Long term irradiation data uncertainty analysis

Customer: **TRANSVALOR**
Site: **CARPENTRAS**

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Outline

Glossary

- PV : Photo Voltaic
- GHI : Global Horizontal Irradiation
- GTI : Global Tilted Irradiation (in-plane irradiation for a fixed PV panel with a given tilt and azimuth)
- DNI (or BTI) : Direct Normal Irradiation (direct irradiation in a plane tracking the sun position)
- TMY : Typical Meteorological Year
- P50 : 50% percentile of a distribution (median)
- P90 : 90% percentile of a distribution (90% of the values will be above this threshold)

Introduction - methodology

Customer has requested a TMY analysis for their site.

Brief description of the site (name and location):

Site name: CARPENTRAS
Latitude: 44.083 (decimal degrees)
Longitude: 5.059 (decimal degrees)
Altitude: 97 (meters)
Long term time series of GTI with:
PV panel tilt: 25.0 (degrees)
PV panel azimuth: 180.0 (degrees)

This report synthesizes the uncertainty computations obtained from the site irradiation long term time series analysis.

The following statistical analysis is based on the "*Central Limit Theorem*".

Wikipedia: In probability theory, the central limit theorem (CLT) states that, given certain conditions, the arithmetic mean of a sufficient large number of iterates of identically distributed independent random

variables, each with a well-defined expected value and well-defined variance, will be approximately normal distributed, regardless of the underlying distribution.

In other words, for the subsequent statistical analysis, we assume that the annual values of irradiation can be considered as a normal (Gaussian) distribution.

The inter annual variability of a radiation component is calculated from the unbiased standard deviation **STD** for the whole period of complete years available from the HelioClim-3 database, this is 13 years from 2005 to 2017.

$$STD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

… with:

- N: total number of years
- x_i: is the i^{th} sample of the yearly irradiation value
- $\bar{x}$: is the average value of the yearly irradiation value over the whole period of data available.

The variability **Vn** for a number of year **n** is obtained from the unbiased standard deviation **STD in percent** with the formula:

$$Vn = \frac{STD}{\sqrt{n}}$$

In statistics, if we admit that the annual values follow a normal distribution, 80% of the values are contained in the interval +/- 1.28155**STD*. By extension we compute the uncertainty with the following expression:

$$uncertainty = 1.28155 * v_n$$

From this, you can deduce the lower and upper boundaries of the 80% values zone which represent respectively the 90% and the 10% of exceedance, also named percentile *P*90 (90% of the values are exceeding the limit) and percentile *P*10 (10% of the values only are exceeding the limit):

$$lower\ bound\ (P90) = \bar{x} - uncertainty$$

$$upper\ bound\ (P10) = \bar{x} + uncertainty$$

The three first sections of this report give respectively the yearly GHI, DNI and GTI values and provide an uncertainty analysis of these results. The three last sections inform on the monthly values and the corresponding main statistical figures, such as the average monthly values and the corresponding standard deviation.

