Long term irradiation data uncertainty analysis

Customer: **XXXX**
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: 100 (meters)

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 10 years from 2005 to 2014.

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

… 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 two first sections of this report give respectively the yearly GHI and DNI values and provide an uncertainty analysis of these results. The third and fourth sections inform on the monthly values and the corresponding main statistical figures, such as the average monthly values and the corresponding standard deviation. The last section concludes this analysis by providing the most relevant statistical results.

Uncertainty analysis on the yearly GHI values

Yearly average:	**1620**	kWh/m²
Standard deviation:	**2.0**	%

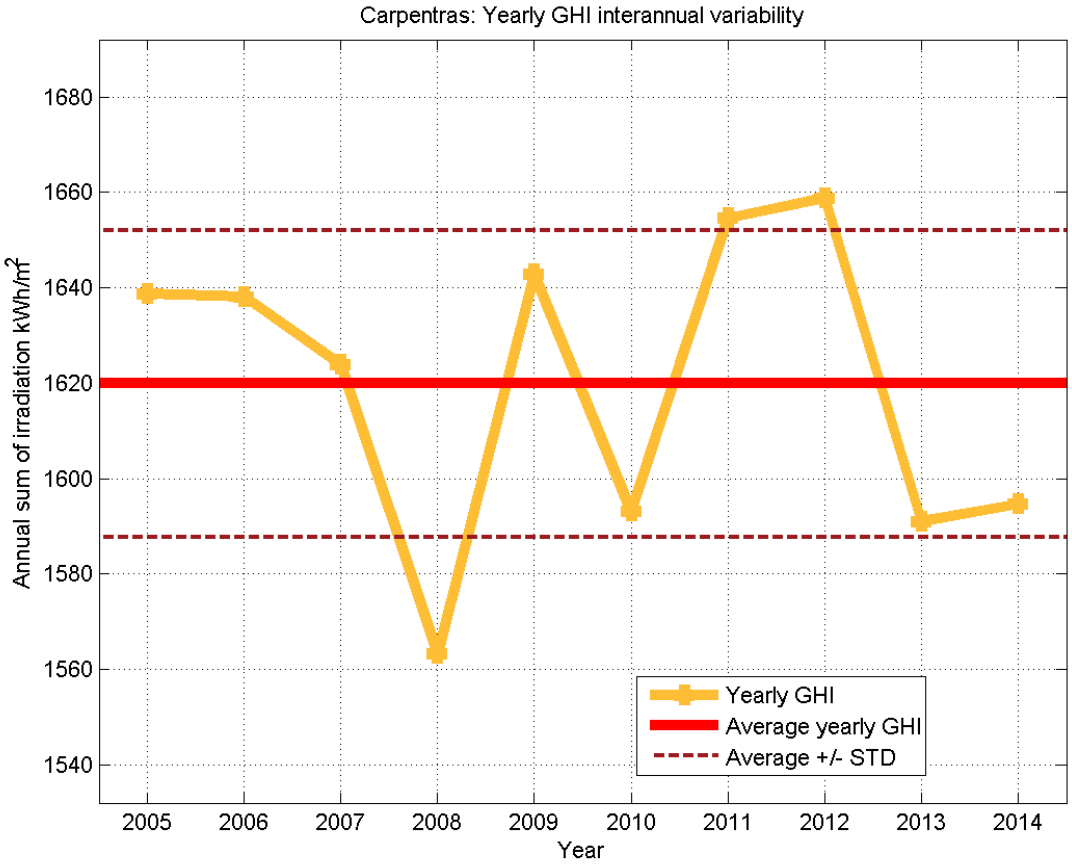

Figure 1: yearly GHI values (yellow points) and its average value (red line), in kWh/m². The inter-annual variability is illustrated by the upper and lower bounds (red dashed line).

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	1.1	1.0	0.9	0.8	0.8	0.7	0.7	0.6
Uncertainty (+/-%)	2.5	1.8	1.5	1.3	1.1	1.0	1.0	0.9	0.8	0.8
Lower bound (P90)	1579	1591	1596	1599	1601	1603	1604	1605	1606	1607
Upper bound (P10)	1661	1649	1644	1641	1638	1637	1636	1635	1634	1633

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:	**1959**	kWh/m²
Standard deviation:	**3.5**	%

