

UNIVERSIDAD DE VALLADOLID

International Semester in Industrial Engineering

Academic Year 2022/2023

The Environment and Renewable Energy



SELF CONSUMPTION PVSyst PROJECT REPORT

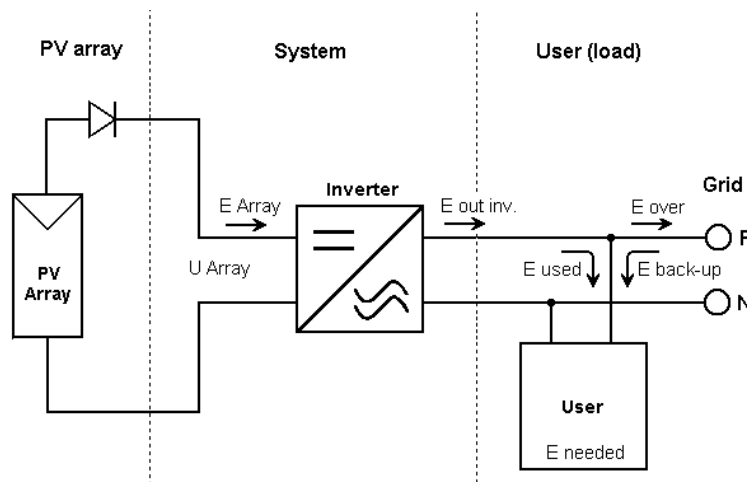
Student: BENIAMINO FRACCHIOLLA

ABSTRACT

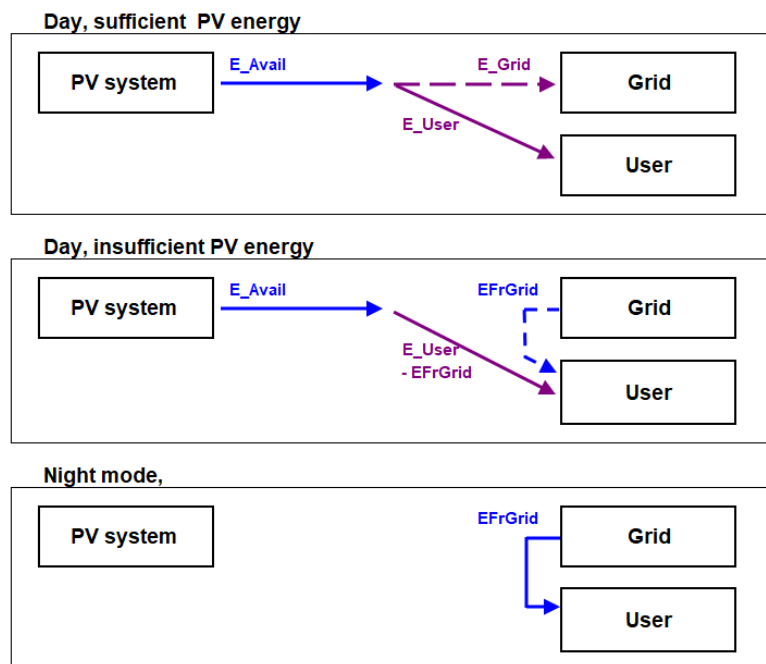
The main objective of this exercise is to design two grid connected photovoltaic systems using the PVSyst software. The first located in IndUva Building, Valladolid and the second located in our own country Bari, Italy.

The two projects will have a planned power of 55kWp and the orientation of the PV modules will be the best for the different location. To compare the performances of the two installation PV panel model and inverter model was already given. In addition will be taken in account losses to obtain more realistic results.

Instead of the last assignment about grid connected system, where the energy needed from the user was zero now it has a weight into the calculation, as shown as follows:



The previous image will be the configuration used in these two projects. In this case user's needs could be satisfied by the grid, PV panel or both of them. Following an example taken from PVSyst documentation:



The user's needs are managed as daily profile, with a seasonal modulation. All of us will be treated as AC loads. The following table shows the daily profile in spring in hourly values. In summer the daily profile is 80% of the spring profile, 120% in autumn and 150% in winter.

HOURLY VALUES							
Hour	Power (kW)		Hour	Power (kW)		Hour	Power (kW)
0:00	3.68		8:00	4.56		16:00	18.64
1:00	4.66		9:00	6.26		17:00	18.42
2:00	2.68		10:00	3.54		18:00	6.24
3:00	2.16		11:00	2.36		19:00	3.70
4:00	3.08		12:00	1.96		20:00	2.78
5:00	2.86		13:00	3.62		21:00	3.26
6:00	3.16		14:00	11.06		22:00	11.88
7:00	2.72		15:00	1.00		23:00	7.00

This report is divided, as follows, in five parts:

1. **Inputs of first report**
2. **Procedure of first report**
3. **Inputs of second report**
4. **Procedure of second report**
5. **Outputs**

