CLEAN ENERGY FOR EU ISLANDS

Solar farm in local community

Feasibility study and conceptual design Ilha da Culatra

Author: Joao Cruz (3E)

Reviewers: Guillaume Tixier (3E), Marie Angot (3E), Carlos Guerrero (3E)

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CLEAN ENERGY FOR EU ISLANDS

Secretariat • Rue d'Arlon 63, BE-1000 Brussels
Phone +32 2 400 10 67 • E-mail info@euislands.eu • Website euislands.eu

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Directorate B — Internal Energy Market
Unit B2 — Wholesale markets; electricity & gas
Contact: Nicole Versijp
E-mail: Nicole.Versijp@ec.europa.eu
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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 Culatra in Portugal. This technical note covers the preliminary study regarding the business area to be developed on the island. The Project consist of 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, chapter 5 presents the results of the long-term yield assessment, whereas the chapter 6 presents the analysis of the PV production versus the consumption profile of the island.

2. Site specifications

The Project is planning to develop several rooftops photovoltaic plants (the plant) in the island of Culatra, Portugal. The pre-selected site is located in the south of Portugal, approximately 3.4 km south from the Olhão village in the Faro district. The foreseen buildings have several typologies: warehouses for fishermen, a sports / local community centre, a primary school, a kindergarten, a church and some shaded walkways. The PV plant will be used to power the island, the connection type and point of connection are not yet defined at this stage.

A site visit was performed in August 2019 in order to meet the local community and assess the selected buildings for PV installation

The location of the project and pre-defined areas 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.

Culatra PV project	**Value**	**Unit**
Latitude	36.99337	°N
Longitude	-7.839793	°O
Altitude	3	m (a.s.l)

Table 1 : Summary of the project location

According to the performed site visit, shared documentation and satellite images the site does not seem to present any major constraints.

According to Figure 1, the island was divided into 3 sectors:

- Yellow – north sector
- Orange – west sector
- Red – central and south sector

North sector

Building structures in this sector are warehouses to support local fishermen. There is a cluster of small warehouses (Figure 2 – orange rectangle) and a larger warehouse (Figure 2 – yellow rectangle). These structures will be renovated/rebuilt. According to the information (inputs from locals and UALG – University of Algarve), it is assumed, for now, that the roofs of these structures will be flat. Therefore, in order to optimize the available surface and as well to optimize the production curve - to match to a domestic profile, a double orientation (East/West) is chosen for all flat roofs.

Figure 2: Overview of the north sector

West sector

2 different typologies are part of the west sector. A church and some shaded walkways.

For the church, modules follow the inclination and orientation of the roofs, they distributed taking into account the shadow created by the church tower on the roof – only the roof section facing south was used (Figure 3 – yellow rectangle).

As for the shaded walkways, modules will be installed over them, meaning that they will be installed on the horizontal plane (Figure 3 – orange sector).

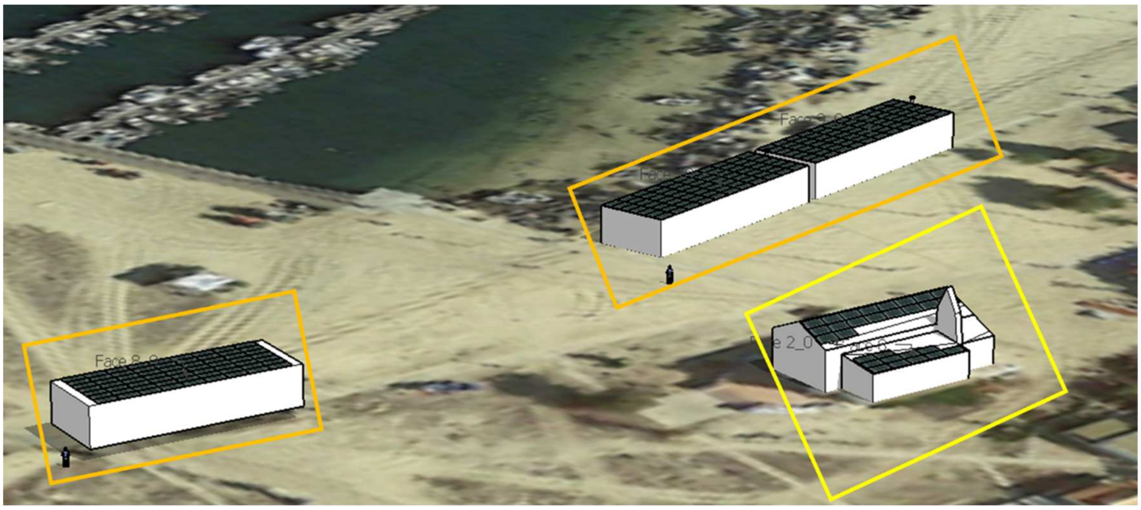

Figure 3: Overview of the west sector

Figure 4: West sector - Shaded walkway

Figure 5: West Sector - Church

Central and south sector

Three (3) different types of typology are part of this sector. A sports / local community centre, a primary school and a kindergarten.

In the sports / community centre, Figure 7, modules will be installed following the inclination and orientation of the roof (Figure 3 – yellow rectangle).

In the primary school, Figure 8 and Figure 9, modules will be installed following the inclination and orientation of the roof and as well on a sunshield that follows the inclination and orientation of the roof[1]

In the kindergarten, Figure 9, modules will follow the modules will be installed following the inclination and orientation of the roof (Figure 3).

[1] Although the 3D module received by the author states that the sunshield is flat, the Author recommends that it follows the inclination of the roof of the primary school in order to increase production and as well to increase the auto cleaning effect of the rain.

Figure 6: Overview of the centre and south sector

Figure 7: Central and south sector - sports/community centre

Figure 8: Central and south sector - primary school (without sunshield)