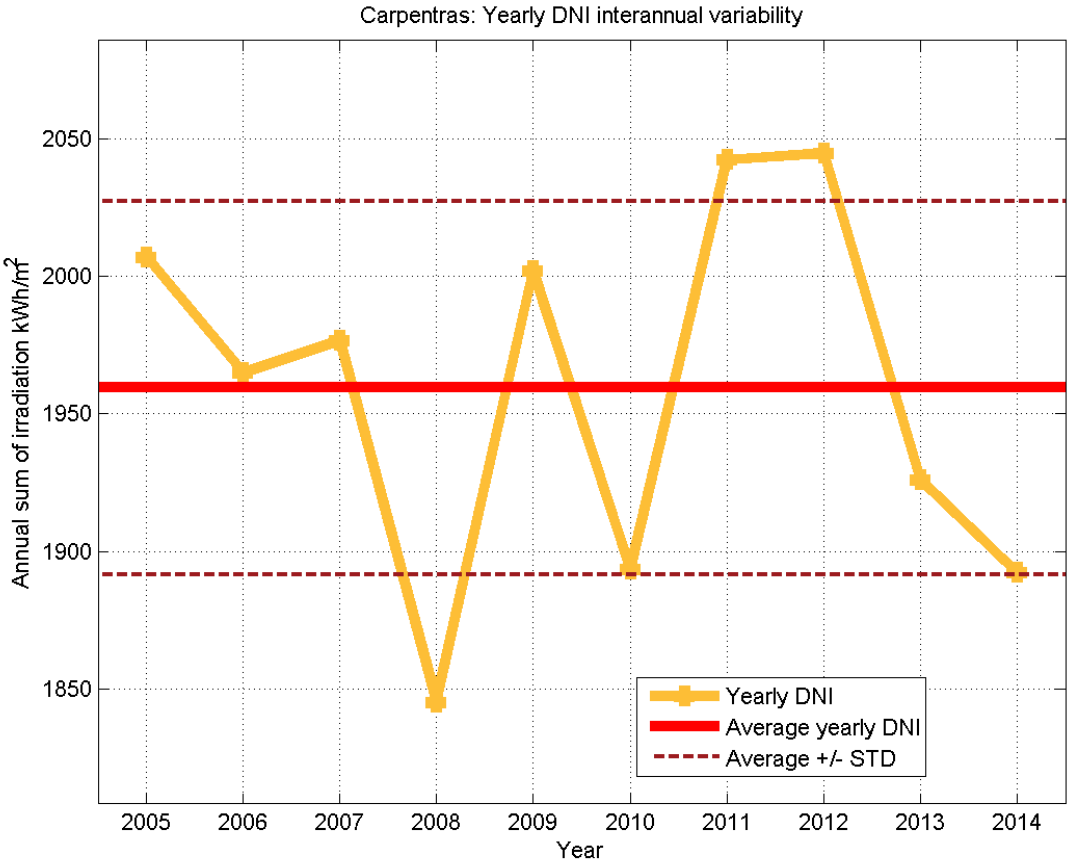

Figure 2: yearly DNI values (yellow points) and its average value (red line), in kWh/m². The inter-annual variability is illustrated by the upper and lower bounds (red dashed line).

Years	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Variability (+/-%)	3.5	2.5	2.0	1.7	1.6	1.4	1.3	1.2	1.2	1.1
Uncertainty (+/-%)	4.4	3.1	2.6	2.2	2.0	1.8	1.7	1.6	1.5	1.4
Lower bound P90	1872	1898	1909	1916	1921	1924	1927	1929	1930	1932
Upper bound P90	2046	2021	2010	2003	1998	1995	1992	1990	1988	1987

Table 2: DNI 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.

