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Clean energy for EU islands: Solar carpark prefeasibility study

Cres-Lošinj, Croatia

Clean energy for EU islands

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Summary

The Cres-Lošinj archipelago published in 2019 its Clean Energy Transition Agenda, where electricity production by solar PV was identified as a stepping stone in the decarbonisation of the archipelago's electricity sector.

The project considered in this report is referred to as "INSOLARCARPARK". It is located in the town of Mali Lošinj, Cres-Lošinj archipelago, Croatia. This is a roof mounted PV power plant which serves as a shading area for vehicles in a car park, with a total peak power (DC) of 518.1 kWp. The PV modules are mono-crystaline and installed at a 4° tilt angle, with West and East orientations aligned with the orientations of the car parking bays. The project includes string inverters.

Table 1 shows expected values for the average in-plane irradiation, the initial performance ratio, and the average expected yield (P50).

Table 1: Average expected yield (P50)

Parameter	**Value**	**Unit**
System peak power	518.10	kWp
Mean yearly in-plane irradiation	1,504	kWh/m²/yr
Performance ratio at plant start-up (PR) *	88.3%	
Specific yield (P50) - year 1 **	1,313	kWh/kWp/yr
System yield (P50) - year 1 **	680	MWh/yr
Yearly degradation factor	-0.5%	
System yield (P50) - 20 years	12,976	MWh

* PR without plant availability and module degradation (see section 4.1)

** Including availability and average degradation during year 1 (see section 4.2)

This study indicates that a 518.10 kWp solar PV car park at Cres-Lošinj will produce 12,976 MWh of electricity over a project lifespan of 20 years, based on a P50 probability. The system will cost approximately €580,525 to complete and €4,660 per year to operate and maintain using a third-party O&M contractor.

Glossary

CAPEX	Capital expenditure, representing both the hardware, installation and soft costs of a solar PV system.
OPEX	Operating expenditure, specifically for the operation and maintenance of the solar PV system done under contract.
Peak power (Wp)	This is the power of a PV module for standard test conditions (STC). The sum of the modules of a power plant then gives the total peak power of the power plant, expressed in kWp or MWp.
Performance ratio (PR)	The performance ratio (PR) is an important indicator for characterising the behaviour of a PV plant. The PR represents the ratio in % between the actual and theoretical energy production taking into account the available sunlight in the plane of the PV modules. It is determined by the choice of system components as well as design and maintenance requirements, but also by the location and vicinity of the project. The result of the initial PR indicated in this report represents the PR at plant start-up.
Average expected yield (P50)	This is the average expected long-term production for a PV plant (i.e. with a 50% probability of exceeding it). It can be presented as production in MWh/year or as the ratio between production and peak power of the plant. In the latter case, we speak of specific yield, generally presented in kWh/kWp/year.
Yield with 90% probability of exceedance (P90)	The value of the P90 gives the expected yield in 90% of cases (90% probability of exceeding). In other words, the risk of not reaching this value is 10%. This results from the combination of all the uncertainties of the yield calculation, particularly the uncertainty related to the annual variation of the irradiation, obtained by means of probability laws. When calculating the P90, it is important to differentiate observation periods, which can vary from 1 year to 20 or 25 years depending on the life of the project. The different risk measures are defined according to whether one wants to assess the risk associated with cash flow over a single year or the cumulative income over the lifetime, which changes the way in which the uncertainty associated with annual variations is taken into account. When quantifying the risk over a single year, the uncertainty of climate variability is taken into account in its entirety. Over a longer observation period, this same uncertainty is reduced since less sunny years are generally compensated by years with more sun.
Transposition factor	The Transposition Factor is the ratio of the incident irradiation (GlobInc) on the plane, to the horizontal irradiation (GlobHor). I.e. what you gain (or loose) when tilting the collector plane. It may be defined in hourly, daily, monthly or yearly values. It is computed by applying a transposition model to the horizontal hourly values. The models that PVSyst offers are the Hay and Perez model. The result depends namely on the diffuse irradiance.
Perez model	The Perze model is a transposition model, which is a more sophisticated model requiring good (well measured) horizontal data.

