CLEAN ENERGY FOR EU ISLANDS

Solar farm in business zone area

Feasibility study and conceptual design

Korčula

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CLEAN ENERGY FOR EU ISLANDS

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The Clean Energy for EU Islands Secretariat

Who we are

The launch of the Clean Energy for EU Islands Initiative in May 2017 underlines the European Union's intent to accelerate the clean energy transition on Europe's more than 1,400 inhabited islands. The initiative aims to reduce the dependency of European islands on energy imports by making better use of their own renewable energy sources and embracing modern and innovative energy systems. As a support to the launch of the initiative, the Clean Energy for EU Islands Secretariat was set up to act as a platform of exchange for island stakeholders and to provide dedicated capacity building and technical advisory services.

The Clean Energy for EU Islands Secretariat supports islands in their clean energy transition in the following ways:

• It provides technical and methodological support to islands to develop clean energy strategies and individual clean energy projects.

• It co-organises workshops and webinars to build capacity in island communities on financing, renewable technologies, community engagement, etc. to empower them in their transition process.

• It creates a network at a European level in which islands can share their stories, learn from each other, and build a European island movement.

The Clean Energy for EU Islands Secretariat provides a link between the clean energy transition stories of EU islands and the wider European community, in particular the European Commission.

1. Introduction

Objectives

As part of a Call for Proposals launched in 2019 for project support to islands, the Clean Energy for EU Islands Secretariat is providing Technical Advisory services to the island Korčula in Croatia. This technical note covers the preliminary study regarding the business area to be developed on the island. The Project consist of a free land area for ground-mounted PV and several buildings rooftops. A basic conceptual design including preliminary layout has been prepared to serve as a base for technical specifications.

Guide to the reader

A brief description of the project details and location is provided in chapter 2. Chapter 3 focuses on the sizing of the photovoltaic project. Chapter 4 presents the mechanical integration and layout, whereas the chapter 5 presents the results of the long-term yield assessment.

2. Site specifications

The Project is planning to develop a ground-mounted and rooftops photovoltaic plant in the island of Korčula, Croatia. The pre-selected site is located in the centre of the islands, approximately 4km west from the Pupnat village in the Općina Korčula district. The foreseen area has a total available surface of 13 hectares just by the local road n°118. The site is also crossed by the 110kV power line running along the island. As the PV plants will be used to power local businesses to be implanted in the area, they might be connected to a 35kV small closed distribution system with a single substation. The location of the project and pre-defined area to be considered are presented in the following Figure 1.

Figure 1:Site location (source: Google Earth)

The following Table 1 summarizes the projects locations.

Korčula PV project	**Value**	**Unit**
Latitude	42.948450	°N
Longitude	16.984464	°E
Altitude	461	m (a.s.l)
Area	13	Ha

Table 1 : Summary of the project location

According satellite images and shared pictures, the terrain does not present any major constraint as it is rather flat with some vegetation (low to medium height trees (3-5m) to be cleared). There are also no habitations or secondary buildings. The soil seems to be mostly dry and slightly rocky, this should not prevent installation of ground-mounted structures.

Figure 2: Site picture taken from drone showing 110kV line (source: Korčula Project)

The author was informed that the site is planned to be divided in two sections with a ground-mounted PV area in the southern part of the plot (~6 Ha) and industrial building to be built on the northern part, closer to the road, with rooftop PV to be installed (~6.5 Ha). It is considered for the preliminary study that 10 buildings plots will be used in this area with a surface of 2.5Ha each (~2Ha rooftop surface), separated by 30m wide roads. A standard building height of 12m was considered for this assessment. A preliminary layout of the business area to be developed is shown in below (industrial areas in yellow, roads in black).