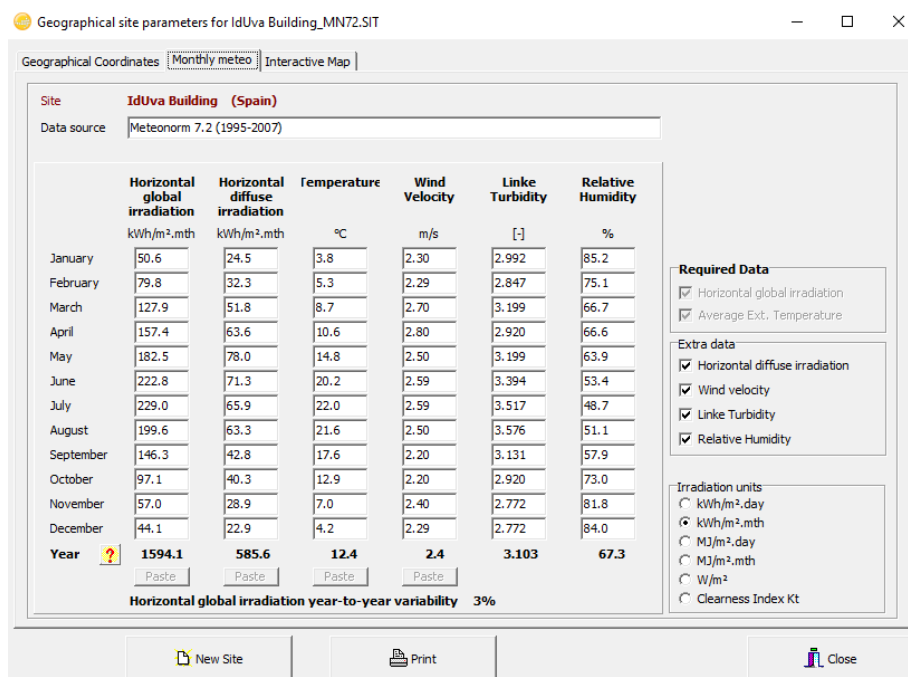
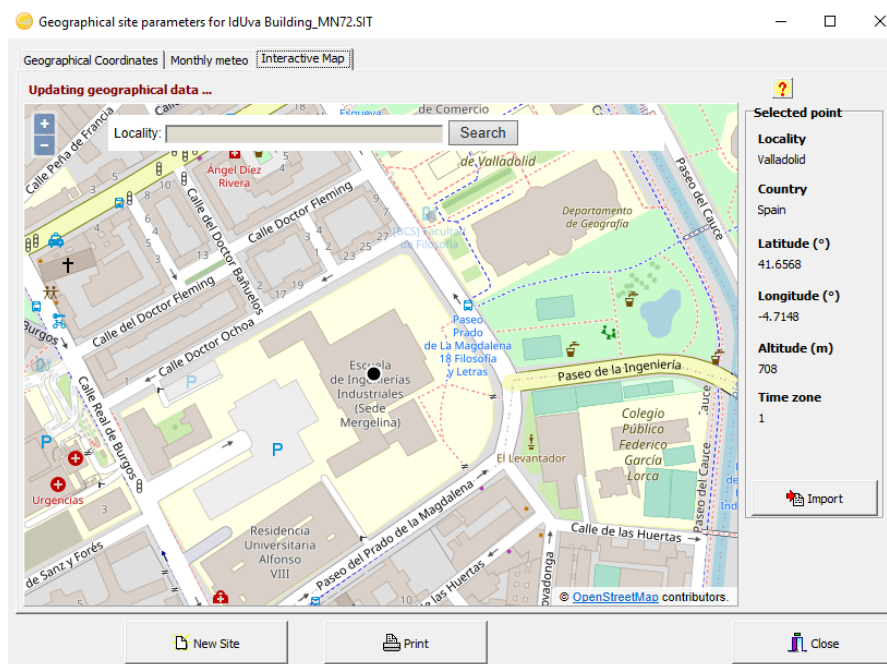
Every part shown will explored in the following report.

INPUTS OF THE FIRST REPORT

1. Location: the location was set in IndUva Building, the university of Valladolid, and the meteorological values are already provided by the map of PVSyst.
2. PV system components: as an overview the system will include PV modules and inverter taken from database.
3. User's needs: a planned power of 55kWp and daily profile of consumption with a seasonal modulation.