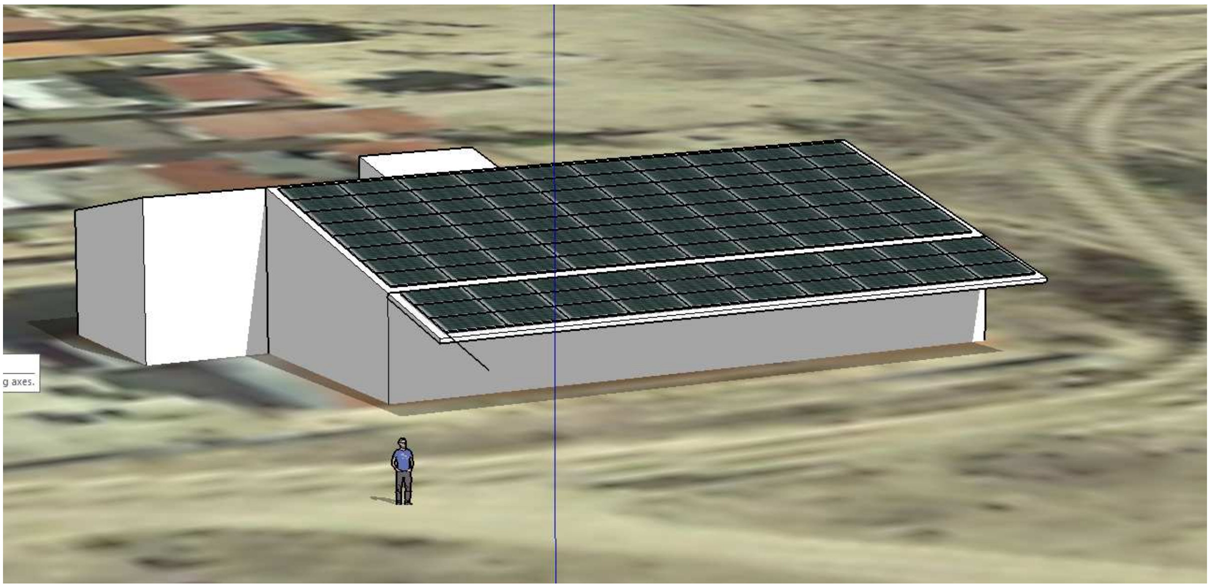

Figure 9:Central and south sector - primary school - 3D model with sunshield

Figure 10: Central and south sector - kindergarten

3. Sizing of the PV project

Based on the available area and taking into account the information shared about the Project and the site visit, the PV plant was designed based on standard industry practice and the Author own knowledge. The overall layout was designed in order to optimise surface 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 859 standard monocrystalline PV modules with a peak power of 360Wp, from a market leader manufacturer. String inverters from market leader manufacturer have been selected to allow for more flexibility in the design and easier maintenance.

Mounting structures: Standard structures with 10° tilt for flat rooftops and standard structures for inclined roofs, where the tilt angle will follow the inclination of the roof.

North sector

Parameter	**Warehouse - cluster**	**Warehouse- big**	**Unit**
System size	104.40	20.16	kWp
N°. of modules	290	56	pcs
Type of modules	Mono crystalline - 360 Wp		
N°. of inverters			pcs
Type of inverters	String inverter 20kW & 3kW	String inverter 13.2 kW	
N°. of mod/string	17 & 3	14	pcs
N°. of string/inv	8 & 3	2	pcs
DC/AC ratio	1.22 & 1.08	0.76	
Modules tilt	10	10	°
Modules azimuth	42/222	71/251	° (0-360)
Typology	Flat roof double oriented	Flat roof double oriented	Unit

Table 2 : Conceptual design for Culatra PV project – north sector

West sector

Parameter	**Church**	**Walkways**	**Unit**
System size	10.44	77.76	kWp
N°. of modules	29	216	pcs
Type of modules	Mono crystalline - 360 Wp		
N°. of inverters	1	3	pcs
Type of inverters	String inverter 13.2 kW	String inverter 20 kW	
N°. of mod/string	18 & 11	18	pcs
N°. of string/inv	1	12	pcs
DC/AC ratio	0.8	1.3	
Modules tilt	23 & 7	0	°
Modules azimuth	182	0	° (0-360)
Typology	Inclined	Flat	Unit

Table 3 : Conceptual design for Culatra PV project – west sector

Central and south sectors

Parameter	***Sports / Community centre***	***Primary School***	***Kindergarten***	***Unit***
System size	38.52	39.60	18.36	kWp
N°. of modules	107	110	51	pcs
Type of modules	Mono crystalline - 360 Wp			
N°. of inverters	1	17	1	pcs
Type of inverters	String inverter 36 kW		String inverter 20 kW	
N°. of mod/string	14 & 17 & 14	20 & 15	17	pcs
N°. of string/inv	2 & 3 & 2	4 & 2	3	pcs
DC/AC ratio	1.07	1.1	0. 92	
Modules tilt	12	12	32	°
Modules azimuth	274 & 183 & 94	183	188	° (0-360)
Typology	Inclined	Inclined	Inclined	Unit

Table 4 : Conceptual design for Culatra PV project – central and south sectors

PV plant - all sectors

Parameter	**PV plant** (all sectors)
System size	309.24
N°. of modules	859
Type of modules	Mono crystalline - 360 Wp
N°. of inverters	15
Type of inverters	String inverters 3 to 36kW
DC/AC ratio	1.12

Table 5: PV plant - all sectors

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 documents.

For flat rooftops, the ballast mounting structure will be East/West oriented with a 10° tilt angle. Each row will be separated by a 30 cm 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.

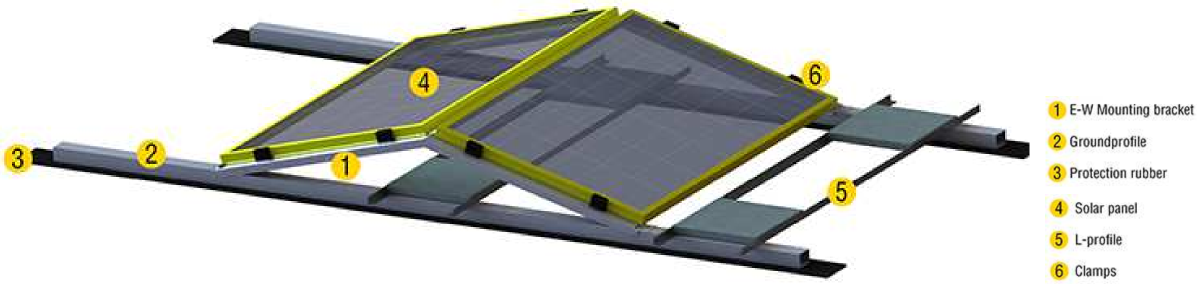

Figure 11 : Example of rooftop ballast mounting structure

For inclined rooftops and the walkways, the structures will be directly fixed to the roofs. It assumed at this stage that all inclined roofs and walkways are suitable to fix this type of structure. The loading capacity of the mounting system components 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.