Uncertainty analysis on the yearly GHI values

Yearly average:	1626	kWh/m²
Standard deviation:	**2.0**	%

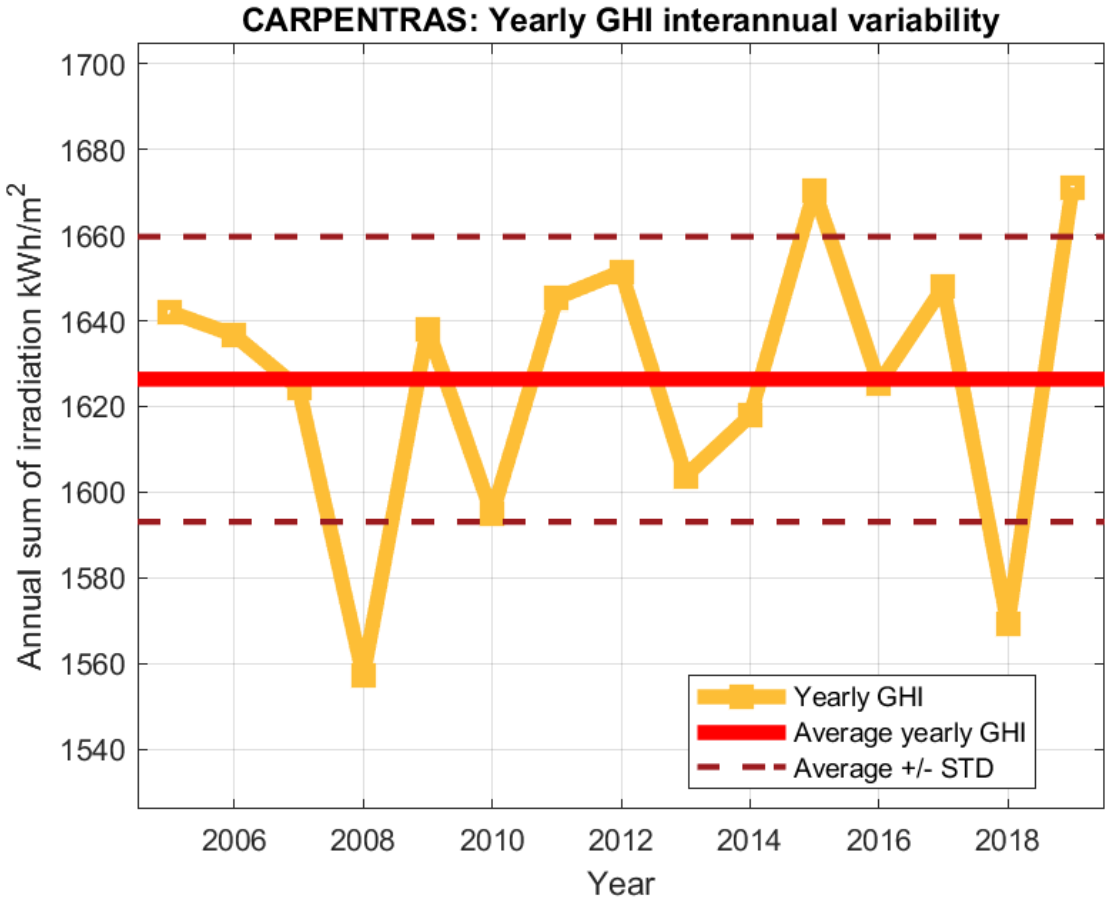

Figure 1: yearly GHI values (yellow points) and its average value (red line), in kWh/m². The inter-annual variability is illustrated by the upper and lower bounds (red dashed line).

The following table proposes a statistical analysis of the inter-annual variability as a function of the number of years used for this estimation.
This table shows that the greater the number of years available, the lower the variability.

Years	1	2	3	4	5	6	7	8	9	10
Variability (+/-%)	2.0	1.4	1.2	1.0	0.9	0.8	0.8	0.7	0.7	0.6
Uncertainty (+/-%)	2.6	1.9	1.5	1.3	1.2	1.1	1.0	0.9	0.9	0.8
Lower bound (P90)	1584	1596	1602	1605	1607	1609	1610	1611	1612	1613
Upper bound (P10)	1669	1657	1651	1648	1645	1644	1642	1641	1641	1640

Table 1: GHI annual variability, uncertainty and percentiles (P90 and P10) for a 1 to 10 years period