PROCEDURE OF THE FIRST REPORT

1. *Set the project's destination (Name, Geographical location and weather file):* in this case the building location was not already present into the database. So, it was added during the simulation as new site;



2. *Set the orientation of the PV module:* as specified before the tilt and azimuth angle will be taken as the optimal, as optimization method was chosen the one that take an average between winter and summer needs (called: *yearly irradiation yield*) this because a grid connected system aims to produce all the possible energy and feed the electrical grid and not perfectly satisfy a building demand;

Orientation, Variant "Variant with self consumption"

Field type: Fixed Tilted Plane

Field parameters

Plane Tilt: 34.8 [°]
Azimuth: 0.0 [°]

Optimization by respect to

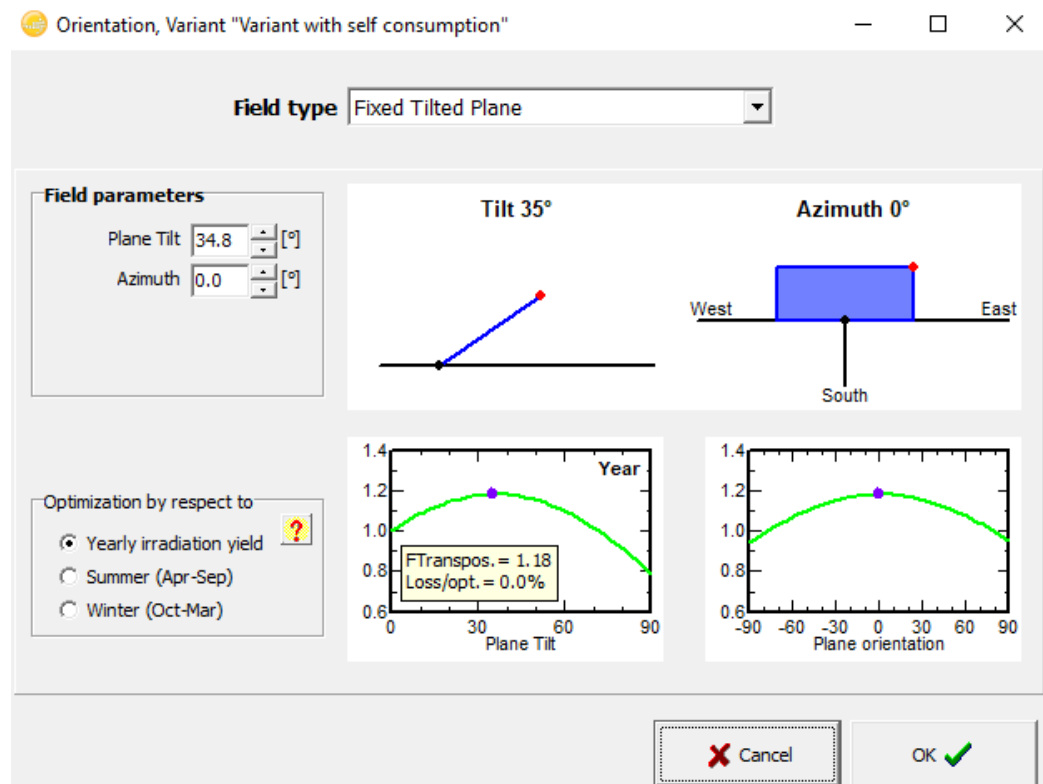
☒ Yearly irradiation yield ?
☐ Summer (Apr-Sep)
☐ Winter (Oct-Mar)

Yearly meteo yield

Transposition Factor FT: 1.18
Loss By Respect To Optimum: 0.0%
Global on collector plane: 1883 kWh/m²

Show Optimization

Cancel OK



3. *Set the user's need:* the user's needs are managed as daily profile, with a seasonal modulation. All of us will be treated as AC loads.

User's needs definition, Variant "Variant with self consumption"

Comment: New User's needs

General features | **Daily profile** | Graph

Kind of load profile

- ☐ No Auto-consumption
- ☐ Fixed constant consumption
- ☐ Monthly values
- ☒ Daily profiles
- ☐ Probability profiles
- ☐ Household Consumers
- ☐ Load values from a CSV hourly/daily file

Daily profiles

- ☐ Constant over the year
- ☒ Seasonal modulation
- ☐ Monthly normalization
- ☐ Weekly modulation