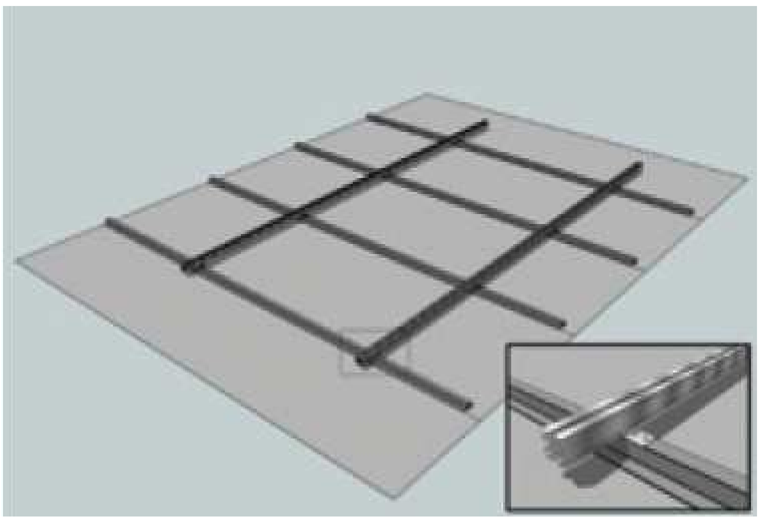

Figure 12 : Example of a mounting structure for inclined roofs

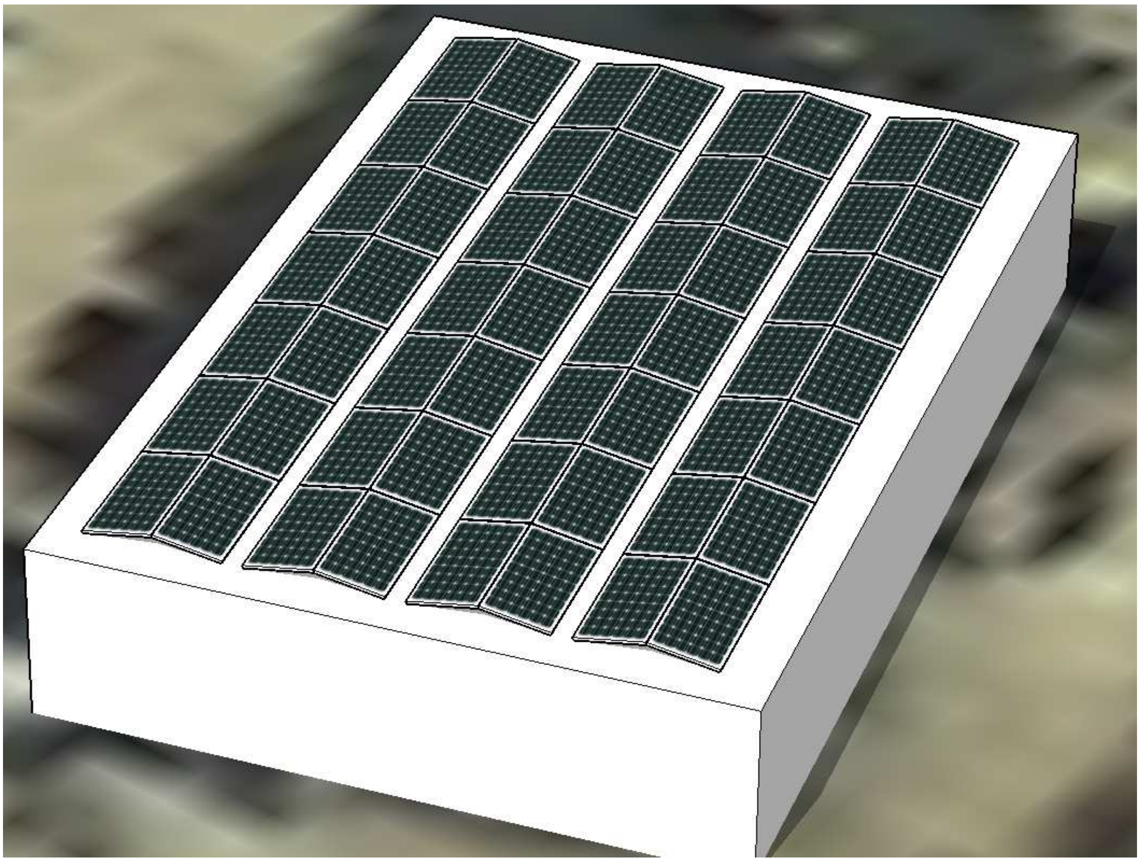

Figure 13 : Detailed view of a double orientation configuration for a flat roof - big warehouse

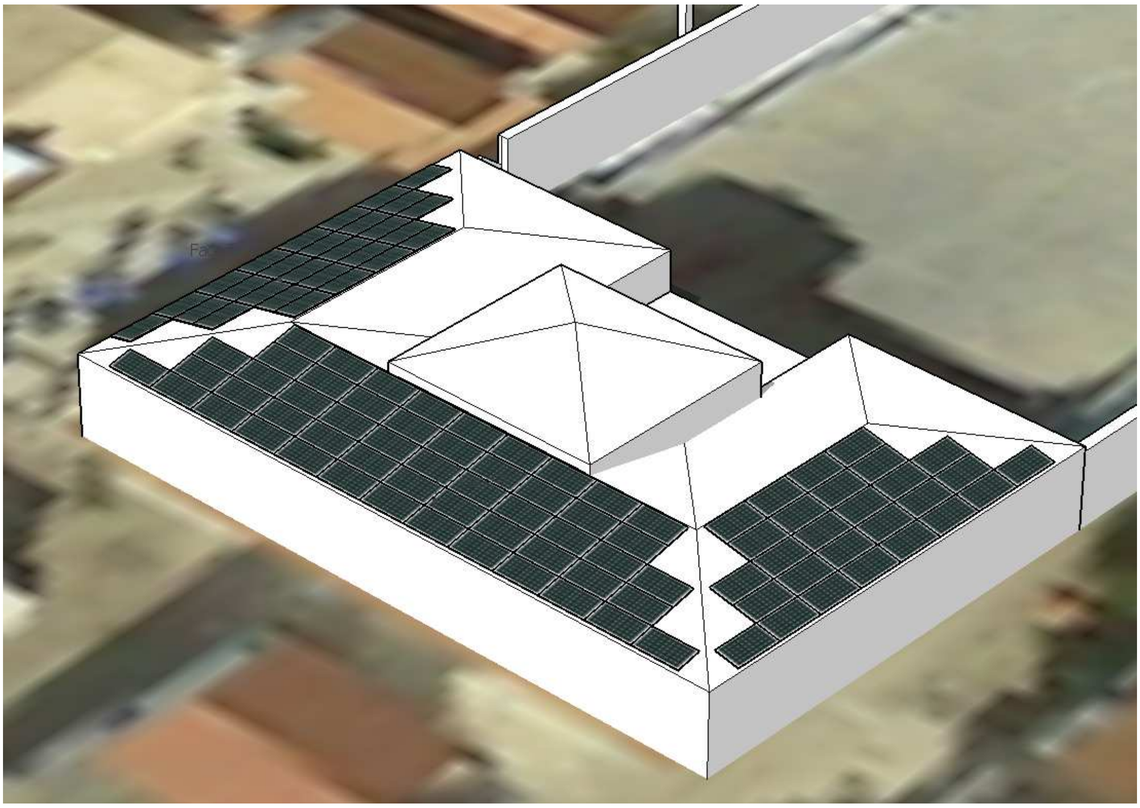

Figure 14: Detailed view of a configuration for inclined roof(s) – sports / community centre

Figure 15: Soiling affecting the roofs - sports/community centre - bird droppings. please refer to Yield Calculations.