Uncertainty analysis of the DNI yearly values

Yearly average:	1972	kWh/m²
Standard deviation:	3.7	%

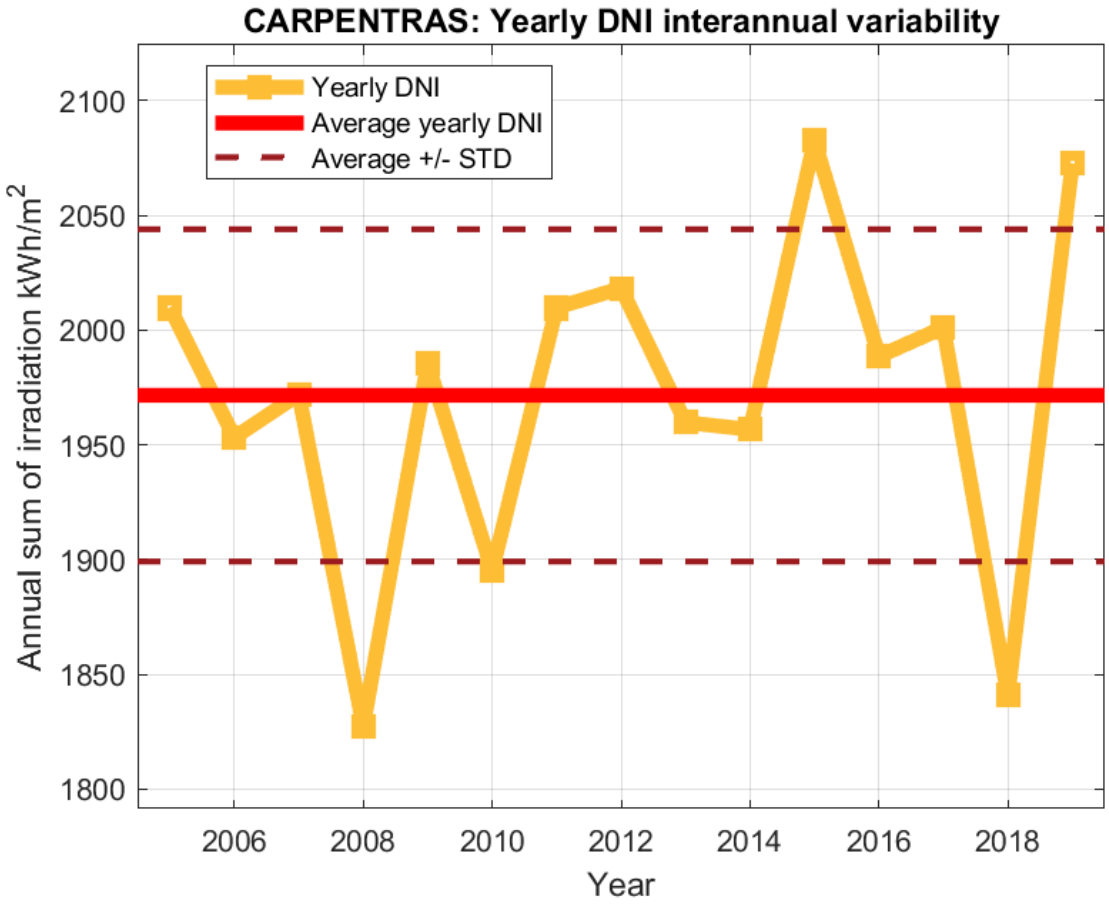

Figure 2: yearly DNI values (yellow points) and its average value (red line), in kWh/m². The inter-annual variability is illustrated by the upper and lower bounds (red dashed line).

Years	1	2	3	4	5	6	7	8	9	10
Variability (+/-%)	3.7	2.6	2.1	1.8	1.6	1.5	1.4	1.3	1.2	1.2
Uncertainty (+/-%)	4.7	3.3	2.7	2.4	2.1	1.9	1.8	1.7	1.6	1.5
Lower bound (P90)	1879	1906	1918	1925	1930	1934	1937	1939	1941	1942
Upper bound (P10)	2064	2037	2025	2018	2013	2009	2007	2004	2003	2001

Table 2: DNI annual variability, uncertainty and percentiles (P90 and P10) for a 1 to 10 years period