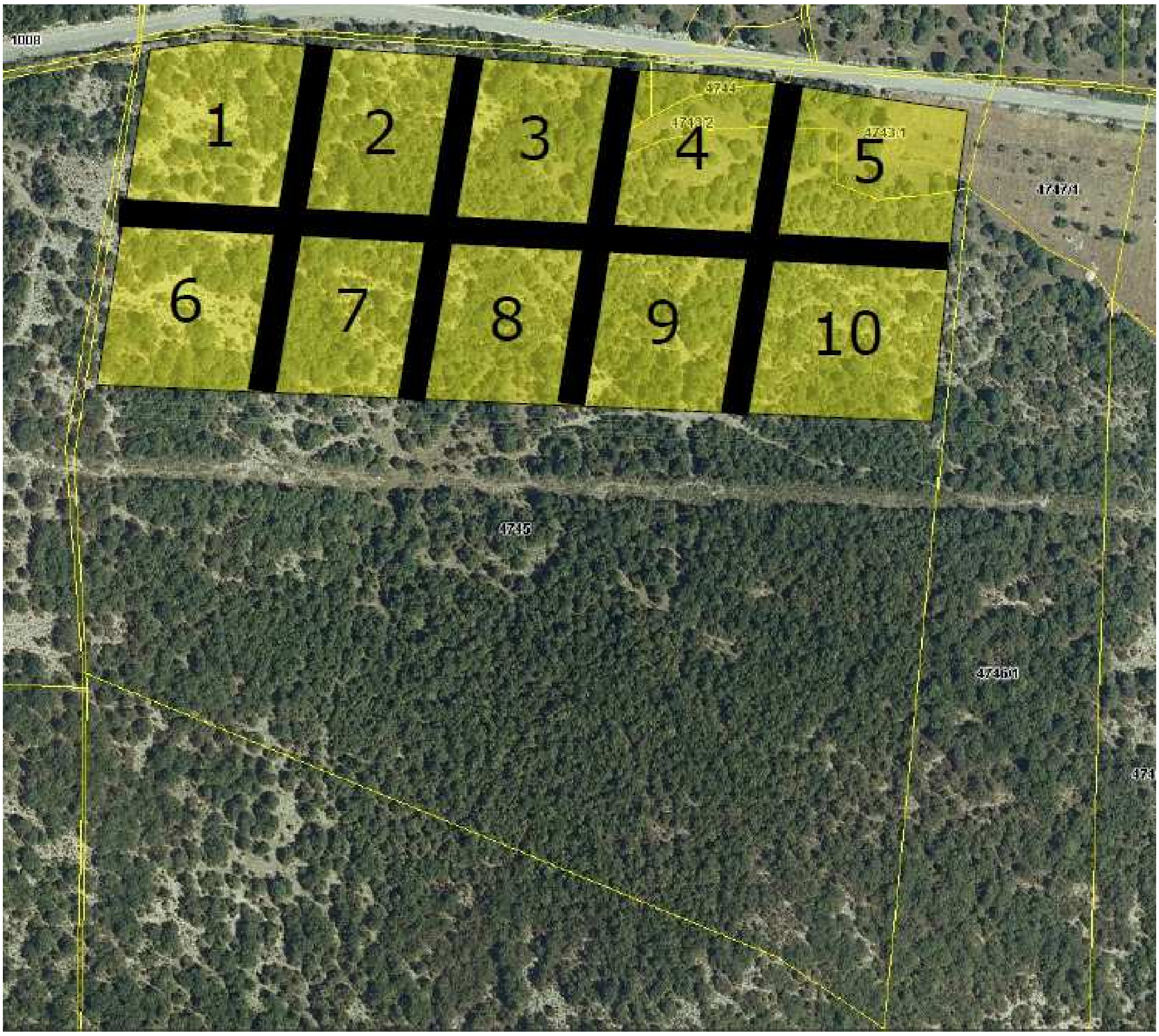


Figure 3: Preliminary layout of the business area

3. Sizing of the PV project

Based on the available area, both ground-mount and rooftop, and taking into account the information shared about the Project, the PV plant was designed based on standard industry practice and its own knowledge. The overall layout was designed in order to optimise the land use and electricity generation output. The final layout and peak power installed can be modified and adapted in later stages based on contractual offers for engineering, procurement and construction of the Project.

Its preliminary design was based on 19,512 standard polycrystalline PV modules with a peak power of 350Wp. String inverters from market leader manufacturer have been selected to allow for more flexibility in the design and easier maintenance.

The main components to be used for the design have been selected as follows:

- PV modules: Solvis, polycrystalline 72-cells, SV72-350 (350Wp), as suggested by the Project developer (European manufacturer)
- String inverters: SMA Sunny Tripower, STP 60-10 (60kVA)
- Mounting structures: Standard fix tilt aluminium and stainless-steel structures with 10° tilt for rooftops and 30° for ground-mounted.

Parameter	**Ground-Mounted**	**Rooftops**	**Unit**
System size	4561.2	2 268.0	kWp
N°. of modules	13,032	6,480	pcs
Type of modules	Solvis SV72-350		
N°. of inverters	66	40	pcs
Type of inverters	SMA STP 60-10		
N°. of mod/string	18	18	pcs
N°. of string/inv	11	9	pcs
DC/AC ratio	1.15	0.95	
Modules tilt	30	10	°
Modules azimuth	180	95/275	° (0-360)
Topography	Flat terrain	Flat roof	

Table 2 : Conceptual design for Korčula PV project

4. Mechanical integration and layout

Mechanical layout of the installation was based on the standard mounting structures features and the author's experience in similar projects considering, the conceptual design of components and the surface available from the project land.

The ground-mounted structures consist of a standard table design of 2x18 modules in portrait position to accommodate 2 strings in height, with horizontal cabling, on each table. This standard design was used as a base to fill the available space. The pitch considered is 9m between each row of tables to optimise both the shading losses and the land use. The structures will have to be designed in such a way that the lowest point of the structure is 2 meters since there are plans to later integrate another business operation that requires smooth movement under the panel.

Figure 4 and Figure 5 show the standard table configuration.

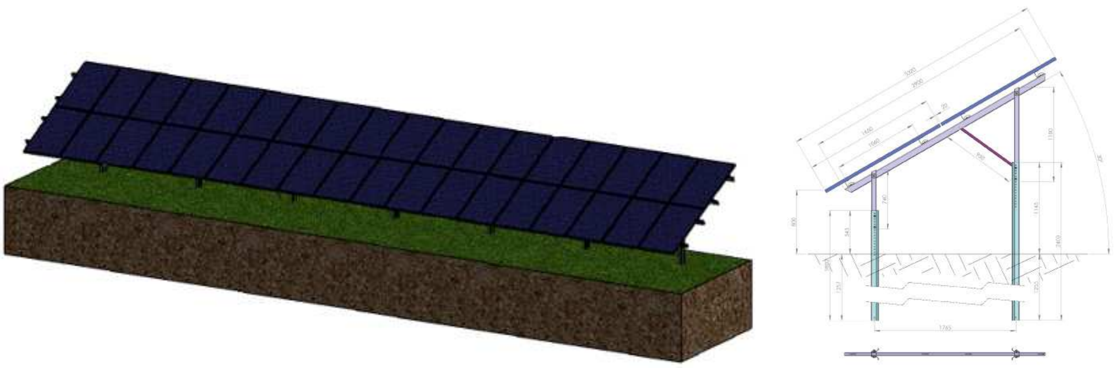


Figure 4: Standard ground-mounted table for Korčula PV project

For the rooftop projects, the ballast mounting structure will be East/West oriented with a 10° tilt angle. Each row will be separated by a 50cm walkway to ease maintenance activities. The loading capacity of the mounting system components and the necessary ballast will have to be determined based on the building rooftop characteristics. The dimensioning is performed using the current load assumptions specified in the Eurocodes under consideration of the framework conditions and specifications resulting from wind tunnel tests.