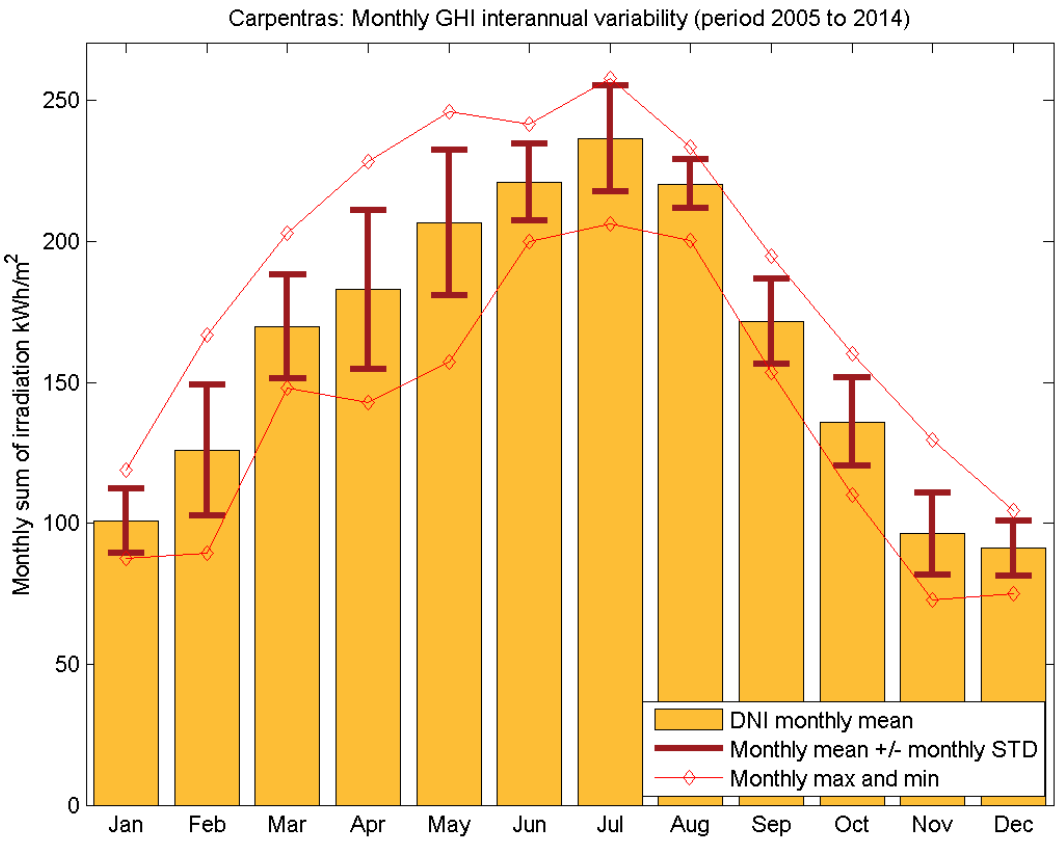

Figure 3: Monthly average GHI values (yellow bars), in kWh/m², min/max monthly value (red lines), and variability around the average value (vertical red segment).

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.

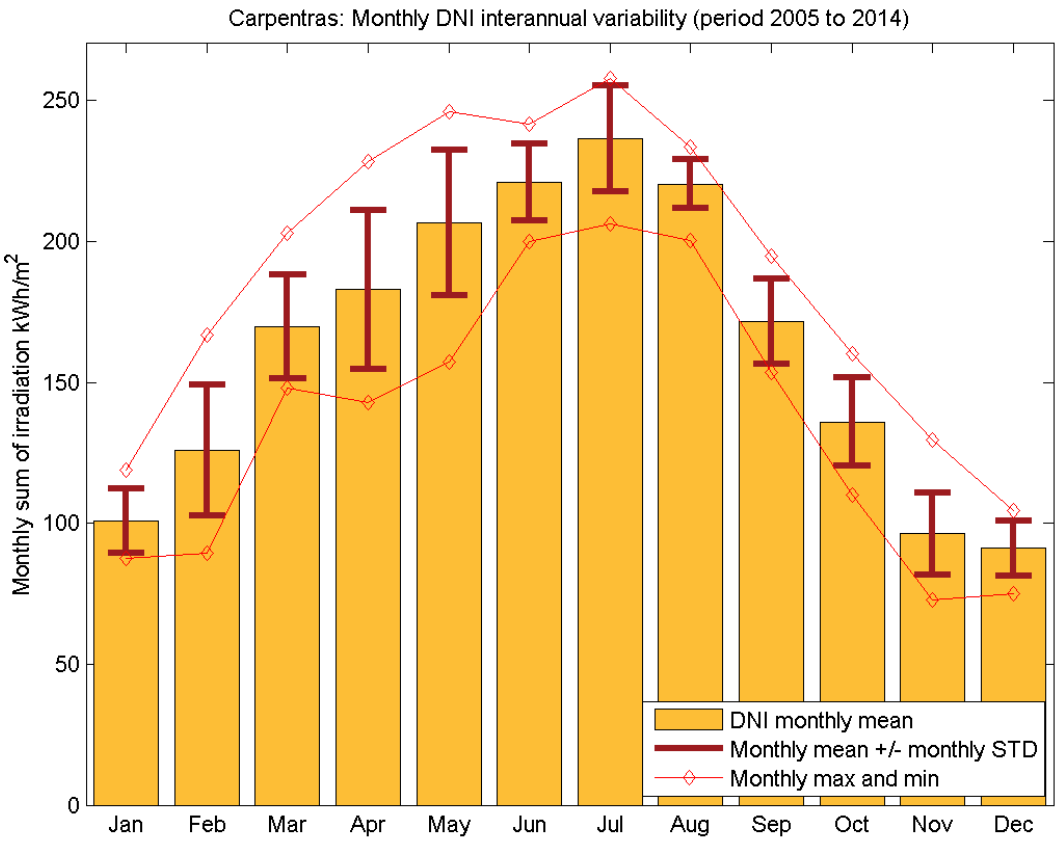

Figure 4: Monthly average DNI values (yellow bars), in kWh/m², min/max monthly value (red lines), and variability around the average value (vertical red segment).

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