User's needs Yearly energy defined

Average power: **6.14 kW**

Yearly energy: **53.8 MWh/year**

Info system: Defined PV array

Nominal PV Power: **51.0 kWp**

Estimated system yield: **76.2 MWh/year**

PnomPV / PLoad average: **5.86 Power ratio**

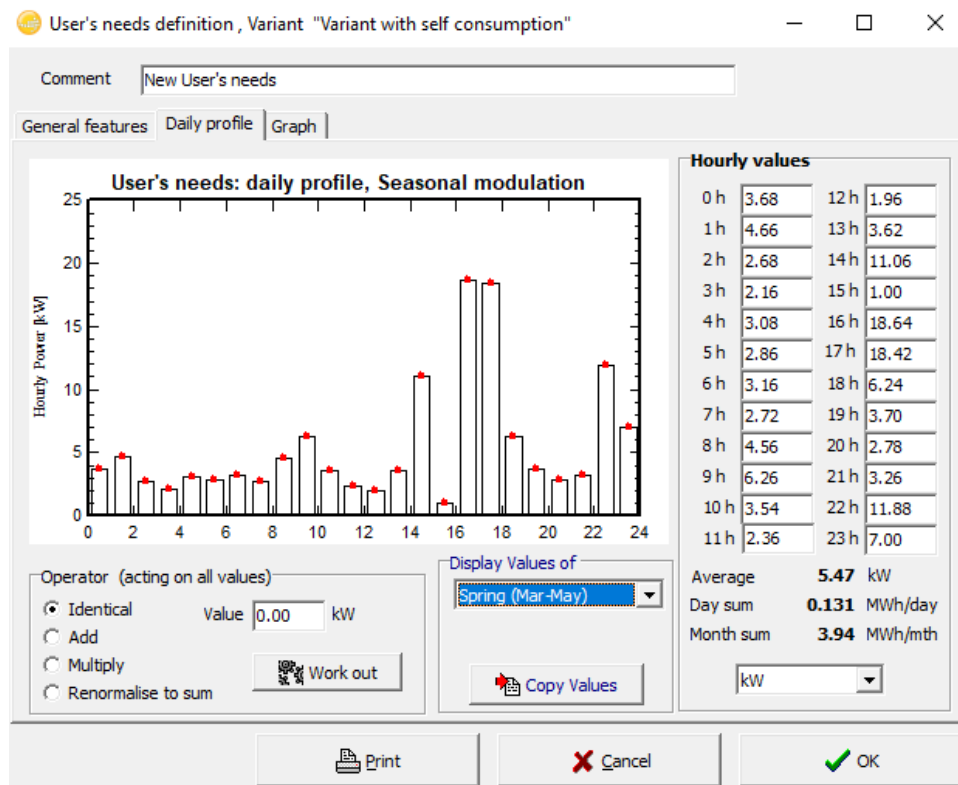
An auto-consumption with an average of 147.4 kWh/day has been defined