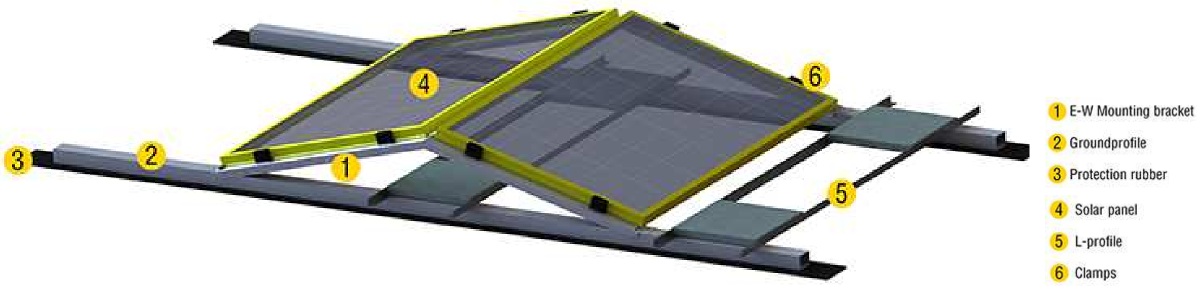


Figure 5 : Example of rooftop ballast mounting structure

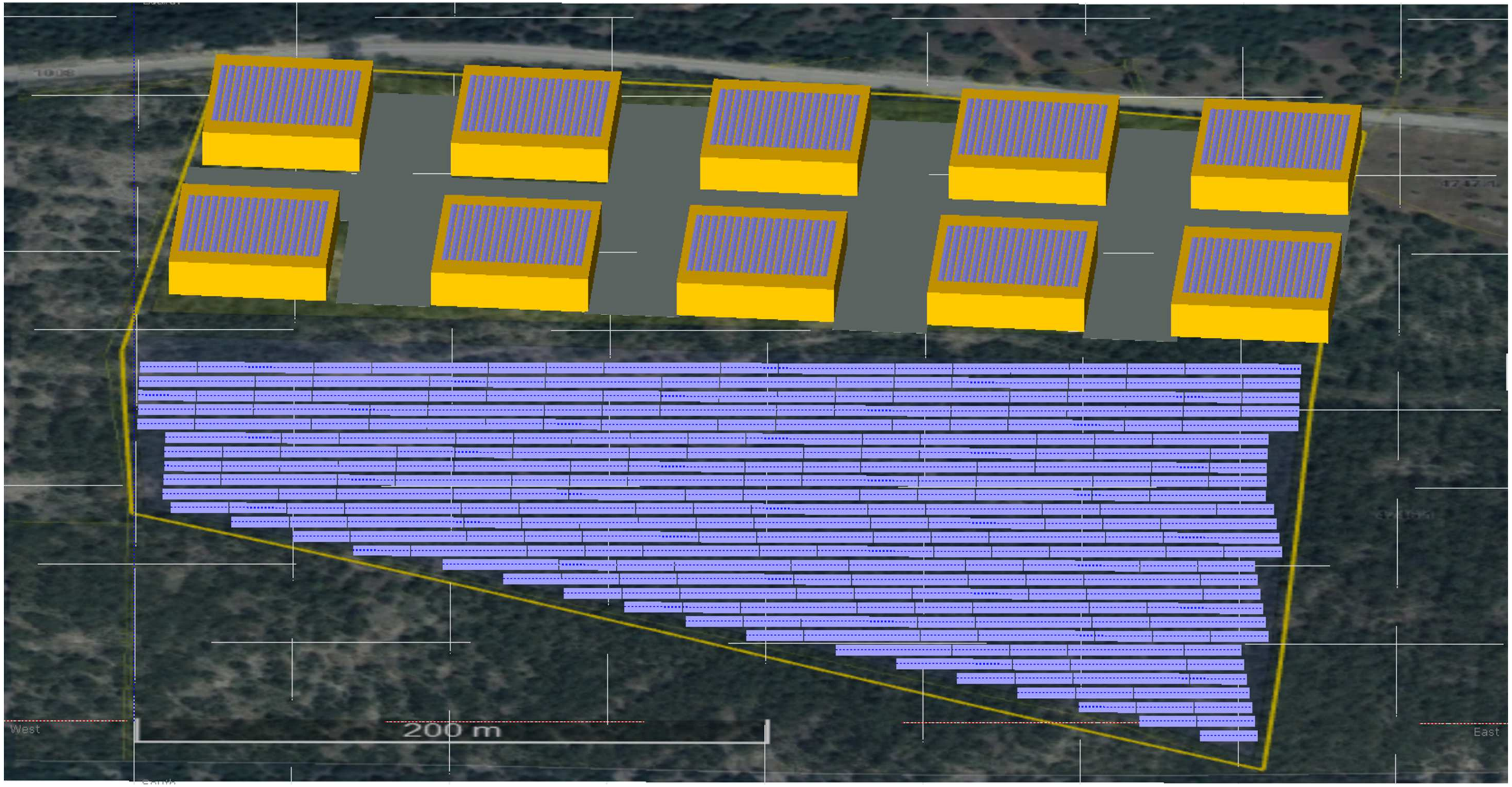


Figure 6 : Overall site layout for Korčula PV plant business area

5. Long-term yield assessment

Meteorological data

Global irradiance and temperature

Different meteorological data sources were considered for the yield study. For a description of the data providers, see Annex C. Table 3 gives a comparison of horizontal irradiation results.

Source	Nb of years	Average irradiation
Meteonorm	20	1,492
Soda-HelioClim	14	1,649
3E Solar Data	14	1,545
PVGIS-CMSAF	10	1,642
SolarGIS	22	1,560

Table 3: Global irradiation on the horizontal plane (kWh/m²/yr)

Each horizontal irradiation source is used to calculate the yield before combining the results by using a statistical weighting function. This function takes into account the specific characteristics of the data, such as the number of years available and the uncertainty of resource quantification according to the author's own experience. Table 4 shows the weighted horizontal irradiation as well as the in-plane irradiation. These weighted values are given as an indication only since they are not directly used in the calculations. The transposition factor is obtained from the irradiation data of 3E Solar Data and the Perez transposition model. The ambient temperature used in the simulations is also presented. It comes from 3E Solar Data's database.

Parameter	Value	Unit
Weighted horizontal irradiation	1,062	kWh/m²/yr
Transposition factor	-0.8%	
In-plane irradiation	1,054	kWh/m²/yr
Ambient temperature	9.8	°C

Table 4: Weighted irradiation, transposition factor and temperature

Monthly breakdown

The monthly breakdown of the meteorological data is given in Table 5.

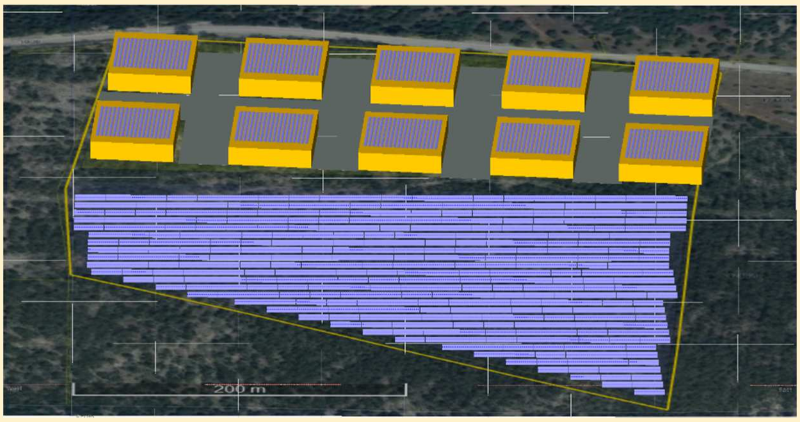
Month	**Horizontal irradiation (kWh/m²)**	**In-plane irradiation (kWh/m²)**	**Ambient temperature (°C)**
January	49	68	9.5
February	64	84	8.1
March	110	127	11.5
April	156	167	13.2
May	199	201	19.6
June	222	219	23.0
July	231	231	25.2
August	203	216	24.8
September	140	161	19.8
October	95	119	16.6
November	52	70	13.3
December	45	67	10.6
Year	**1 565**	**1 732**	**16.3**

Table 5: Monthly breakdown of the meteo data

Yield Calculations

System performance at project start-up

The system performance was calculated by using dynamic models (PVSYST v6.85) as well as its own assessment tool (LTYA V2.7). Table 6 gives a summary of the system performance loss assumptions.