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 6 gives a comparison of horizontal irradiation results.

Source	Nb of years	Average irradiation
Meteonorm	20	1,937
Soda-HelioClim	14	1,862
3E Solar Data	14	1,851
PVGIS-CMSAF	10	1,931
SolarGIS	22	1,866

Table 6: 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 7 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	1,882	kWh/m²/yr
Transposition factor	2.2%	
In-plane irradiation	1,923	kWh/m²/yr
Ambient temperature	18.3	°C

Table 7: Weighted irradiation, transposition factor and temperature

Monthly breakdown

The monthly breakdown of the meteorological data is given in Table 8.

Month	**Horizontal irradiation (kWh/m²)**	**In-plane irradiation (kWh/m²)**	**Ambient temperature (°C)**
January	81	88	14.1
February	95	100	12.4
March	145	150	14.1
April	187	189	15.7
May	227	226	19.3
June	237	235	23.0
July	246	245	24.6
August	218	220	24.1
September	169	173	23.2
October	122	128	19.0
November	84	91	15.9
December	71	78	13.3
Year	**1,882**	**1,923**	**18.3**

Table 8: Monthly breakdown of the meteo data

Yield Calculations

System performance at project start-up

The system performance was calculated by using dynamic models (PVSYST v6.84) as well as its own assessment tool (LTYA V2.7). Table 9 gives a summary of the system performance loss assumptions.

Parameter	**Assumption**
Horizon shading	No horizon line was considered. No far shadings.
Dirt and soiling	Soiling losses were estimated at -3.5% (author's assumption). This is assumed that modules will be affected by dust (sand, salt, and bird droppings - Figure 15). No yearly cleanings are assumed in the simulation. 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 surface use and electricity generation output.
Reflection (IAM)	Usual glass parametrisation was considered (Ashrae b0=0.05).
Irradiance dependencies	The PV module file available in PVSyst database was used (PAN-file).
Near shading: electrical loss according to strings	Linear shadings were considered since the project is very low shadow impacted.
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 for flat roofs (Uc=29 W/m².K). For the shaded walkways

	and inclined roofs, the backside of the modules is not ventilated (Uc=20 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 1.5% at STC (author's assumption).
Transformer	No information is available at this stage of the project. No transformers are considered.
Availability	A commercial availability of 99%. Grid availability is assumed to be 100%.
Auxiliaries	Loss for auxiliaries were estimated at 0.3% (3's assumption).
Additional	-

Table 9: System performance loss assumptions

A simulation using the provided system parameters was performed with the above assumptions. Figure 16 shows an overview of the overall system losses resulting in an initial PR value of **81.9%.** 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.

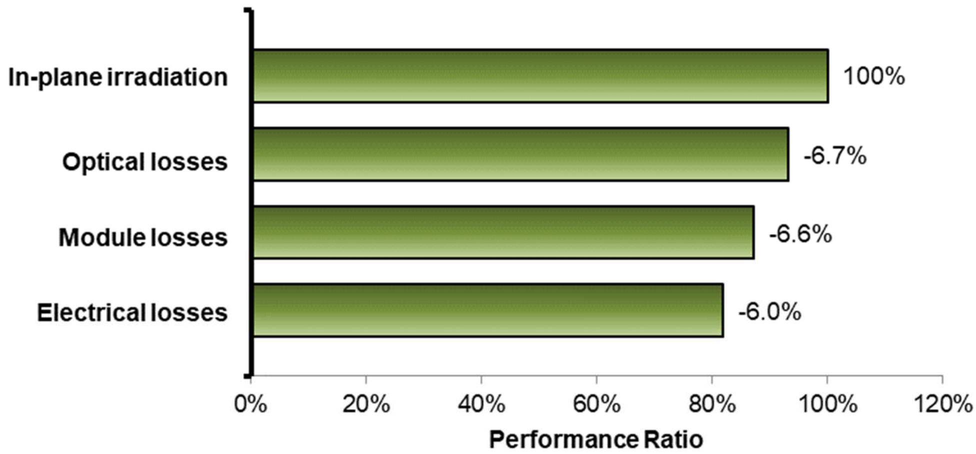

Figure 16 : General system losses and initial performance ratio (year zero)

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 10.

Parameter	**Assumption**
Light induced degradation (initial)	LID is estimated at -1.3% for monocrystalline 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 10: System performance degradations

Figure 17 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.

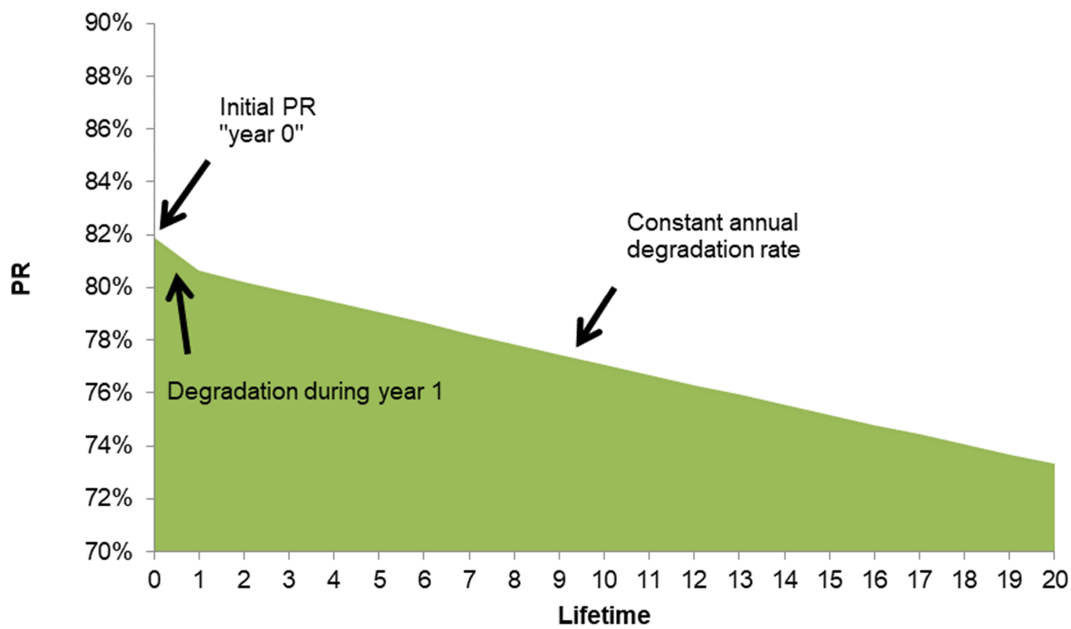

Figure 17: PR evolution during the life of the project

Mean expected yield (P50)