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Introduction

The Clean Energy Transition Agenda of the Cres-Lošinj archipelago was developed in 2019 by the Island Development Agency OTRA and key stakeholders from the islands. This strategic plan identified electricity as one of the main pillars of the archipelago's clean energy transition, with a strong focus given to solar PV. Currently, potential locations of solar PV development are being investigated by the Island Development Agency. This report outlines a pre-feasibility study for a solar carport next to the port of Mali Lošinj.

Site overview

The location of the proposed photovoltaic installation is in a carpark next to the mooring area for boats in the town of Mali Lošinj, Cres-Lošinj archipelago, Croatia. The project is identified as the INSOLCARPARK. It is a carpark solar roof project.

Figure 1: Site location

System design

A solar carpark consists of solar PV modules that are mounted on a support frame over the parking bays of a car park. The solar carpark provides shading for the vehicles underneath it, while also generating electricity. A typical setup is illustrated in Figure 2.

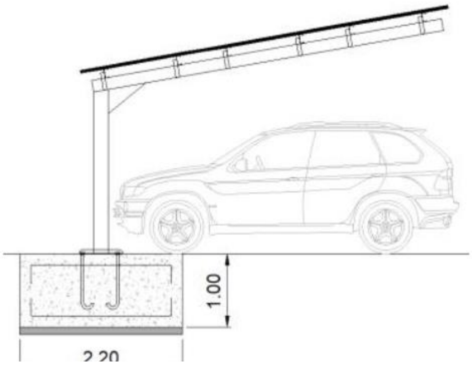


Figure 2: Typical solar carpark setup (source: SOLARSTEM brochure)

Layout

The solar PV system layout is based on the available drawings. The intention of the design is to maximize the available solar energy production using the available space while working within the technology and site limitations. The PV modules cover all of the parking bays and parts of the roadways. This maximises the system size and shading effect for vehicles. The tilt angle of the modules are 4 degrees with a total of 942 PV modules, representing a total capacity of 518 kWp. A layout is provided in the Figure 3.

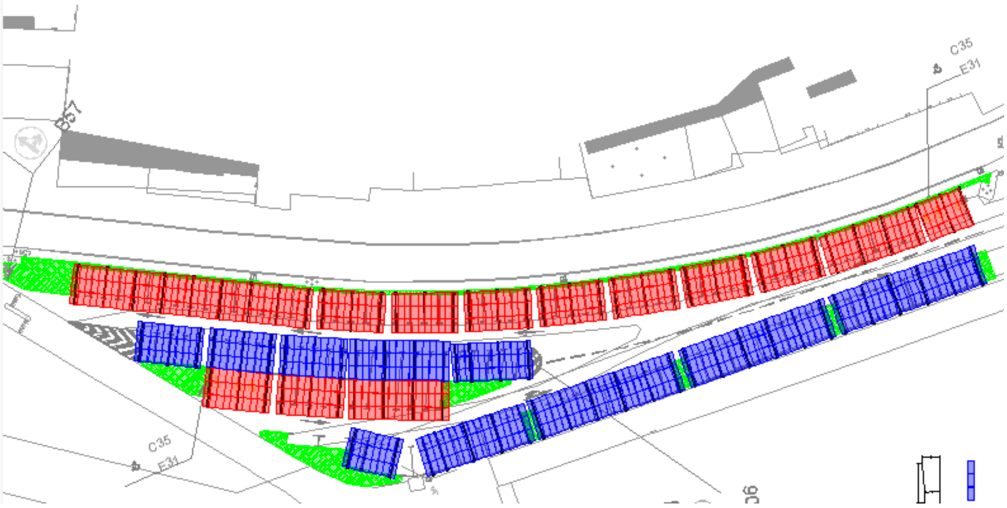


Figure 3: Solar module layout, red represents east facing modules and blue represent west facing modules.