Parameter	**Assumption**
Horizon shading	Far shading was taken into consideration according to the horizon profile from SolarGIS data.
Dirt and soiling	Soiling losses were estimated at -1.5% (author's assumption). Losses due to snow if any are not included into the calculations.
Near shading : Irradiance loss	Mutual shading losses based on project design assumptions were considered to optimise the land use and electricity generation output. Sheds spacing of 9m for the ground-mount part and 2.5m for the rooftop layout as presented below: 

Reflection (IAM)	Usual glass parametrisation was considered (Ashrae b0=0.05).
Irradiance dependencies	the PV module file (.PAN) was created based on the datasheet provided.
Near shading: electrical loss according to strings	Simulations consider the PV modules are connected horizontally with respect to the support structures. (2 strings in height).
Power tolerance of modules	Flash test results were not available at this stage; however, the author assumed a quality gain based on the power tolerance stated in the product datasheet (author's assumption).
Temperature dependencies	Simulations consider the rear surface of the PV modules are open (Uc=29 W/m².K).
Mismatching	Module mismatch losses were estimated at 0.5% for unsorted PV modules (author's assumption).
DC cabling	DC cable losses calculations were not provided. Corresponding losses were set to 1.0% at STC (author's assumption).
Inverter	The inverter file available in PVSyst database was used (OND-file).
AC cabling	AC cable calculations were not provided. Corresponding losses were set to 1.0% at STC (author's assumption).
Transformer	Standard losses for step-up transformer 400V-35kV with iron loss of 0.1% and copper 0.9% were considered.
Availability	A commercial availability of 99%. Grid availability is assumed to be 99.5%.
Auxiliaries	Loss for auxiliaries were estimated at 0.3% (3's assumption).
Additional	Overhead transmission lines over the site have been considered in the 3D scene for shading.

Table 6: System performance loss assumptions

A simulation using the provided system parameters was performed with the above assumptions. Figure 7 shows an overview of the overall system losses resulting in an initial PR value of **83.4 %.** This PR value represents the initial performance of the PV system and does not include any degradation rate. In order to predict the evolution of the yield over the lifetime, the annual decrease of the performance ratio is analysed in the following section. Detailed performance losses can be found in the above table.

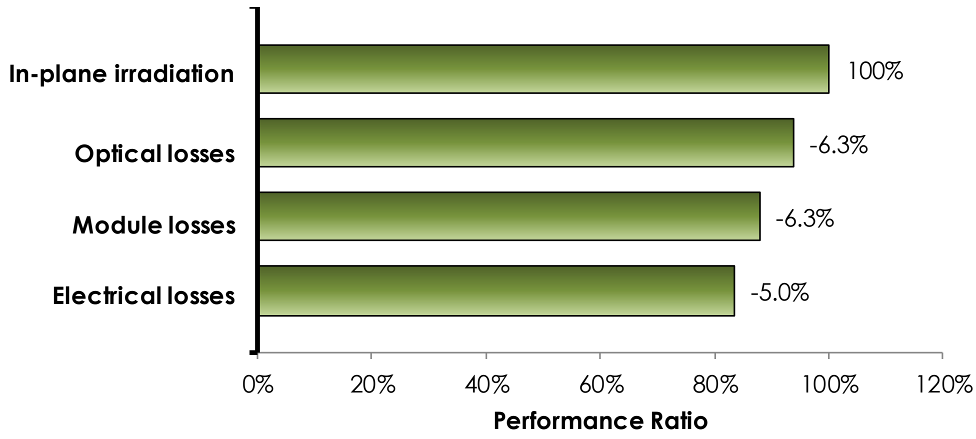


Figure 7 : General system losses and initial performance ratio (year zero)

System performance over project lifetime

A light induced degradation (LID) and annual degradation rate were considered to estimate the system performance over the project lifetime. They both are described in Table 7.

Parameter	**Assumption**
Light induced degradation (initial)	LID is estimated at 0.2% for polycrystalline silicon modules (author's assumption).
Annual degradation factor (ageing)	Annual degradation is estimated at 0.5%/year for crystalline silicon modules (author's assumption).

Table 7: System performance degradations

Figure 8 provides an overview of the evolution of the PR over the life of the project. As mentioned in previous section, the initial PR at project start up (year zero) does not take into account any degradation of the modules. Thereafter, the average PR during the first year of operation includes the initial loss known as LID (depending on module technology) as well as half of the annual degradation factor. This annual degradation remains constant during the life of the project. For more information on the degradations applied, refer to Annex C.

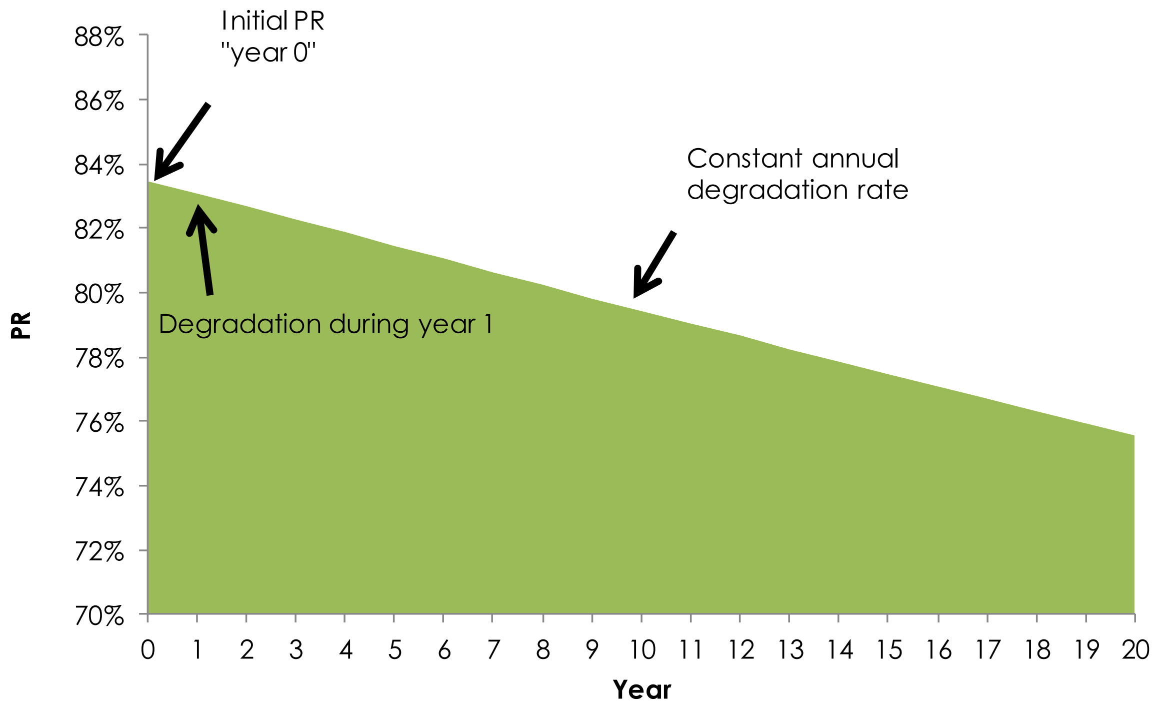


Figure 8: PR evolution during the life of the project

Mean expected yield (P50)

Table 8 shows the average expected yield (P50) of the system. As mentioned, results are obtained by weighting the results obtained from the different meteorological sources.