Table 11 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	309.24	kWp
*Initial performance ratio (PR) - year 0 **	81.9%	
First year degradation factor	-1.6%	
Yearly degradation factor	-0.5%	
*Specific yield (P50) - year 1 ***	1,556	kWh/kWp/yr
*System yield (P50) - year 1 ***	481	MWh/yr
System yield (P50) - 20 years	9,178	MWh

Table 11: 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 12. 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	2.2%
Affecting the resource estimation	Resource quantification	3.5%
	In-plane conversion	1.0%
Affecting the system performance	Optical	2.0%
	Module	1.8%
	Electrical	1.5%
	Degradation factors	0.3%

Table 12: Uncertainties considered for the calculation of the probabilities

Expected yield with 90% probability of exceedance (P90)

Table 13 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	1,450	kWh/kWp/yr
	System yield (P90) - year 1	448	MWh/yr
	Global uncertainty	5.4%	
5 years	Specific yield (P90) - year 1	1,459	kWh/kWp/yr
	System yield (P90) - year 1	451	MWh/yr
	Global uncertainty	5.1%	
10 years	Specific yield (P90) - year 1	1,460	kWh/kWp/yr
	System yield (P90) - year 1	452	MWh/yr
	Global uncertainty	5.0%	
20 years	Specific yield (P90) - year 1	1,461	kWh/kWp/yr
	System yield (P90) - year 1	452	MWh/yr
	Global uncertainty	5.0%	

Table 13: Expected yield with 90% probability of exceedance (P90)

Figure 18 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.

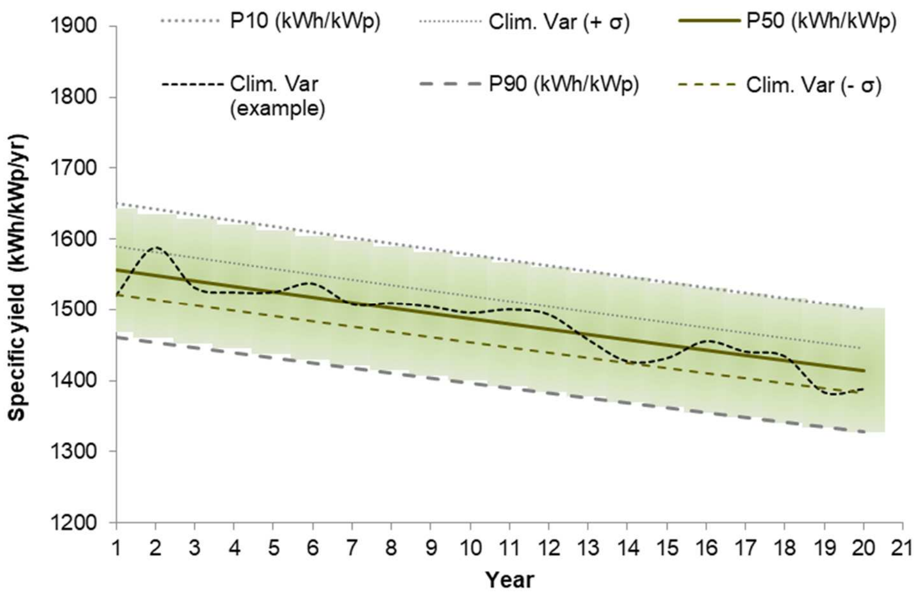

Figure 18: Yearly expected mean specific yield (P50) and its exceedance probabilities (P10 and P90)

Yearly and monthly breakdown

Table 14 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	80.6%	481	452
2	80.2%	479	449
3	79.8%	476	447
4	79.4%	474	445
5	79.0%	472	443
6	78.6%	469	441
7	78.2%	467	438
8	77.9%	464	436
9	77.5%	462	434
10	77.1%	460	432
11	76.7%	458	430
12	76.3%	455	427
13	75.9%	453	425
14	75.6%	451	423
15	75.2%	448	421
16	74.8%	446	419
17	74.4%	444	417
18	74.1%	442	415
19	73.7%	440	413
20	73.3%	437	411

Table 14: Yearly performance ratio and expected yield (P50 and P90)

Table 15 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	84.2%	23
February	84.8%	26
March	83.3%	39
April	81.5%	48
May	79.4%	56
June	78.4%	57
July	77.6%	59
August	78.5%	53
September	80.0%	43
October	82.5%	33
November	83.7%	24
December	84.5%	21
Year	**80.6%**	**481**

Table 15: Monthly performance ratio and system yield at year 1 (P50)

6. PV production versus consumption of the island

The objective of this section is to do a high-level analysis of the generation of the PV plant versus the consumption of the island.

The PV generation profile was obtained with PVSyst and it is the same that was used for the LTYA however with a few differences since the profile extracted from PVSyst that is used in the LTYA undergoes further data treatment (e.g. irradiation data, availability losses, etc.).

The electricity consumption profile of Culatra was shared by *EDP Distribuição*. The quarter-hourly profile refers to the year of 2019. This profile was adapted to hourly averages in order to be comparable with the profile generated from PVSyst (Table 16).

Three (3) parameters are analysed:

- PV to Culatra (kW) – this is the electricity generated by the PV plant (all sectors), that is consumed by the island.
- Grid to Culatra (kW) – this is the grid electricity that is consumed by Culatra.
- PV to grid (kW) – this is the excess electricity produced by the PV plant that is above the island demand and that therefore is injected into the public grid.

Month	**Culatra Consumption profile (kWh)**	**PV plant total production (kWh)**
January	87,707	23,277
February	75,867	26,647
March	85,471	38,989
April	86,323	48,159
May	96,585	56,005
June	103,299	57,410
July	123,391	59,184
August	136,770	53,746
September	112,301	43,355
October	93,763	33,146
November	86,745	23,822
December	92,558	20,645
Year	**1,180,780**	**484,384**

Table 16 : Monthly breakdown of Culatra's consumption profile and PV production

Month	Grid to Culatra (kWh)	PV to Culatra (kWh)	PV to Grid (kWh)
January	66,557	21,157	2,127
February	53,992	21,881	4,772
March	55,285	30,191	8,804
April	50,493	35,836	12,328
May	54,417	42,173	13,837
June	56,091	47,212	10,202
July	70,275	53,120	6,068
August	84,672	52,102	1,648
September	72,416	39,890	3,470
October	64,345	29,424	3,728
November	65,151	21,600	2,228
December	72,230	20,335	317
Year	**765,925**	**414,921**	**69,529**

Table 17: Monthly breakdown of PV to Culatra, Grid to Culatra and PV to grid

Yearly repartition of electricity consumption and production

According to Figure 19 over the year, PV production can cover around 414,921 kWh of Culatra electricity needs, with 69,529 kWh not being consumed and therefore being injected in the public grid. This means that the public grid needs to cover 765,925 kWh of the island needs.

