long}$ [%]	$U_{DNI\text{-}combined}$ [%]
1	11.0 (8.6)	9.4 (7.3)	14.5 (11.3)
20	11.0 (8.6)	2.1 (1.6)	11.2 (8.7)
25	11.0 (8.6)	1.9 (1.5)	11.2 (8.7)
30	11.0 (8.6)	1.7 (1.3)	11.1 (8.7)

8.4 Probabilities of exceedance, Pxx values

Minimum expected GHI and DNI long-term yearly average values are calculated by subtracting $U_{GHI\text{-}combined}$ and $U_{DNI\text{-}combined}$, from P50 value respectively, for various probabilities of exceedance Pxx (i.e., for different confidence levels).

The Pxx values are offered considering different number of years ahead ($U_{GHI\text{-}years}$ and $U_{DNI\text{-}years}$, respectively). However, the standard approach is to consider Year 1 uncertainty (line with shaded background color), the reasons explained in .

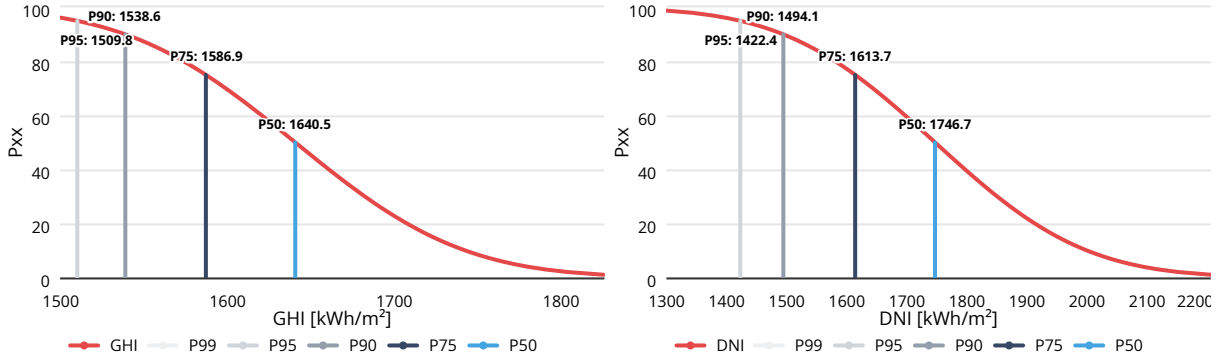
Table 8.6 Minimum GHI yearly long-term average values expected at different levels of probability of exceedance (Pxx) [kWh/m2]

Years (N)	P1	P5	P10	P25	P50	P75	P90	P95	P99
1	1825.4	1771.2	1742.4	1694.1	1640.5	1586.9	1538.6	1509.8	1455.6
20	1777.5	1737.4	1716.0	1680.2	1640.5	1600.8	1565.0	1543.6	1503.5
25	1776.9	1736.9	1715.6	1680.1	1640.5	1601.0	1565.4	1544.1	1504.1
30	1776.5	1736.7	1715.4	1679.9	1640.5	1601.1	1565.6	1544.3	1504.5

Table 8.7 Minimum DNI yearly long-term average values expected at different levels of probability of exceedance (Pxx) [kWh/m2]

Years (N)	P1	P5	P10	P25	P50	P75	P90	P95	P99
1	2205.3	2071.0	1999.3	1879.7	1746.7	1613.7	1494.1	1422.4	1288.1
20	2101.8	1997.8	1942.3	1849.6	1746.7	1643.7	1551.1	1495.6	1391.6
25	2100.5	1996.9	1941.6	1849.3	1746.7	1644.1	1551.8	1496.5	1392.9
30	2099.7	1996.3	1941.2	1849.0	1746.7	1644.4	1552.2	1497.1	1393.7

Figure 8.1 Expected long-term yearly average values for GHI and DNI for different Pxx scenarios considering Year 1



9 Acronyms

ALB	Ground surface albedo
AP	Atmospheric pressure
CFSR	National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis
D2G, DIF/GHI	Ratio of diffuse to global horizontal irradiation
DIF	Diffuse horizontal irradiation, if integrated solar energy is assumed. Diffuse horizontal irradiance, if solar power values are discussed
DNI	Direct normal irradiation, if integrated solar energy is assumed. Direct normal irradiance, if solar power values are discussed
ERA5, ERA5 Land	Climate reanalysis data, providing atmospheric, land-surface and sea-state parameters. Service operated by ECMWF
GFS	Global Forecast System. Service operated by NOAA
GHI	Global horizontal irradiation, if integrated solar energy is assumed. Global horizontal irradiance, if solar power values are discussed
GTI	Global tilted (global in-plane) irradiation, if integrated solar energy is assumed. Global tilted irradiance, if solar power values are discussed
LTA	Long-term average values
MACC-II/CAMS	Monitoring Atmospheric Composition and Climate - Interim Implementation of the Copernicus Atmosphere Monitoring Service operated by ECMWF
MERRA-2	Modern Era Reanalysis for Research and Applications operated by NASA
Meteosat	Meteosat satellites operated by EUMETSAT organization
MODIS	MODerate resolution Imaging Spectroradiometer operated by NASA
p01, p10, ... pxx	Calculated percentile values, pxx stands for the x-th percentile, p50 is median
PREC	Precipitation total
PVOUT Specific	AC energy delivered by a PV system and normalized to 1 kWp of installed capacity
PVOUT Total	AC energy delivered by the total installed capacity of a PV system
PWAT	Precipitable water. The total amount of vapor in a column of the atmosphere
RH	Relative humidity at 2 meters
SDWE	Snow depth water equivalent
SRTM3	Global digital elevation model prepared by the Shuttle Radar Topography Mission at the spatial resolution of 3 arc-second
SUN_AZIMUTH	Sun azimuth angle
SUN_ELEVATION	Sun elevation angle
TD	Dew point temperature at 2 meters
TEMP	Air temperature at 2 meters
WBT	Wet bulb temperature at 2 meters
WD	Wind direction at 10 meters
WG	Wind gust at 10 meters

WS	Wind speed at 10 meters

10 Glossary

P50 value	Best estimate or median value represents 50% probability of exceedance. For annual and monthly solar irradiation summaries it is close to average, since multiyear distribution of solar radiation is (in a simplified approach) considered to be a normal distribution.
Solar irradiance	Solar power (instantaneous energy) falling on a unit area per unit time [W/m^2]. Terms solar resource or solar radiation are used when considering both irradiance and irradiation.
Solar irradiation	Amount of solar energy falling on a unit area over a stated time interval [Wh/m^2].

11 References

11.1 Solargis methodology

[1] Solargis digital terrain models: https://kb.solargis.com/docs/geospatial-mapping-1

[2] Solargis solar, meteorological, and environmental database: methods, inputs, numerical models, validation, data parameters, and properties: https://kb.solargis.com/docs/solar-meteorological-and-environmental-data

[3] Validation of Solargis model parameters: https://kb.solargis.com/docs/accuracy-validation

[4] Geographical representation of Solargis model data: https://kb.solargis.com/docs/geospatial-mapping

[5] Solar resource uncertainty: https://kb.solargis.com/docs/uncertainty

[6] Solargis Analyst software: https://kb.solargis.com/docs/analyst

11.2 Data sources from third parties

CFSR	© 2025 National Oceanic and Atmospheric Administration (NOAA)
ERA5	© 2025 European Centre for Medium-range Weather Forecasts (ECMWF)
ERA5 Land	© 2025 European Centre for Medium-range Weather Forecasts (ECMWF)
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