Parameter	**Value**	**Unit**
System peak power	6,829.20	kWp
*Initial performance ratio (PR) - year 0 **	83.4%	
First year degradation factor	-0.4%	
Yearly degradation factor	-0.5%	
*Specific yield (P50) - year 1 ***	1,439	kWh/kWp/yr
*System yield (P50) - year 1 ***	9,828	MWh/yr
System yield (P50) - 20 years	187,494	MWh

Table 8: Mean expected yield (P50)

* PR without any degradation rates (i.e. year zero), including availability.

** Accounting for average degradation during year 1.

Uncertainties affecting yield estimates

The expected yield is affected by several uncertainties of different types. The uncertainty due to the climate variability is stochastic and its effect is levelled out when calculating long-term averages. Most other uncertainties, e.g. those related to the modelling, the site or the system, are systematic and its effect is not levelled out when calculating long-term averages. The uncertainties affecting the yield estimates are summarized in Table 9. All uncertainty values are standard deviations and apply to well-functioning systems. Negative outliers in performance due to bad installation, low-quality components or extreme local conditions (e.g. heavy soiling or unidentified shading) are not taken into account in these uncertainties. The uncertainty values have been determined based on an extensive literature study and own calculations.

Uncertainty	**Variable**	**Value**
Due to the yearly variation	Climate variability	2.8%
Affecting the resource estimation	Resource quantification	3.5%
	In-plane conversion	2.0%
Affecting the system performance	Optical	1.3%
	Module	1.5%
	Electrical	1.2%
	Degradation factors	0.3%

Table 9: Uncertainties considered for the calculation of the probabilities

Expected yield with 90% probability of exceedance (P90)

Table 10 shows the expected yield that is exceeded with 90% probability of exceedance for different observation periods.

Considered period	**Parameter**	**Value**	**Unit**
1 year	Specific yield (P90) - year 1	1,333	kWh/kWp/yr
	System yield (P90) - year 1	9,104	MWh/yr
	Global uncertainty	5.7%	
5 years	Specific yield (P90) - year 1	1,345	kWh/kWp/yr
	System yield (P90) - year 1	9,188	MWh/yr
	Global uncertainty	5.2%	
10 years	Specific yield (P90) - year 1	1,347	kWh/kWp/yr
	System yield (P90) - year 1	9,199	MWh/yr
	Global uncertainty	5.1%	
20 years	Specific yield (P90) - year 1	1,348	kWh/kWp/yr

	System yield (P90) - year 1	9,205	MWh/yr
	Global uncertainty	5.0%	

Table 10: Expected yield with 90% probability of exceedance (P90)

Figure 9 shows the yearly expected specific yield (P50) together with its 10% (P10) and 90% (P90) exceedance probability for the entire lifetime of the project. Additionally, the typical climate variability is indicated in the same figure.

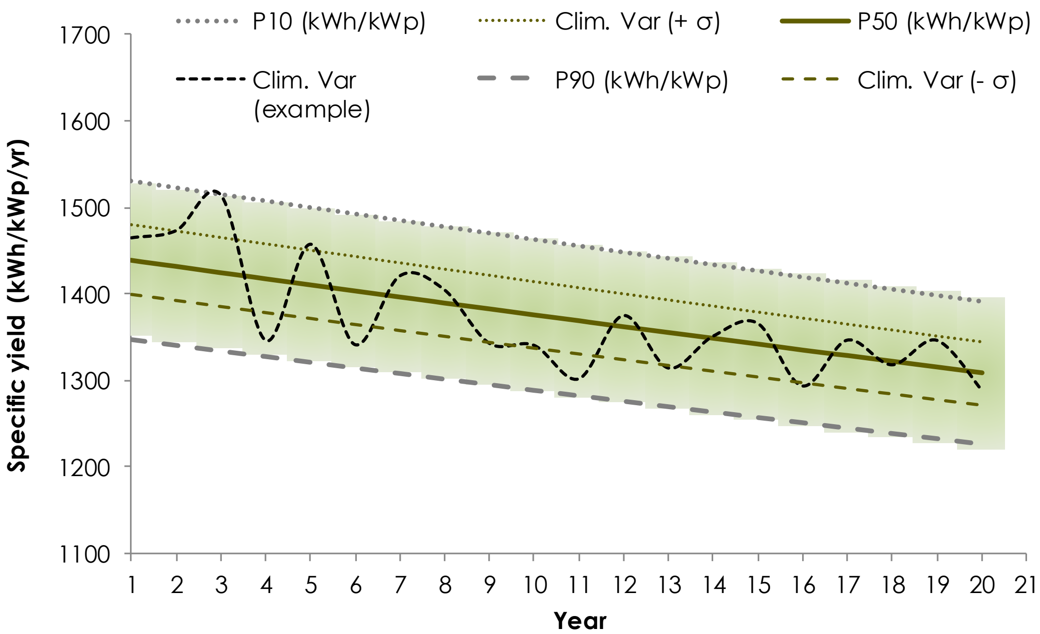


Figure 9: Yearly expected mean specific yield (P50) and its exceedance probabilities (P10 and P90)

Yearly and monthly breakdown

Table 11 shows the yearly performance ratio after applying the degradation factors, as well as the corresponding P50 and P90 results. The P90 is given for an observation period equal to the project lifetime.

Year	Performance ratio (PR)	System yield (P50) (MWh)	System yield (P90) - 20 yr (MWh)
1	83.1%	9,828	9,205
2	82.7%	9,779	9,159
3	82.3%	9,730	9,113
4	81.9%	9,681	9,067
5	81.5%	9,633	9,022
6	81.1%	9,585	8,977
7	80.6%	9,537	8,932
8	80.2%	9,489	8,887

9	79.8%	9,442	8,843
10	79.4%	9,394	8,799
11	79.0%	9,347	8,755
12	78.6%	9,301	8,711
13	78.3%	9,254	8,667
14	77.9%	9,208	8,624
15	77.5%	9,162	8,581
16	77.1%	9,116	8,538
17	76.7%	9,070	8,495
18	76.3%	9,025	8,453
19	75.9%	8,980	8,411
20	75.6%	8,935	8,369

Table 11: Yearly performance ratio and expected yield (P50 and P90)

Table 12 shows the monthly values for the performance ratio and the average yield (P50) at year 1.

Month	**Performance ratio (PR) - year 1**	**System yield (P50) - year 1 (MWh)**
January	85.8%	399
February	87.1%	499
March	85.5%	743
April	84.8%	968
May	82.7%	1,137
June	81.5%	1,217
July	80.8%	1,277
August	81.0%	1,197
September	82.9%	911
October	84.1%	684
November	84.8%	405
December	84.8%	391
Year	**83.1%**	**9,828**

Table 12: Monthly performance ratio and system yield at year 1 (P50)

Annex A: Additional results

Detailed performance losses

Table 13 shows the PR breakdown at year zero.