Heritage

Heritage decisions need to be taken by a heritage council. However, the visual impact of the system can be adjusted by adjusting the tilt angle of the modules. A flat (0 degrees) angle will have a minimal impact when viewed from street level, whereas a more upright angle will have a more prominent visual impact from street level. The proposed 4 degrees tilt angle is sufficiently low to reduce the visual impact. Some existing car park designs are shown in Figure 4.

Figure 4: Examples of solar carpark installations. (Source: SOLARSTEM brochure)

It is important to note that the visual impact of a solar roof compared to a standard roof will be similar. Any modification to the tilt angle will affect the energy production of the solar PV system.

Long Term Yield Assessment

The objective of this section is to calculate the long-term yield of the PV system associated with several confidence intervals. To do this, different sources of meteorological data were used to estimate the most realistic yield. Dynamic simulation models (PVsyst) are used to characterise the system's behaviour and calculate the corresponding output. Both the uncertainties affecting the solar resource as well as the system's efficiency were taken into account to determine the statistical characteristics of the predicted values. Using these data, the expected average output (P50) is calculated to better quantify the risks associated with the PV project, particularly in its first year of operation. In conjunction with the long-term yield study, it is recommended that a system design audit be conducted to assess the risks associated with detailed engineering.

Project overview

Simulation parameters are based on documents provided by the Client. The main system parameters are summarised in Table 2.

Table 2: System parameters

PARAMETER	VALUE	UNIT
System peak power	518.10	kWp
Latitude	44.5361	°N
Longitude	14.4656	°E
Altitude	1	m a.s.l.
Tilt	4	°
Azimuth	Multi (95, 72, -90, -107)	°
Type of modules	Longi LR5-72HPH-550W	
Nb of modules	942	
Type of inverters	Huawei SUN2000-105KTL	
Nb of inverters	4	
Type of structures	Fixed tilt	
Topography (if applicable)	Flat terrain	

Meteorological data

Global irradiation and temperature

A variety of meteorological data sources were considered for the yield study. Table 3 gives a comparison of horizontal irradiation results.

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

SOURCE	No. of years	Average irradiation
Soda-HelioClim	16	1,553
3E Solar Data	16	1,495
PVGIS-CMSAF	10	1,507
SolarGIS	26	1,485

Each horizontal irradiation source was 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.

Table 4: Weighted irradiation, transposition factor and temperature

PARAMETER	VALUE	UNIT
Weighted horizontal irradiation	1,503	kWh/m²/yr
Transposition factor	0.1%	
In-plane irradiation	1,504	kWh/m²/yr
Ambient temperature	16.6	°C

Monthly breakdown

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

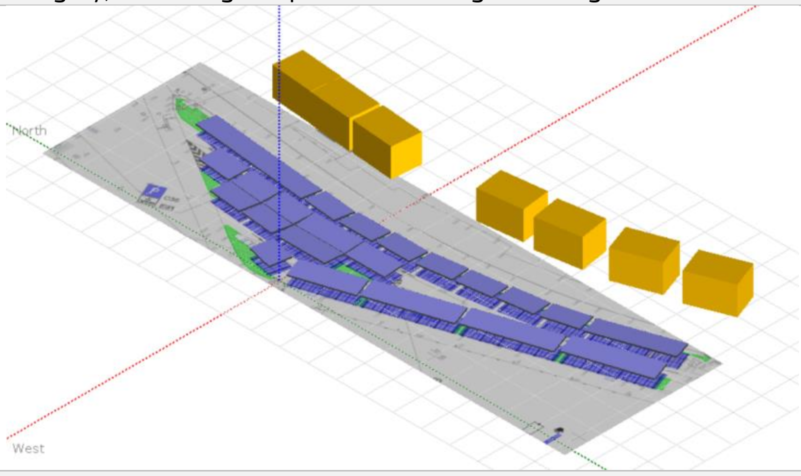
Table 5: Monthly breakdown of the meteo-data

MONTH	HORIZONTAL IRRADIATION (kwh/m²)	IN-PLANE IRRADIATION (kwh/m²)	AMBIENT TEMPERATURE (°C)
January	41	42	11.1
February	64	64	10.6
March	114	114	9.8
April	153	153	13.8
May	192	192	17.1
June	213	214	22.9
July	224	224	24.3
August	193	194	23.4
September	137	138	20.9
October	88	88	18.9
November	46	46	13.3
December	37	37	12.3
Year	**1,503**	**1,504**	**16.6**

Yield calculation

3E calculated the system performance by using dynamic models (PVSyst v7.2) as well as its own assessment tool (LTYA v2.9). Table 6 gives a summary of the system performance loss assumptions.