Model

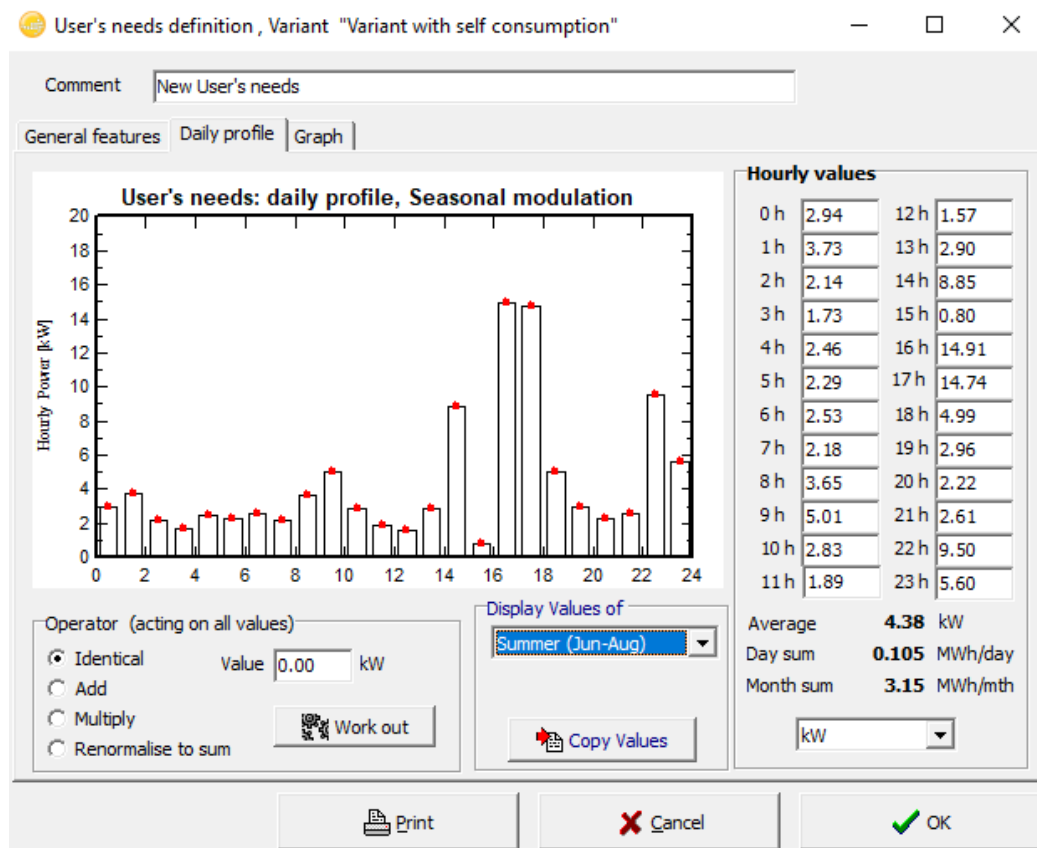
Load Save

Print Cancel OK

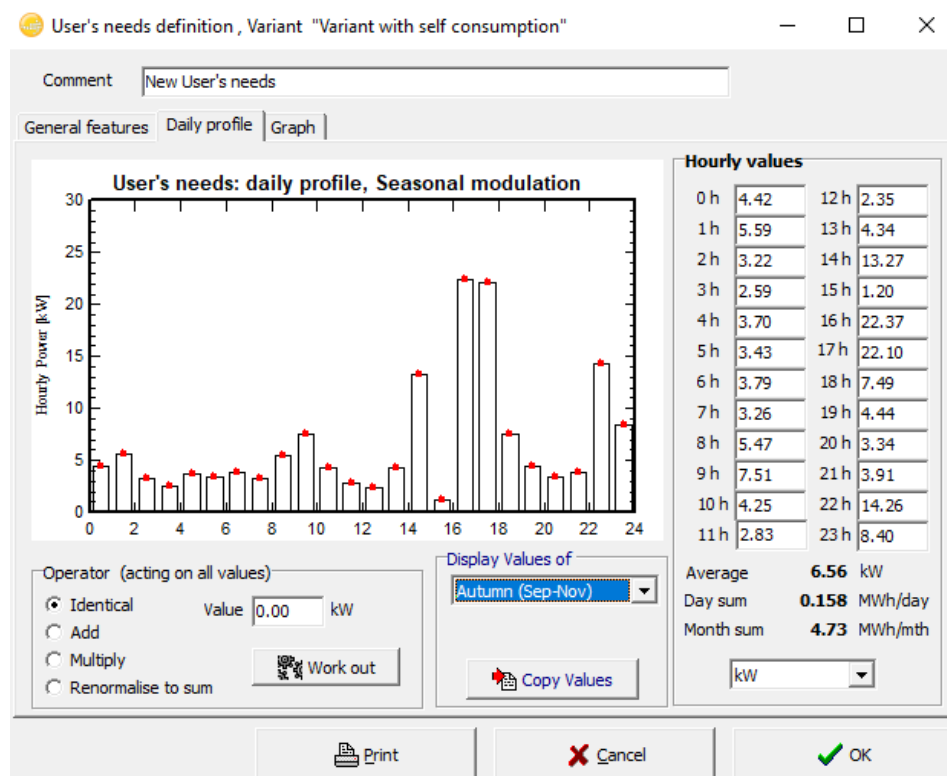
So, starting with the consumption of spring, there will be defined the others copying and multiplying them by a certain factor:



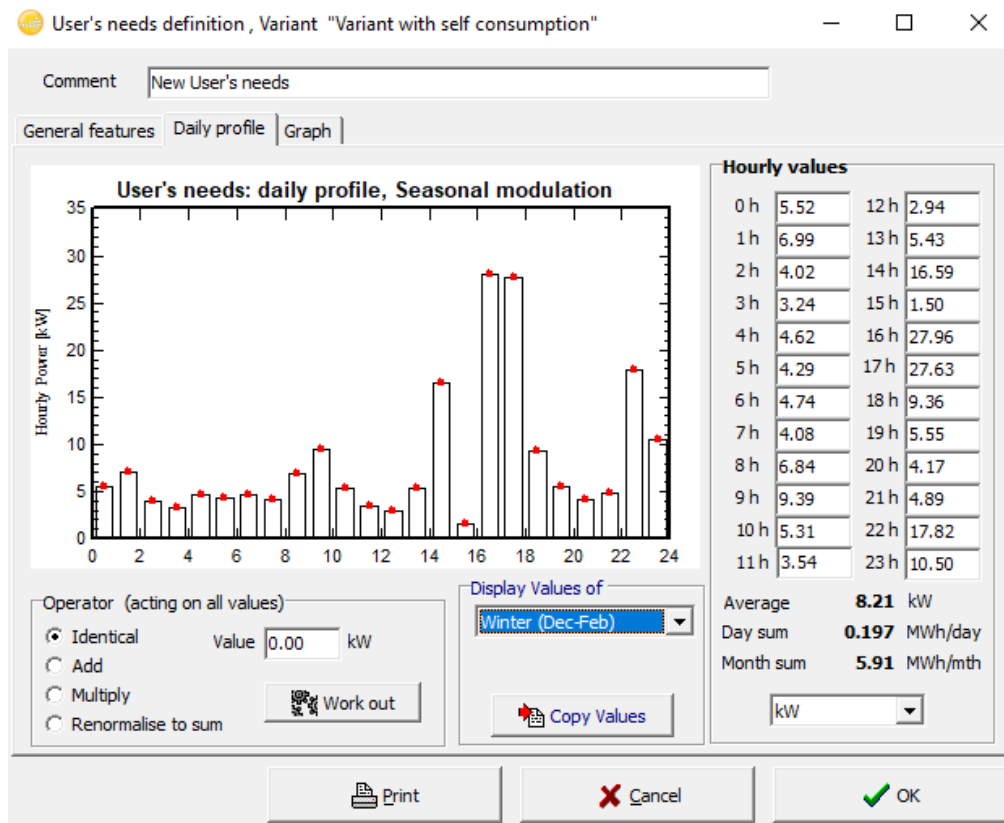
Summer needs are defined as 0.8 times spring needs.