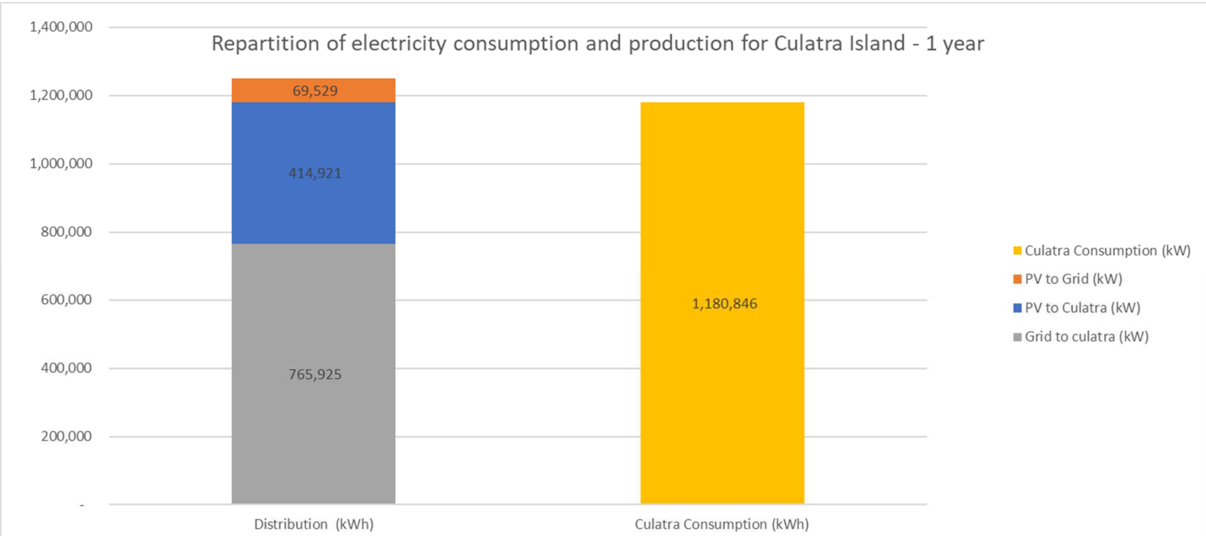

Figure 19 : Distribution of electricity produced by the PV plant (blue), electricity from the public grid (grey) and electricity injected into the public grid from the PV plant (orange) and in yellow, the total consumption of Culatra.

During winter (6 months), PV production can cover around 144,588 kWh of Culatra electricity needs (Figure 20), with 21,976 kWh not being consumed and therefore being injected in the public grid. This means that the public grid needs to cover 377,561 kWh of the island needs.

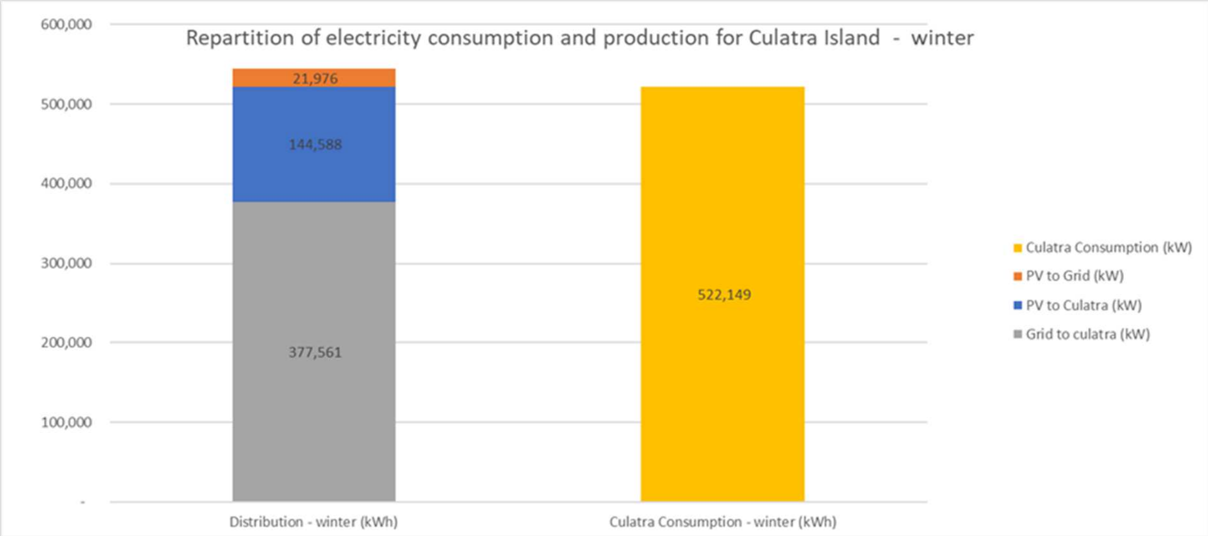

Figure 20: Distribution of electricity produced by the PV plant (blue), electricity from the public grid (grey) and electricity injected into the public grid from the PV plant (orange) and in yellow, the total consumption of Culatra, during winter.

During summer (6 months), PV production can cover around 270,333 kWh of Culatra electricity needs (Figure 21), with 47,554 kWh not being consumed and therefore being injected in the public grid. This means that the public grid needs to cover 388,364 kWh of the island needs.