Table 6: System performance loss assumptions

PARAMETERS	**ASSUMPTIONS**
Horizon shading	The horizon shading line was considered. It was extracted from SolarGIS Prospect.
Dirt and soiling	Soiling losses were estimated at 1.5%.
Near shading: irradiance loss	Shading losses were considered based on project Google Earth imagery, indicating the presence of large buildings near the site.
	
Reflection (IAM)	Usual glass parametrisation was considered (Ashrae b0=0.05).
Irradiance dependencies	PV module file from the PVsyst database (PAN-file).
Near shading: electrical loss according to strings	Electrical loss from strings were not considered.
Power tolerance of modules	A quality gain based on the power tolerance stated in the product datasheet was assumed.
Temperature dependencies	Simulations consider the rear surface of the PV modules are open (U_c=29 W/m^2.K).
Light induced degradation (initial)	LID is estimated at 0% for the selected modules, n-type.
Mismatching	Module mismatch losses were estimated at 0.4% for unsorted PV modules. String mismatch is supposed to be 0.1%.
DC cabling	DC cable calculations were not provided. Corresponding losses were assumed to be 1.5% at STC.
Inverter	The inverter file from the EPC (OND-file) was used.
AC cabling	AC cable calculations were not provided. Corresponding losses were assumed to be 1%.

The plant availability and module degradation rate were considered to estimate the system performance over the project lifetime. They both are described in Table 7.

Table 7: System performance loss assumptions - lifetime

PARAMETER	ASSUMPTION
Availability	A commercial availability of 99% was considered. Grid availability is assumed to be 100%.
Annual degradation factor (ageing)	Annual degradation is estimated at 0.5%/year.

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.

Table 8: Mean expected yield (P50)

PARAMETER	VALUE	UNIT
System peak power	518.10	kWp
Performance ratio at plant start-up (PR)[1]	88.3%	
Plant availability	99.0%	
Yearly degradation factor	-0.5%	
Specific yield – Year 1[2]	1,313	kWh/kWp/yr
System yield – Year 1	680	MWh/yr
System yield – 20 Years	12,976	MWh

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 summarised 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 by 3E based on an extensive literature study and own calculations.

Table 9: Uncertainties considered for the calculation of the probabilities

UNCERTAINTY	VARIABLE	VALUE
Due to the yearly variation	Climate variability	2.8%
Affecting the resource estimation	Resource quantification	3.5%
	In-plan conversion	2.0%
Affecting the system performance	Optical	1.3%
	Module	1.2%
	Electrical	1.1%
	Degradation	0.3%

[1] PR without plant and module degradation
[2] Including availability and average degradation during year 1

Yearly and monthly breakdown

Table 10 shows the yearly performance ratio, as well as the corresponding P50 results.

Table 10: Yearly performance ratio and expected yield

YEAR	PERFORMANCE RATIO (PR)	SYSTEM YIELD P50 (MWh)
1	87.2%	680
2	86.8%	677
3	86.3%	673
4	85.9%	670
5	85.5%	667
6	85.0%	663
7	84.6%	660
8	84.2%	657
9	83.8%	653
10	83.4%	650
11	82.9%	647
12	82.5%	644
13	82.1%	640
14	81.7%	637
15	81.3%	634
16	80.9%	631
17	80.5%	628
18	80.1%	625
19	79.7%	622
20	79.3%	618

Table 11 shows the monthly values for the performance ratio and the average yield (P50) at year 1.