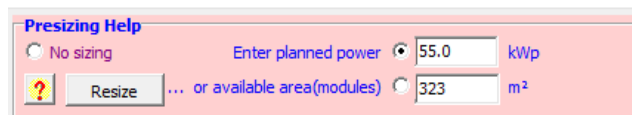
Autumn needs will be 1.2 times of spring needs.



Winter needs will be 1.5 times of spring needs.



As can be noticed the graphs along every seasons have the same shape but different scale of values. Also in this case a the PV system has a planned power of 55kWp.



Set the system in terms of: array and pre-sizing of inverter, define system components and define losses;

4. *Array and inverter pre-sizing:* typically, there is an oversizing of the PV panels' total power respect to inverter power about 10-20% because inverter allows overload. In the first time the inverter was selected as an intersection of its operative voltage with the voltage of an array of PV panels in serial connection (V_{mpp} 20 Celsius degree).

After this, the minimum voltage of a single array dependent on the higher temperature of the location (V_{mpp} 60 Celsius degree) and it has to be higher respect the minimum voltage of the inverter

The maximum voltage of a single array dependent on the minimum temperature of the location (V_{oc} -10 Celsius degree) and it has to be lower than input maximum voltage of the inverter;

5. *Define system component:*

Chosen inverter	It was given, this to have a low number of degrees of freedom in the problem
Chosen PV	It was given, this to have a low number of degrees of freedom in the problem

So, as follows:

Grid system definition, Variant "Variant with self consumption 2"

Global System configuration
 1 Number of kinds of sub-arrays
 Simplified Schema

Global system summary
 Nb. of modules 165
 Module area 329 m²
 Nb. of inverters 1
 Nominal PV Power 56.1 kWp
 Maximum PV Power 54.4 kWdc
 Nominal AC Power 50.0 kWac

PV Array
Sub-array name and Orientation
 Name PV Array
 Orient. Fixed Tilted Plane
 Tilt 35°
 Azimuth 0°

Presizing Help
☐ No sizing Enter planned power 55.0 kWp
☒ Resize ... or available area(modules) 323 m²

Select the PV module
 Available Now Filter All PV modules
 Hanwha Q Cells 340 Wp 32V Si-poly Q.PLUS L-G4.1 340 Since 2016 Manufacturer 2017
 Sizing voltages : Vmpp (60°C) 32.5 V
 Voc (-10°C) 52.2 V
☐ Use Optimizer

Select the inverter
 All inverters Output voltage 400 V Tri 50Hz
 Ingeteam 50 kW 405 - 750 V LF Tr 50/60 Hz Ingecon Sun 50 Until 2013
 Nb. of inverters 1
 Operating Voltage: 405-750 V Global Inverter's power 50.0 kWac
 Input maximum voltage: 900 V

Design the array
Number of modules and strings
 Mod. in series 15 between 13 and 17
 Nbre strings 11 between 10 and 11
 Overload loss 0.1 %
 Pnom ratio 1.12 Show sizing
 Nb. modules 165 Area 329 m²

Operating conditions
 Vmpp (60°C) 487 V
 Vmpp (20°C) 578 V
 Voc (-10°C) 782 V
 Plane irradiance 1000 W/m²
 Imp (STC) 98.9 A
 Isc (STC) 105 A
 Isc (at STC) 105 A
 Max. operating power at 1000 W/m² and 50°C 50.5 kW
 Array nom. Power (STC) 56.1 kWp

System overview Cancel OK

6. *Define losses*: will be taken in account losses to obtain more realistic results, such as the following. They will be explained losses that were added on standard losses during simulation classroom:

PV field detailed losses parameter

Ageing Thermal parameter
 Ohmic Losses
 Unavailability Module quality - LID - Mismatch
 Spectral correction Soiling Loss
 IAM Losses
 Auxiliaries

You can define either the Field thermal Loss factor or the standard NOCT coefficient: the program gives the equivalence !