Losses breakdown	**Loss / Gain**
Horizon shading	**-0.6%**
In-plane conversion	**10.6%**
Optical	**-5.6%**
- Dirt and soiling	-1.5%
- Near shading: irr. loss	-1.5%
- Snow	0.0%
- Reflection	-2.7%
Module	**-6.3%**
- Irradiance dependencies	-1.5%
- Near shading: acc. to strings	0.0%
- Power tolerance of modules	0.4%
- Temperature dependencies	-4.7%
- Spectral dependencies	0.0%
- Mismatching	-0.5%
Electrical	**-5.0%**
- DC cabling	-0.7%
- Inverter	-2.1%
- AC cabling	-0.6%
- Transformer	0.0%
- Availability	-1.5%
- Auxiliaries	-0.3%
- Additional (e.g. line loss)	0.0%
Total	**-16.6%**
Initial performance ratio (year 0)	**83.4%**

Table 13: PR breakdown at year zero

Expected yield with various probabilities at 100% availability

Table 14 shows the expected yield with various probabilities, at 100% availability.

	Parameter	Value	Unit
1 year	System | specific yield (P50) - year 1	9,977 | 1,461	MWh/yr | kWh/kWp/yr
	System | specific yield (P75) - year 1	9,593 | 1,405	MWh/yr | kWh/kWp/yr
	System | specific yield (P90) - year 1	9,243 | 1,353	MWh/yr | kWh/kWp/yr
	System | specific yield (P99) - year 1	8,611 | 1,261	MWh/yr | kWh/kWp/yr
5 years	System | specific yield (P50) - year 1	9,977 | 1,461	MWh/yr | kWh/kWp/yr
	System | specific yield (P75) - year 1	9,636 | 1,411	MWh/yr | kWh/kWp/yr
	System | specific yield (P90) - year 1	9,327 | 1,366	MWh/yr | kWh/kWp/yr
	System | specific yield (P99) - year 1	8,790 | 1,287	MWh/yr | kWh/kWp/yr
10 years	System | specific yield (P50) - year 1	9,977 | 1,461	MWh/yr | kWh/kWp/yr
	System | specific yield (P75) - year 1	9,641 | 1,412	MWh/yr | kWh/kWp/yr
	System | specific yield (P90) - year 1	9,339 | 1,367	MWh/yr | kWh/kWp/yr
	System | specific yield (P99) - year 1	8,814 | 1,291	MWh/yr | kWh/kWp/yr
20 years	System | specific yield (P50) - year 1	9,977 | 1,461	MWh/yr | kWh/kWp/yr
	System | specific yield (P75) - year 1	9,644 | 1,412	MWh/yr | kWh/kWp/yr
	System | specific yield (P90) - year 1	9,344 | 1,368	MWh/yr | kWh/kWp/yr
	System | specific yield (P99) - year 1	8,827 | 1,292	MWh/yr | kWh/kWp/yr

Table 14: Expected yield with various probabilities (100% availability)

Annex B : Products datasheet

PV modules

MADE IN EUROPE

SOLVIS
PHOTOVOLTAIC MODULES

MODEL SV72

- Premium quality
- Power output range 335-350 Wp
- 100% EL testing
- Mechanical load up to 5400 Pa
- Low weight
- Module efficiency up to 18,04 %
- Positive power tolerance -0/+4,9 W
- Made in Europe
- IEC EN 61215
  IEC EN 61730-1, -2
- IEC EN 62716 Ed.1
- IEC EN 61701
- IEC TS 62804-1 (PID resistance)

Warranty:

- 10 years manufacturing defects
- 12 years limited, 90% output power
- 25 years limited, 80% output power

Electrical parameters at Standard Test Conditions (STC)					
MODEL		SV72-335	SV72-340	SV72-345	SV72-350
Peak power P_{MPP}	[W]	335	340	345	350
Peak power tolerance	[W]	-0/+4,9			
Short circuit current I_{SC}	[A]	9,01	9,05	9,10	9,14
Open circuit voltage V_{OC}	[V]	47,23	47,52	47,81	48,10
Rated current I_{MPP}	[A]	8,56	8,61	8,65	8,70
Rated voltage V_{MPP}	[V]	39,20	39,58	40,00	40,38
Current and voltage tolerance	[%]	±3			
Module efficiency	[%]	17,26	17,52	17,78	18,04

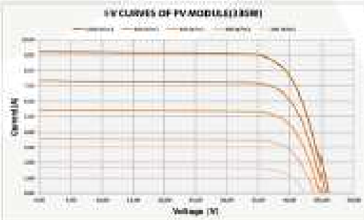
STC: 1000W/m² irradiance, 25 °C cell temperature, AM1, 5 g spectrum according to EN 60904-3
Average relative efficiency reduction of 3,4 % at 200 W/m² according to EN 60904-1

OPERATING CONDITIONS		
Temperature range	[°C]	-40 to +85
Maximum system voltage	[V]	1000
Max. series fuse rating		15A
Limiting reverse current		15A
Maximum surface load capacity		5400 Pa (Snow load)
Resistance against hail		Max. diameter of 25 mm with impact speed 23 m/s

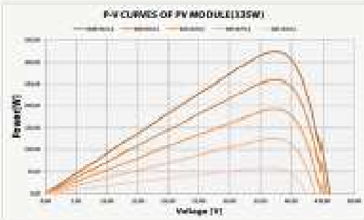
Electrical parameters at Nominal Operating Cell Temperature (NOCT)					
MODEL		SV72-335	SV72-340	SV72-345	SV72-350
Peak power P_{MPP}	[W]	242,2	246,0	249,8	253,6
Peak power tolerance	[W]	-0/+4,9			
Short circuit current I_{SC}	[A]	7,28	7,32	7,36	7,39
Open circuit voltage V_{OC}	[V]	43,0	43,3	43,6	43,8
Rated current I_{MPP}	[A]	6,92	6,97	7,00	7,04
Rated voltage V_{MPP}	[V]	35,0	35,3	35,7	36,0

NOCT: module operating parameters at 800 W/m² irradiance, 20 °C ambient temperature, 1 m/s wind speed

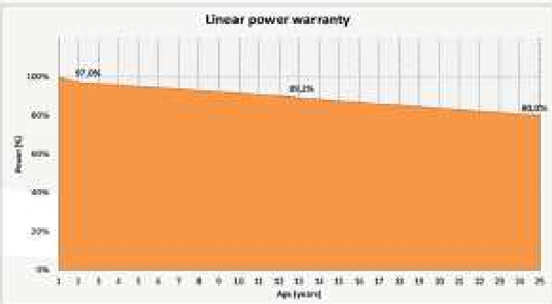
THERMAL CHARACTERISTICS		
Temperature coefficient of P_{MPP}	[%/K]	-0,41
Temperature coefficient of I_{SC}	[%/K]	0,05
Temperature coefficient of V_{OC}	[%/K]	-0,31