Uncertainty analysis of the GTI yearly values

Yearly average:	1918	kWh/m²
Standard deviation:	2.4	%

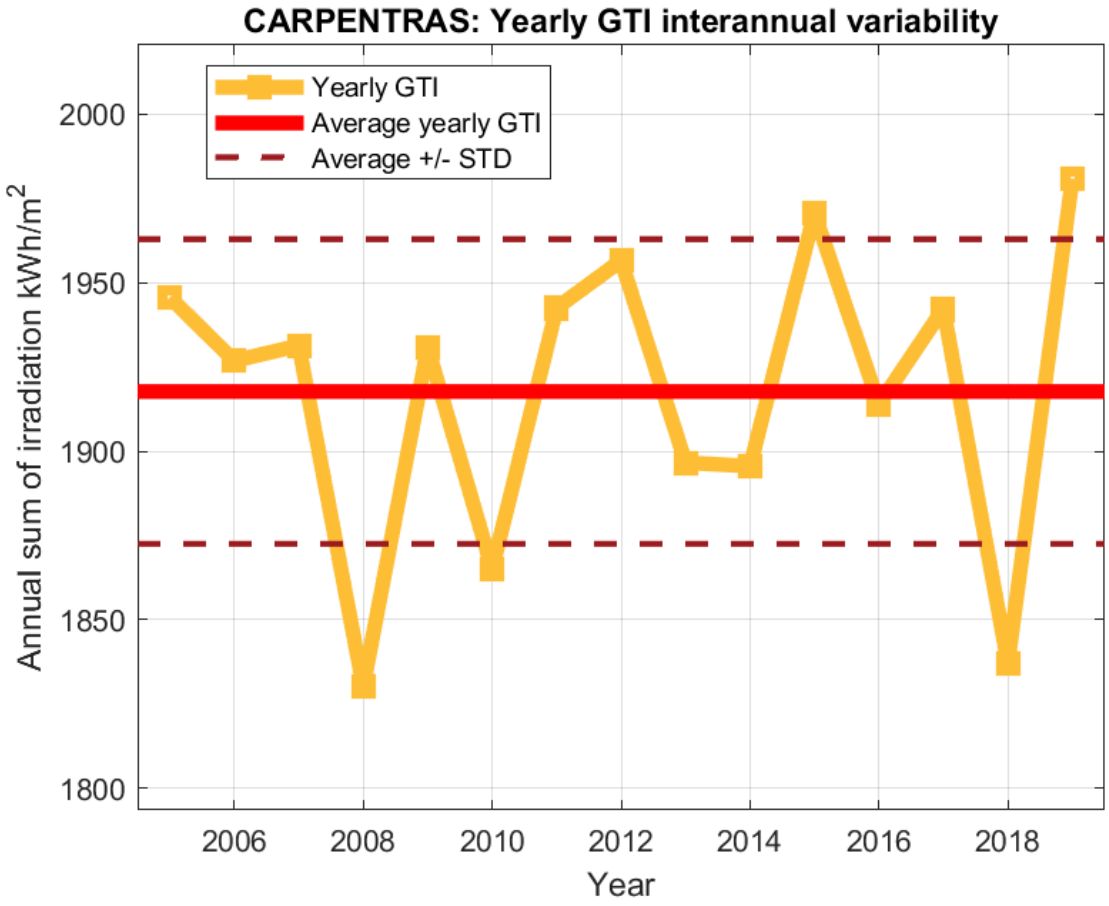

Figure 3: yearly GTI values (yellow points) and its average value (red line), in kWh/m². The inter-annual variability is illustrated by the upper and lower bounds (red dashed line).

Years	1	2	3	4	5	6	7	8	9	10
Variability (+/-%)	2.4	1.7	1.4	1.2	1.1	1.0	0.9	0.8	0.8	0.7
Uncertainty (+/-%)	3.0	2.1	1.7	1.5	1.4	1.2	1.1	1.1	1.0	1.0
Lower bound (P90)	1860	1877	1884	1889	1892	1894	1896	1897	1898	1899
Upper bound (P10)	1976	1959	1951	1947	1944	1941	1940	1938	1937	1936

Table 3: GTI annual variability, uncertainty and percentiles (P90 and P10) for a 1 to 10 years period

GHI monthly statistical results

The following illustration represents the GHI monthly average value for each month of the year. The variability around the average value is indicated by the dark red vertical segment corresponding to the average monthly value +/- the standard deviation for each month. The minimum and maximum values for each month are also depicted in the red curves.