Table 11: Monthly performance ratio and system yield at year 1

MONTH	PERFORMANCE RATIO (PR) – YEAR 1	SYSTEM YIELD (P50) – YEAR 1 (MWh)
January	88.1%	19
February	89.9%	30
March	90.8%	54
April	89.2%	71
May	87.3%	87
June	85.7%	95
July	85.4%	99
August	86.3%	87
September	87.4%	62
October	87.5%	40
November	87.8%	21
December	86.7%	17
Year	**87.2%**	**680**

The expected yields with 100% availability at various probabilities are listed in Table 12.

Table 12: Expected yield with various probabilities (100% availability)

PARAMETER	VALUE	UNIT
System | specific yield (P50) – year 1	687 | 1326	MWh/yr | kWh/kWp/yr
System | specific yield (P75) – year 1	667 | 1287	MWh/yr | kWh/kWp/yr
System | specific yield (P90) – year 1	648 | 1251	MWh/yr | kWh/kWp/yr
System | specific yield (P99) – year 1	616 | 1190	MWh/yr | kWh/kWp/yr

Cost estimate

A cost estimation is provided in this section. Please note that the costs are dependent on various local factors, which includes technology, labour, duties, taxes, among other. A more relevant and accurate cost estimate will be subject to an official quote by a service provider. The costs, excluding tax, are estimated from previous projects that 3E worked on, and are summarised in Table 13. The capital costs exist of the carport structure on which the solar modules will be mounted, the costs of the solar system itself and some contingency costs.

The cost for the carport structure includes the solar canopies covering 130 parking spaces and allowing to place 942 PV modules, 42 integrated light pillars, the mechanical assembly, and the transportation. The foundation is not yet included. Furthermore, these figures are derived from projects in Portugal so the costs could differ somewhat in Croatia.

The cost for the solar system includes the hardware (PV modules, inverters, the non-module hardware), the installation, and soft costs as indicated in ANNEX A: Balancing of System (BoS) costs for solar PV. This is estimated at €922/kW for utility scale solar PV in Croatia based on the most recent power generation cost breakdown by IRENA[3], which is also in line with what 3E sees in the field. Additionally, 3E sees it as best practice to include 5% of the total CAPEX for contingency reasons.

Table 13: System costs

ID	Parameter	Value (EUR)
A	CAPEX (excl. tax)	
1	Capital cost of carport structure	75,280
2	Capital cost of solar system (€922/kWp)	477,600
3	Spares and contingency (5%)	27,645
	Total CAPEX	**580,525**
B	OPEX (excl. tax)	
1	Annual O&M cost (€9/kWp)	4,660

[3] IRENA, Power Generation Costs 2020, https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020