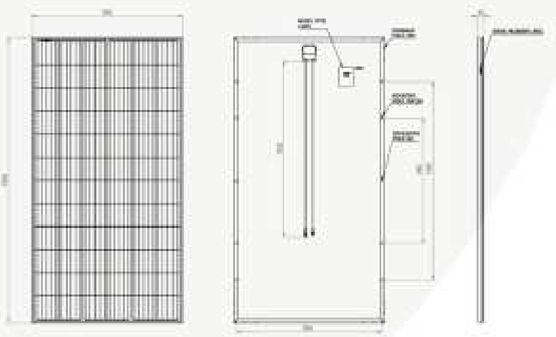


MECHANICAL DATA		
Dimensions (H x W x D)	[mm]	1956 x 992 x 40
Weight	[kg]	22,5
Solar cells		72 cells, polycrystalline Si (PERC), 156 x 156 mm +/- 1mm
Cells encapsulation		Ethylene vinyl acetate (EVA)
Front		Tempered solar glass, 3,2 mm
Back		Composite polyester Film
Frame		Anodized aluminium frame with twin-wall profile and drainage holes
Junction box		IP67 with 3 Bypass diodes
Cable and connectors		Solar cable 4 mm², length 1200 mm



NOTE: For extended models, SV72 YYY, voltages and currents can vary where YYY is optional based on the chosen YYY variant (YYY = letter(s)). F for black frame, B for silver frame and black backsheet, BC for full black modules





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v.20190125

SUNNY TRIPOWER 60

Efficient
- Maximum efficiency of 98.8%
- Superior power density: 60 kW with only 75 kg of weight

Reliable
- Superior PV system availability with 60-kW units
- SMA Inverter Manager as central control unit

Flexible
- DC input voltage of up to 1000 V
- Flexible DC solutions with customer-specific PV array combiner boxes

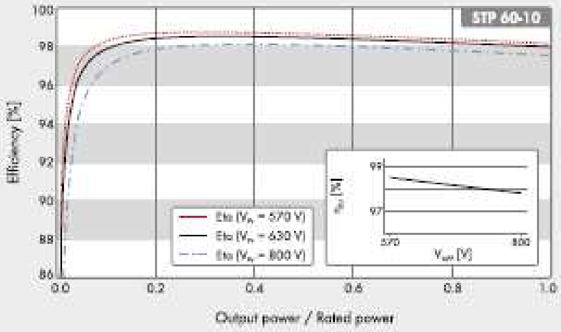
Innovative
- Cutting-edge system design

SUNNY TRIPOWER 60

The Best of Two Worlds

The new Sunny Tripower 60 is part of an innovative global system solution for commercial and industrial PV systems. This solution combines the advantages of a decentralized system layout with the benefits of centralized inverter designs in order to get the best of two worlds. High efficiency, flexible system design, easy installation, simple commissioning and low maintenance requirements contribute decisively to reducing the operating costs for the entire system.

Efficiency Curve



● Standard features ○ Optional – Not available
Data at nominal conditions
Last revision: May 2018

Technical Data	Sunny Tripower 60
Input (DC)	
Max. generator power	90000 Wp
Rated power (DC)	61240 W
Max. input voltage	1000 V
MPP voltage range (at 400 Vac / 480 Vac)	570 V to 800 V / 685 V to 800 V
Min. input voltage (at 400 Vac / 480 Vac)	565 V / 680 V
Start input voltage (at 400 Vac / 480 Vac)	600 V / 720 V
Max. input current / max. short-circuit current	110 A / 150 A
Number of independent MPP inputs/strings per MPP input	1/1 (split up in external combiner box)
Rated DC input voltage (at 400 Vac / 480 Vac)	630 V / 710 V
Output (AC)	
Rated power at nominal voltage	60000 W
Max. apparent AC power	60000 VA
Max. reactive power	60000 Var
Nominal AC voltage	3 / PE, 400 V to 480 V, ±10 %
AC voltage range	360 V to 530 V
AC power frequency/range	50 Hz / 44 Hz to 55 Hz 60 Hz / 54 Hz to 65 Hz
Rated power frequency/rated grid voltage	50 Hz / 400 V
Max. output current (at 400 Vac / 480 Vac) / rated output current	87 A / 72 A / 87 A
Power factor at rated power / displacement power factor adjustable	1 / 0 overexcited to 0 underexcited
THD	≤ 1 %
Feed-in phases/connection phases	3 / 3
Efficiency	
Max. efficiency / Euro-eta / CEC at 400 Vac / CEC at 480 Vac	98.8 % / 98.3 % / 98.0 % / 98.5 %
Protective devices	
Input-side disconnection point	●
Ground fault monitoring/grid monitoring	● / ●
Integrated DC surge arrester / AC surge arrester	Type II / type II + III (combined)
AC short-circuit current capability / galvanically isolated	● / –
All-pole sensitive residual-current monitoring unit	●
Protection class (as per IEC 62109-1) / overvoltage category (as per IEC 62109-1)	I / AC: III; DC: II
General data	
Dimensions (W/H/D)	570 / 740 / 306 mm (22.4 / 29.1 / 12.0 inches)
Weight	75 kg (165.3 lb)
Operating temperature range	-25°C to +60°C (-13°F to +140°F)
Noise emission, typical	58 dB(A)
Self-consumption (at night)	< 3 W
Topology / cooling concept	Transformerless / active
Degree of protection (according to IEC 60529 / UL 50E)	IP65 / NEMA 3R
Climatic category (as per IEC 60721-3-4)	4K4H/4Z4/4B2/4S3/4M2/4C2
Max. permissible value for relative humidity (non-condensing)	95 %
Features / function / accessories	
DC connection / AC connection	Screw terminal / screw terminal
Display	Graphical
Data interface	SunSpec Modbus TCP (via external SMA Inverter Manager)
Off-grid capable / PV-diesel capable	– / ●
Warranty: 5 / 10 / 15 / 20 years	● / ○ / ○ / ○
Certificates and approvals (more available upon request) * Does not apply to all national appendices of EN 50438 ** Restricted (Note Manufacturer's Declaration)	ANRE 30, AS 4777, BDEW 2008, C10/11:2012**, CEI 0-16, DEWA 2015, EN 50438*, G59/3, IEC 60068-2-x, IEC 61727, IEC 62109-1/2, IEC 62116, LEY N° 20751, NBR16149, NEN EN 50438, NRS 097-2-1, PEA 2015, R.D.661/2007, Res. n°7:2013, SI4777, TOR D4**, UTE C15-712-1, VDE 0126-1-1, VDE-AR-N 4105**, VFR 2014
Type designation	STP 60-10

Annex C: Additional Information

Meteorological data sources

Meteorological data from different sources is used to calculate the long-term productivity of projects. Most of the time, these data are derived from satellite observations as described in the supplier presentations below. When the Client is able to provide data measured on site or in the vicinity, the author prefers the MCP type correlation method because it allows the local characteristics of the climate to be taken into account.