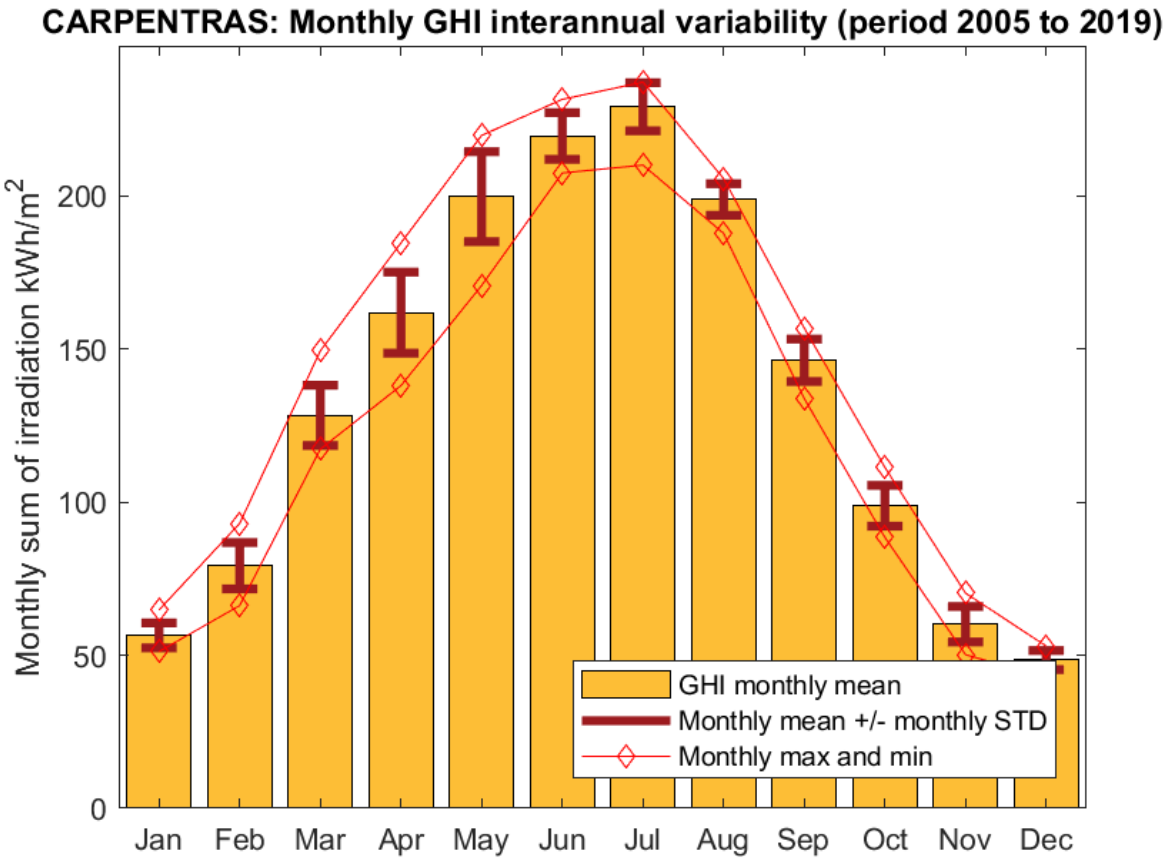

Figure 4: Monthly average GHI values (yellow bars), in kWh/m², min/max monthly value (red lines), and variability around the average value (vertical red segment).

DNI monthly uncertainty analysis

The following illustration represents the DNI monthly average value for each month of the year. The variability around the average value is indicated by the dark red vertical segment corresponding to the average monthly value +/- the standard deviation for each month. The minimum and maximum values for each month are also depicted in the red curves.