Field Thermal Loss Factor
 Thermal Loss factor $U = U_c + U_v * \text{Wind vel}$
 Constant loss factor U_c 29.0 W/m²·K
 Wind loss factor U_v 0.0 W/m²·K / m/s
Default value acc. to mounting
☒ Free mounted modules with air circulation
☐ Semi-integrated with air duct behind
☐ Integration with fully insulated back

NOCT equivalent factor
 NOCT (Nominal Operating Cell temperature) is often specified by manufacturers for the module itself. This is an alternative information to the U-value definition which doesn't make sense when applied to the operating array.
 Don't use the NOCT approach. This is quite confusing when applied to an array !
 See the NOCT anyway

Losses graph Cancel OK

Thermal parameter: to take in account the type of the installation. A “free mounted” installation means that there is enough space under the PV panel to allow air flow and the best dissipation of heat than others mounting system.

PV field detailed losses parameter

Ageing		Unavailability		Spectral correction	
Thermal parameter	Ohmic Losses	Module quality - LID - Mismatch	Soiling Loss	IAM Losses	Auxiliaries

DC circuit: ohmic losses for the array

Specified by

☐ Global wiring resistance 85.8 mOhm ☐ Calculated

☒ Loss fraction at STC 1.50 % ☒ Default

Voltage Drop across series diode 0.7 V ☒ Default

AC losses after the inverter (Full system)

AC circuit: inverter to injection point

☐ Significant length, to be accounted for

Length Inverter to injection 0.0 m

Loss fraction at STC 0.00 %

Voltage drop at STC 5.2 V

External transformer

☐ External transformer present default

Iron loss (constant value) 0.00 % 0.00 kW ☐

Resistive/Inductive losses 0.00 % at STC ☐

(quadratic, $R \propto I^2$, $R = 0.0$ mOhm

☐ Night disconnect

Voltage drops across series diode: Each diode causes a voltage drop of almost 0.7 Volt. Diodes are typically used to transport electricity from one string to another.

PV field detailed losses parameter

Ageing		Unavailability		Spectral correction	
Thermal parameter	Ohmic Losses	Module quality - LID - Mismatch	Soiling Loss	IAM Losses	Auxiliaries

Module quality default

Module efficiency loss 3.0 % ☒

Deviation of the average effective module efficiency with respect to manufacturer specifications.

Module Mismatch Losses default

Power Loss at MPP 1.0 % ☒

Loss when running at fixed voltage 2.5 % ☒

Not relevant when MPPT operation

LID - Light Induced Degradation default

LID loss factor 2.0 % ☒

Degradation of crystalline silicon modules, in the first operating hours by respect to the manufacturing flash test STC values.

Strings voltage mismatch Default

Power Loss at MPP 0.1 % ☒

Light Induced Degradation: as is already shown from the software, take in account the degradation of crystalline silicon modules in the first operating hours by respect to manufacturing test in standard test condition.


PV field detailed losses parameter




Ageing Unavailability Spectral correction

Thermal parameter Ohmic Losses Module quality - LID - Mismatch Soiling Loss IAM Losses Auxiliaries