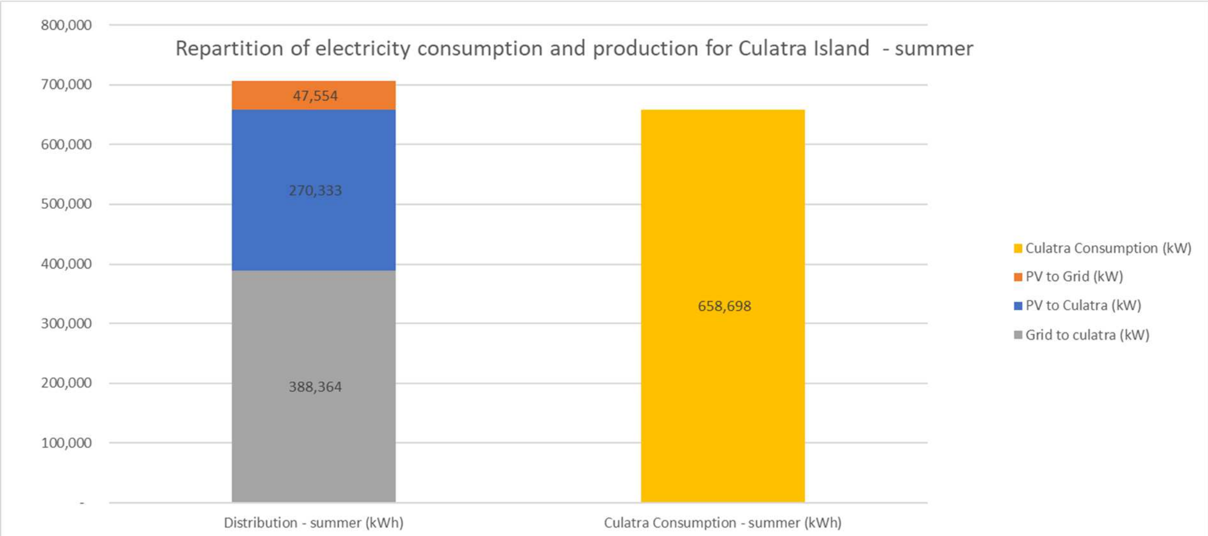

Figure 21: Distribution of electricity produced by the PV plant (blue), electricity from the public grid (grey) and electricity injected into the public grid from the PV plant (orange) and in yellow, the total consumption of Culatra, during summer.

During summer, PV production increases, so does the seasonal occupancy of the island and as well tourism. Consequently, the electricity demand of the island will increase. This is the main reason to explain the reduction of electricity demand from the grid despite the increase on the electricity demand of the islands.

Hourly analysis

The differences / variation regarding the electricity demand of the island can be better seen in the graphs below, where the electricity production/consumption is shown on an hourly basis for a typical week in August and in February.

During winter, it can be observed in Figure 22, that there are 2 peaks (1 smaller at noon and 1 higher in the evening) of electricity demand, the first peak (at noon) more or less coincides with the peak production of the PV plant. In winter the occupation of the island is lower, and the highest consumers of the islands are the restaurants, the following can be concluded:

- For the selected week the peak of PV generation is by norm higher than the peak of demand at noon this means that there is a lot of energy produced that will be injected into the grid.
- During weekends, the occupation rate increases, there is less energy that need to be injected in the public grid (Figure 22 - red circles)
- For a further study the hypothesis of storing the excess of PV production should be investigated (e.g. charging station for electrical tractors - currently they are diesel) that are used to support for the locals on their daily activities, this was briefly discussed with the represents of the local community upon the site visit.

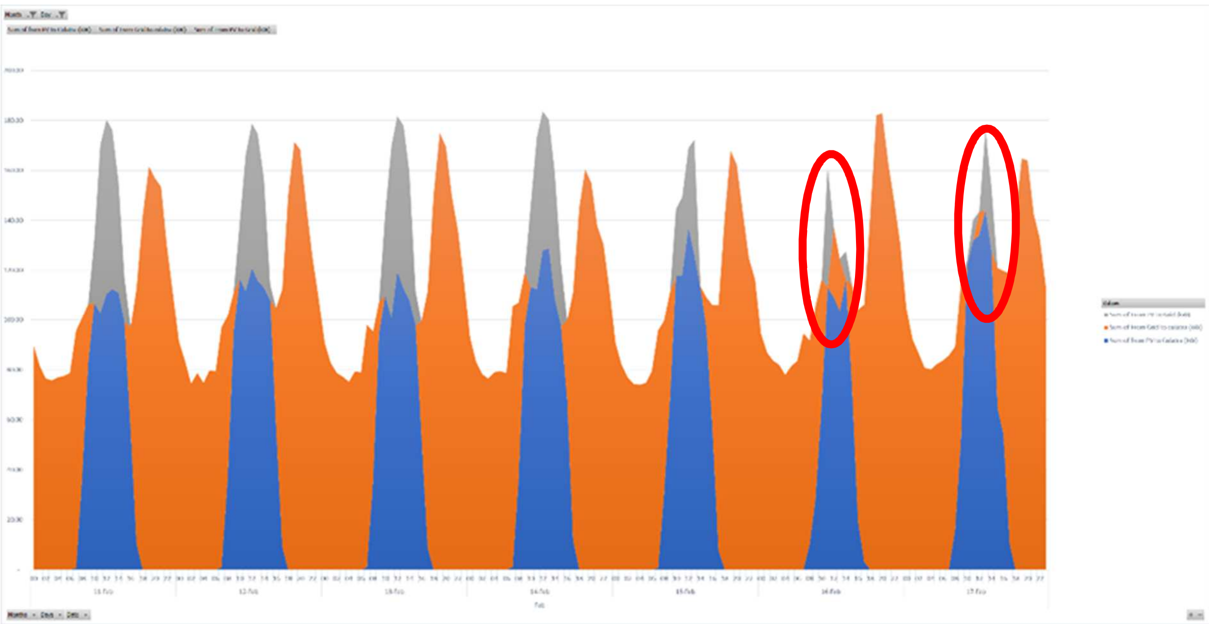

Figure 22: Hourly distribution for a full week in February of electricity produced by the PV plant (blue), electricity from the public grid (orange) and electricity injected into the public grid from the PV plant (grey).

During summer, Figure 23, it can be observed in that there are 2 peaks (1 smaller at noon and 1 higher in the evening) of electricity demand, the first peak (at noon) more or less coincides with the peak production of the PV plant. In summer the occupation of the island is higher, and the highest consumers of the islands are the restaurants, the following can be concluded:

- For the selected week, the peak of PV generation is by norm a match the peak of demand at noon this means that there the PV plant can meet the demand of the island consumption during the noon peak (restaurants serving lunches)