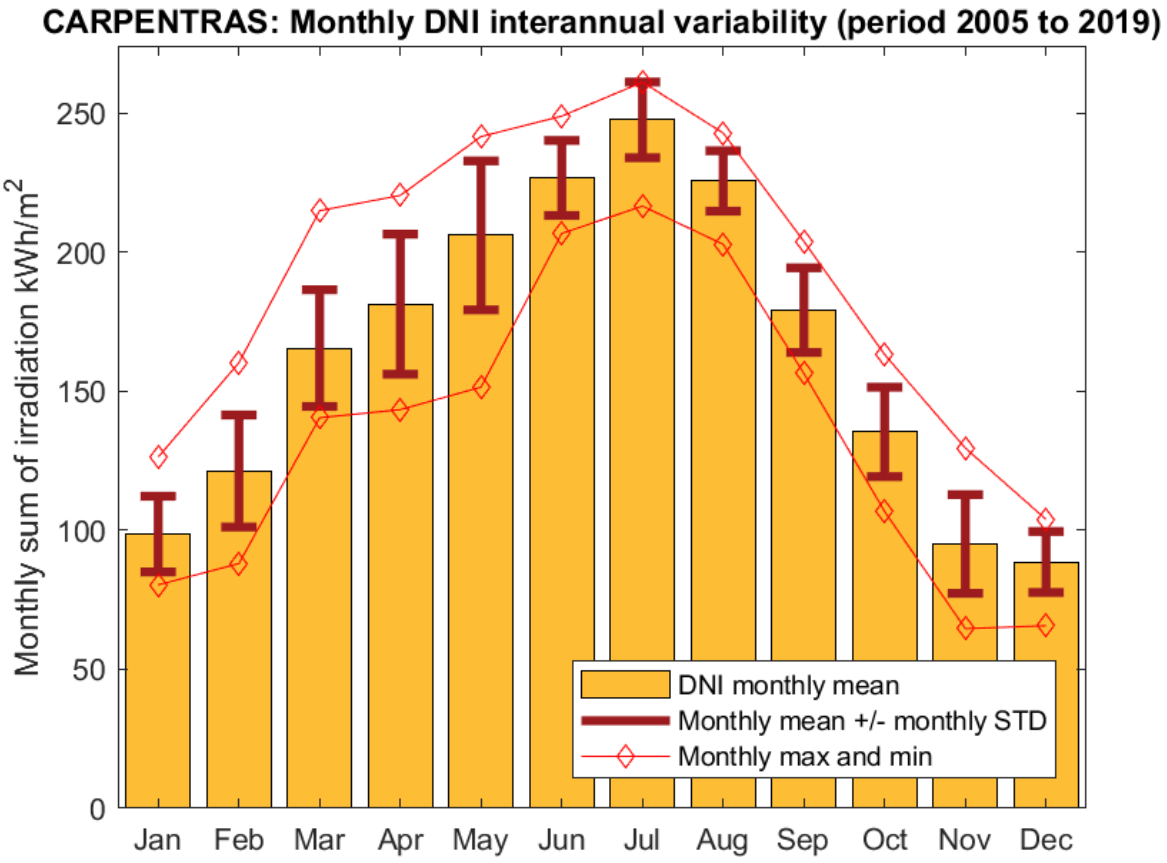

Figure 5: Monthly average DNI values (yellow bars), in kWh/m², min/max monthly value (red lines), and variability around the average value (vertical red segment).

GTI monthly uncertainty analysis

The following illustration represents the GTI monthly average value for each month of the year. The variability around the average value is indicated by the dark red vertical segment corresponding to the average monthly value +/- the standard deviation for each month. The minimum and maximum values for each month are also depicted in the red curves.

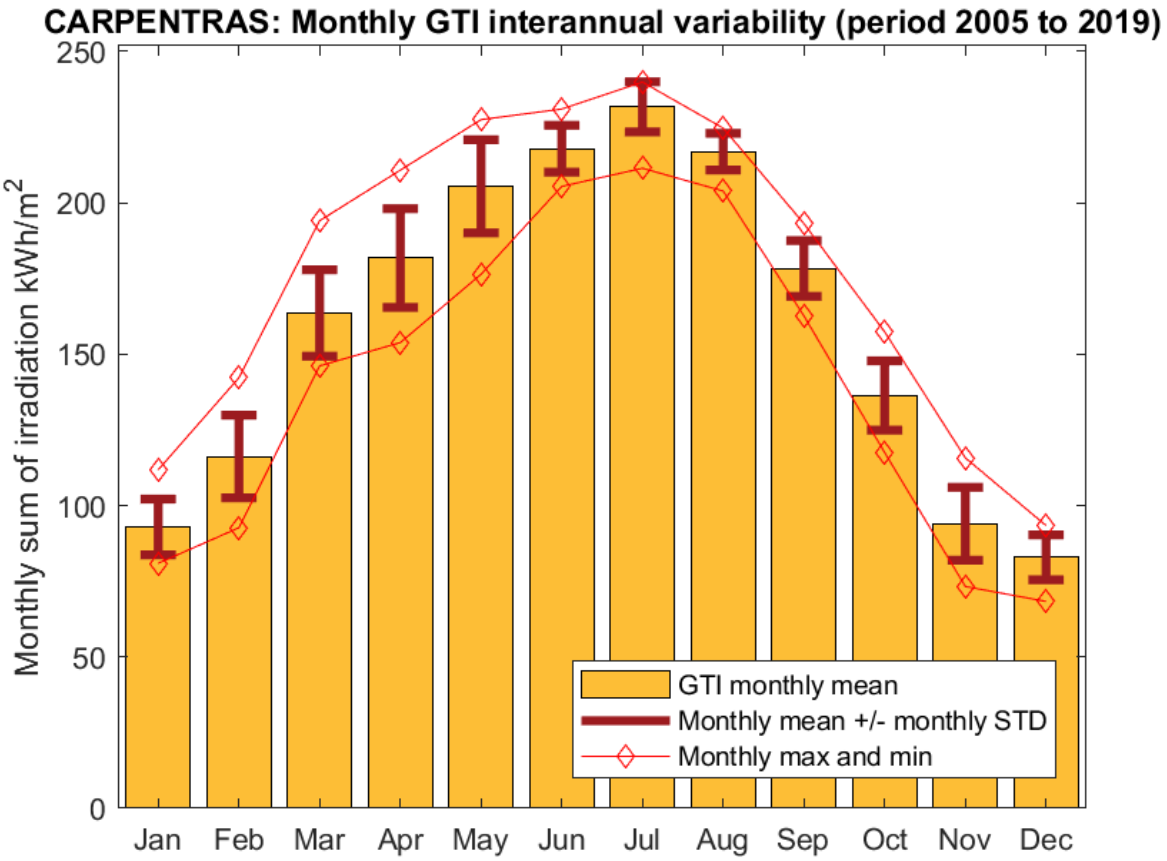

Figure 6: Monthly average GTI values (yellow bars), in kWh/m², min/max monthly value (red lines), and variability around the average value (vertical red segment).

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