Note: Research has revealed that the irradiation in the Benelux, France and Germany showed a significant brightening trend between 1990 and 2005. Though it could be expected that irradiation remains at this higher level in future, yield estimates are inevitably based partly on historical irradiation data from before 2000. As a result, this study may slightly underestimate the actual irradiation.

Meteonorm ©

Meteonorm is a meteorological database containing climatological data for solar engineering applications at every location on the globe. The results are stochastically generated typical years from interpolated long-term monthly means. They represent an average year of the selected climatological time period based on the user's settings. As such the results do not represent a real historic year but a hypothetical year which statistically represents a typical year at the selected location.

Meteonorm conceals not only numerous databases from all parts of the world but also a large number of computational models developed in international research programs. Meteonorm is primarily a method for the calculation of solar radiation on arbitrarily orientated surfaces at any desired location.

The Meteonorm radiation data base is based on 20-year measurement periods (1991-2010), the other meteorological parameters mainly on 1961–1990 and 2000–2009 means.

Soda-Helioclim ©

The HelioClim surface solar radiation (SSR) databases, HelioClim-1 and HelioClim-3, are based on SSR estimation from Meteosat Second Generation images. This satellite-based method used to estimate the SSR is named HelioSat-2 and was proposed and developed by the Center for Observations, Impacts and Energy of MINES ParisTech / ARMINES.

Satellite-based methods for surface solar radiation (SSR) estimation such as HelioSat method represent an operational alternative to interpolation approaches based on meteorological ground stations, as it enables a better spatial and temporal coverage.

Since 2004, the HelioSat-2 algorithm applied to Meteosat Second Generation's Spinning Enhanced Visible and Infrared Imager (SEVIRI) images has been used to update, on a daily basis, the solar resource database HelioClim-3. This database covers Europe, Africa, the Mediterranean Basin, the Atlantic Ocean and part of the Indian Ocean with a spatial resolution of approximately 5 km and a temporal resolution up to 15 minutes. The method calculates the proportion of cloud contained in each MSG pixel compared to the same pixel value in clear sky conditions, to deduce the irradiation value at ground level.

3E Solar Data ©

3E Solar Data makes use of the most advanced cloud physical properties (CPP) models to quantify the solar resource. The CPP algorithms derive cloud, precipitation, and radiation information from satellite instruments on board of the Meteosat Second Generation (MSG) satellites from 2004 onwards. These physics-based, empirically adjusted algorithms enable the continuous monitoring of the physical properties of clouds and the quantification of their influence on surface solar irradiance.

The model exploits state-of-the-art input fields of different variables influencing the atmospheric constituents and surface properties. The most important inputs to the model are a cloud mask products and cloud properties derived from Meteosat/Spinning Enhanced Visible and Infrared Imager (SEVIRI) observations. In addition, Numerical Weather Prediction (NWP) data is used including ECMWF and CAMS data as inputs to the models.

The use of underlying cloud models considering the physical properties of the clouds has improved significantly the accuracy of the satellite-based irradiation data. Moreover, models compensating for satellite sun path and cloud geometry provide the highest accuracy, even at high temporal resolutions (hourly or sub-hourly data).

Over 300 high quality meteorological stations spread across Europe and Africa are used within this Solar Data validation framework, participating in the continuous improvement of the models.

Solargis ©

Solargis provides state-of-art solar irradiance models as they make use of the most modern input data (satellite and atmospheric), which are systematically quality-controlled and validated. Models and input data are integrated and regionally adapted to perform reliably at a wide range of geographical conditions.

Satellite-based irradiance models are able to estimate the solar radiation levels (historic, recent and future levels) without the need of installing ground sensors at the location of interest. For historical and recent data, Solargis uses a semi-empirical solar radiation model. Data from satellites are used for identification of cloud properties using the most advance algorithms. Most of the physical processes of atmospheric attenuation of solar radiation are considered and some physical parameters on the input are also used. Therefore, this approach is capable to reproduce real situations.

The most advanced input data are used in the Solargis algorithms. As a result, satellite-data secure very high temporal coverage (more than 99% in most of regions). As of today, Solargis model has been validated at more than 200 sites worldwide. Historical data cover different periods depending on the area: 1994-2015 for Europe and Africa, 1999-2015 for America, 1999-2005 for the Middle East, and 2007-2015 for Asia and Oceania.

Pvgis ©

PVGIS provides data on solar radiation and photovoltaic (PV) system energy production at any place in most parts of the world. Solar radiation data used by PVGIS usually have been calculated from satellite images. This is the case for the calculations of over Eurasia and Africa (the PVGIS-CMSAF and PVGIS-SARAH databases). For the present version of PVGIS, the satellite data used for the solar radiation estimates are from the METEOSAT satellites. Algorithms used for the satellite-based solar radiation data present in PVGIS have been developed within the CM SAF collaboration.

Recently PVGIS has collaborated with the National Renewable Energy Laboratory to include the NSRDB data into PVGIS (the PVGIS-NSRDB database). This extends the coverage to North and Central America. The data from the NSRDB data set have been calculated using different methods.

Several scientific papers have presented validation results for the satellite solar radiation data used in PVGIS by comparing with ground station measurements. The historical period covered by PVGIS depends on the region of the world considered: 2007-2016 for Europe and Africa, 2005-2015 for America and 2005-2016 for Asia.

MCP method

In case ground measurements of good quality are available for a minimum period (e.g. one year), the author generally combine them with long-term satellite estimations by use of the Measure-Correlate-Predict (MCP) methodology.

The purpose of this methodology is to combine data having a short period of record but site-specific seasonal and diurnal characteristics with a data set having a long period of record but not necessarily site-specific characteristics. Upon completion of a year of ground measurements, a linear regression or other relationship is established between measured data at the target site, spanning a relatively short period, and the satellite data, spanning a much longer period. The complete record of the satellite data is then used in this relationship to predict the long-term historical climate at the target site. Assuming a strong correlation, the strengths of both data sets are captured and the uncertainty in the long-term estimate can be reduced.

MCP is a widely established and recognized methodology for wind resource assessments and its application is gaining ground for solar resource assessment as well.

Degradation factors

An annual decrease of the system performance is considered to reflect the degradation factor of the PV modules. In international research, annual degradation rates lay between 0.2-0.7% for crystalline silicon modules, with degradation in the first year up to 3%. For thin-film technologies, degradation rates have improved significantly during the last years, although they are still statistically closer to 1%.

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