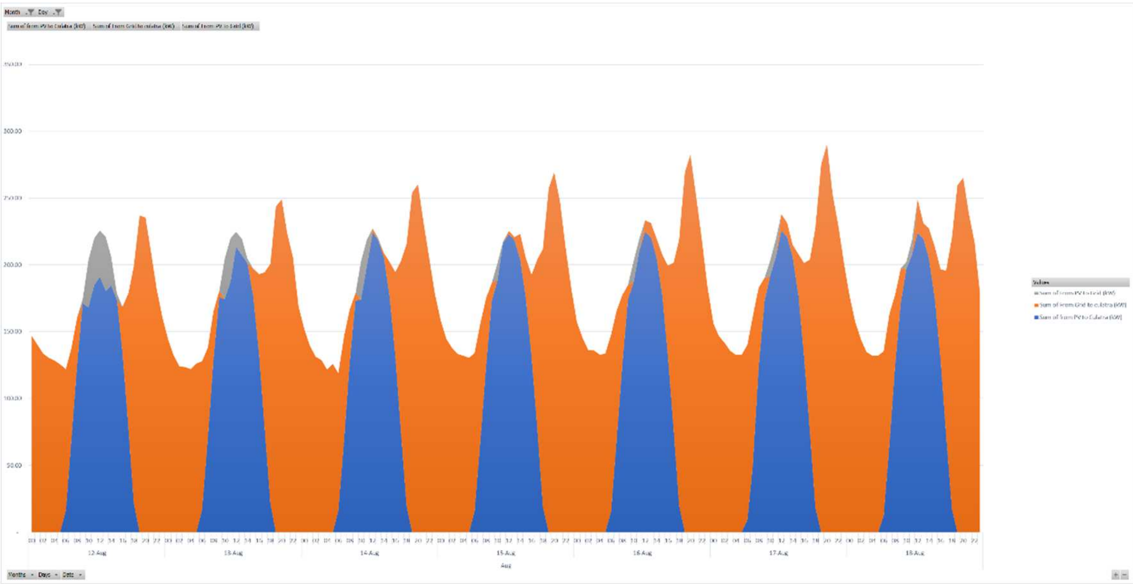

Figure 23: Hourly distribution for a full week in August of electricity produced by the PV plant (blue), electricity from the public grid (orange) and electricity injected into the public grid from the PV plant (grey).

7. CAPEX/OPEX high level analysis

Based on the consumption profile provided and information published ERSE – Entidade Reguladora dos Serviços Energéticos (price regulator in Portugal), the author estimates (high level) an average electricity price of 0.173 Euro/kWh for Culatra island.

Moreover, the PV generated energy that cannot be consumed by the Island can be injected in the public grid. According to price tables published by ERSE, the author estimates an average price (conservative) around to 0.041 Euro/kWh.

As for the CAPEX, it is estimated at 1.2 Euro/Wp given the relatively small scale of the Project and since the location is difficult to reach (material needs to arrive by boat).

OPEX is estimated at 10,000 Euro/MWp.

Based on the information mentioned above, the financial figures presented in Table 18 and Table 19 were calculated.

Table 18 presents an overview of the main costs on the 1st year, while Table 19 presents the IRR calculation over 15 years.

Parameter	**Value**
Capex	371,088 Euro
OPEX	3,092 Euro/Year
Cost reduction due to PV production	71,966 Euro (first year)*
PV production injected to public grid	3,851 Euro (first year)*

Table 18: Cost overview (-following years will be impacted by external factors such as yearly degradation of PV modules)*

Parameter	Value															
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Capital Investment (€)	371,088															
O&M (€)		3,092	3,092	3,092	3,092	3,092	3,092	3,092	3,092	3,092	3,092	3,092	3,092	3,092	3,092	3,092
Annual production (MWh)		484	481	479	476	473	470	467	464	462	459	456	453	451	448	445
Savings (MWh)		415	412	410	407	405	403	400	398	395	393	391	388	386	384	381
Injected to grid (MWh)		70	69	69	68	68	67	67	67	66	66	65	65	65	64	64
Electricity savings (€)		71,966	71,534	71,105	70,678	70,254	69,832	69,413	68,997	68,583	68,171	67,762	67,356	66,952	66,550	66,151
Grid injection revenues (€)		2,851	2,834	2,817	2,800	2,783	2,766	2,750	2,733	2,717	2,700	2,684	2,668	2,652	2,636	2,620
Initial outlay (€)	-371,088															
Annual cash-flow (€)		71,724	71,275	70,829	70,385	69,944	69,506	69,071	68,638	68,207	67,779	67,354	66,931	66,511	66,094	65,679
IRR	17%															

Table 19: 15 years IRR calculation

Annex A: Additional results

Detailed performance losses

Table 20 shows the PR breakdown at year zero.

Losses breakdown	**Loss / Gain**
Horizon shading	**0.0%**
In-plane conversion	**2.5%**
Optical	**-6.7%**
- Dirt and soiling	-3.5%
- Near shading: irr. loss	-0.2%
- Snow	0.0%
- Reflection	-3.2%
Module	**-6.6%**
- Irradiance dependencies	-0.2%
- Near shading: acc. to strings	0.0%
- Power tolerance of modules	0.3%
- Temperature dependencies	-6.2%
- Spectral dependencies	0.0%
- Mismatching	-0.5%
Electrical	**-6.0%**
- DC cabling	-0.8%
- Inverter	-3.2%
- AC cabling	-0.8%
- Transformer	0.0%
- Availability	-1.0%
- Auxiliaries	-0.3%
- Additional (e.g. line loss)	0.0%
Total	**-18.1%**
Initial performance ratio (year 0)	**81.9%**

Table 20: PR breakdown at year zero

Expected yield with various probabilities at 100% availability

Table 21 shows the expected yield with various probabilities, at 100% availability.

	Parameter	Value	Unit
1 year	System | specific yield (P50) - year 1	486 | 1571	MWh/yr | kWh/kWp/yr
	System | specific yield (P75) - year 1	469 | 1516	MWh/yr | kWh/kWp/yr
	System | specific yield (P90) - year 1	453 | 1465	MWh/yr | kWh/kWp/yr
	System | specific yield (P99) - year 1	425 | 1374	MWh/yr | kWh/kWp/yr
5 years	System | specific yield (P50) - year 1	486 | 1571	MWh/yr | kWh/kWp/yr
	System | specific yield (P75) - year 1	470 | 1520	MWh/yr | kWh/kWp/yr
	System | specific yield (P90) - year 1	456 | 1474	MWh/yr | kWh/kWp/yr
	System | specific yield (P99) - year 1	431 | 1393	MWh/yr | kWh/kWp/yr
10 years	System | specific yield (P50) - year 1	486 | 1571	MWh/yr | kWh/kWp/yr
	System | specific yield (P75) - year 1	470 | 1521	MWh/yr | kWh/kWp/yr
	System | specific yield (P90) - year 1	456 | 1475	MWh/yr | kWh/kWp/yr
	System | specific yield (P99) - year 1	432 | 1396	MWh/yr | kWh/kWp/yr
20 years	System | specific yield (P50) - year 1	486 | 1571	MWh/yr | kWh/kWp/yr
	System | specific yield (P75) - year 1	470 | 1521	MWh/yr | kWh/kWp/yr
	System | specific yield (P90) - year 1	456 | 1475	MWh/yr | kWh/kWp/yr
	System | specific yield (P99) - year 1	432 | 1397	MWh/yr | kWh/kWp/yr

Table 21: Expected yield with various probabilities (100% availability)

Annex B: 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 combines 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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