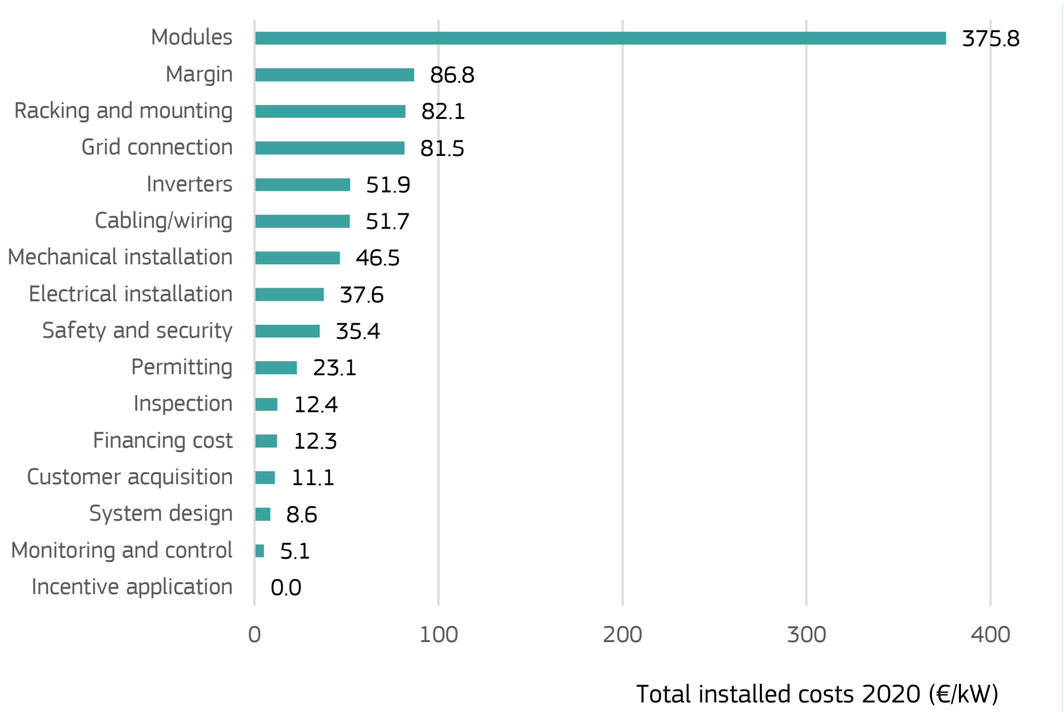


Figure 5 Detailed breakdown of utility-scale solar PV total installed cost in Croatia, 2020
(source: IRENA Power Generation Costs 2020)

Operation and maintenance are all activities or programs linked to the correct and efficient operation of the PV installation. Operation ranges from the supervision and operation of the installation to planning preventive maintenance or predicting capacity. Maintenance refers to the maintenance of the PV installation itself, as well as the maintenance of the site. PV maintenance refers to the replacement or repair of all possible components of the PV system, from the modules and the load-bearing structure to the wiring of each component. Site maintenance refers to activities such as site supervision and compliance with environmental regulations.

The average utility-scale O&M costs in Europe are estimated at €9/kW per year, according to the latest IRENA report[3]. This includes costs such as insurance and asset management as well. However, it does not include the replacement cost for the inverters after 10 – 15 years. This should be accounted for when considering the long-term financial impact of operating a solar PV system over the project lifespan of 20 years.

Conclusions

This study indicates that a 518.10 kWp solar PV car park at Cres-Lošinj will produce 12,976 MWh of electricity over a project lifespan of 20 years, based on a P50 probability. The system will cost approximately €580,525 to construct.

ANNEX A: Balancing of System (BoS) costs for solar PV

Category	Description
Non-module hardware	
Cabling	• All direct current (DC) components , such as DC cables, connectors and DC combiner boxes • All AC low voltage components, such as cables, connectors and AC combiner boxes
Racking and mounting	• Complete mounting system including ramming profiles, foundations and all material for assembling • All material necessary for mounting the inverter and all type of combiner boxes
Safety and security	• Fences • Camera and security system • All equipment fixed installed as theft and/or fire protection
Grid connection	• All medium voltage cables and connectors • Switch gears and control boards • Transformers and/or transformer stations • Substation and housing • Meter(s)
Monitoring and control	• Monitoring system • Meteorological system (*e.g.,* irradiation and temperature sensor) • Supervisory control and data system
Installation	
Mechanical installation (construction)	• Access and internal roads • Preparation for cable routing (*e.g.,* cable trench, cable trunking system) • Installation of mounting/racking system • Installation of solar modules and inverters • Installation of grid connection components
Electrical installation	• DC installation (module interconnection and DC cabling) • AC medium voltage installation • Installation of monitoring and control system • Electrical tests (*e.g.*, DC string measurement)
Inspection (construction supervision)	• Construction supervision • Health and safety inspections
Soft costs	
Incentive application	• All costs related to compliance in order to benefit from support policies
Permitting	• All costs for permits necessary for developing, construction and operation • All costs related to environmental regulations
System design	• Costs for geological surveys or structural analysis • Costs for surveyors • Costs for conceptual and detailed design • Costs for preparation of documentation
Customer acquisition	• Costs for project rights, if any • Any type of provision paid in order to get project and/or off-take agreements in place
Financing costs	• All financing costs necessary for development and construction of PV system, such as costs for construction finance

Margin	• Margin for EPC company and/or for project developer for development and construction of PV system includes profit, wages, finance, customer service, legal, human resources, rent, office supplies, purchased corporate professional services and vehicle fees