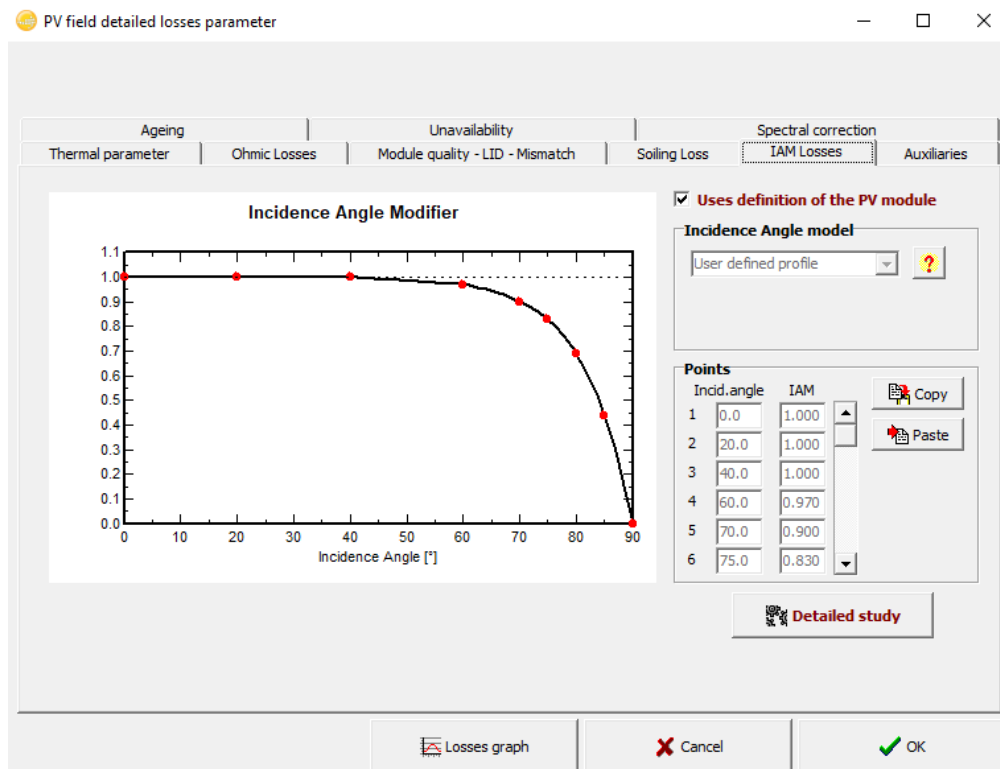
Yearly soiling loss factor

Yearly loss factor % ☒ Default

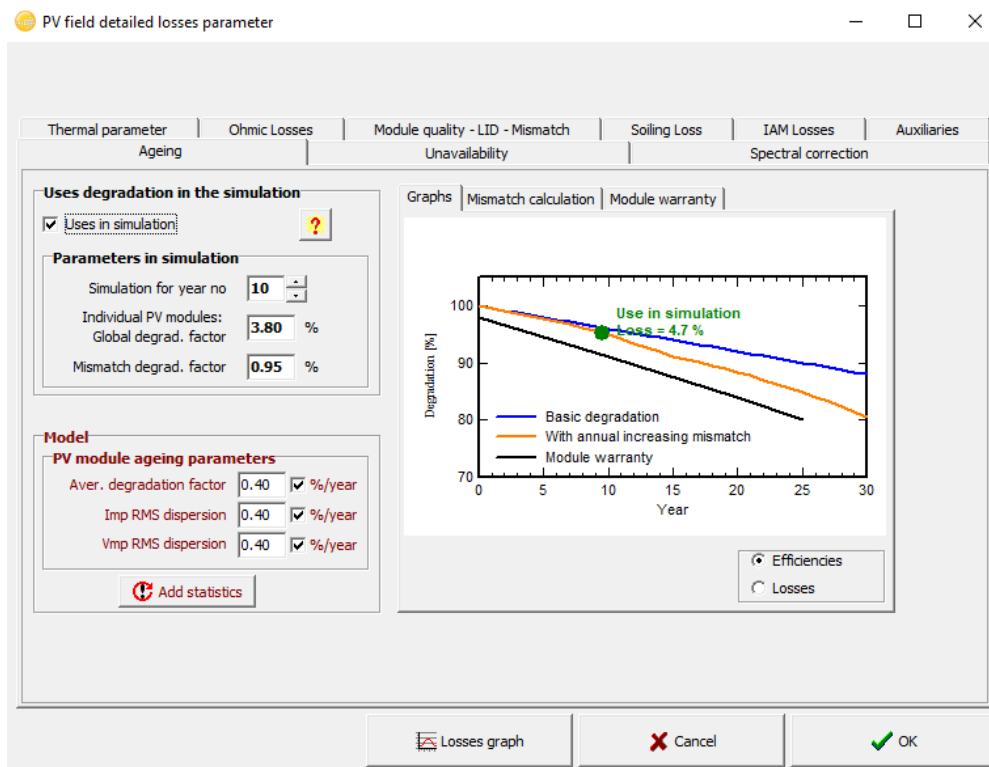
☐ Define monthly values 

 Losses graph  Cancel  OK

Yearly soiling loss factor: to take in account accumulation of dirt and its effect on the system performance of the PV panel.



Incidence Angle Modifier: to take in account the incidence effect corresponds to the decrease of the irradiance really reaching the PV cells' surface, with respect to irradiance under normal incidence. This decrease is mainly due to reflections on the glass cover, which increases with the incidence angle.



Ageing: to take in account the lost of the performance of the PV panel as time goes by. The simulation will be performed after 10 years of usage of the panel.

The window displays the 'Unavailability' tab for 'PV field detailed losses parameter'. It includes sections for 'Unavailability of the system' and 'Unavailability periods'. The 'Unavailability of the system' section shows 'Unavailability time fraction' set to 2.0 % (default), 'Unavailability duration' set to 7.30 days/yr, and 'Number of periods' set to 3. There is a 'Set Random' button and a help icon. The 'Unavailability periods' section has a table with columns 'Beginning Date / Hour' and 'duration'. The table contains three rows of data: 29/04/1990 20:00 for 58 hours, 19/08/1990 17:00 for 58 hours, and 28/11/1990 19:00 for 58 hours. The bottom of the window has buttons for 'Losses graph', 'Cancel', and 'OK'.

Beginning Date / Hour	duration
29/04/1990 20:00	58 hour
19/08/1990 17:00	58 hour
28/11/1990 19:00	58 hour

Unavailability of the system: to take in account the time while panels will be turned off for maintenance operations.

PV field detailed losses parameter

Thermal parameter	Ohmic Losses	Module quality - LID - Mismatch	Soiling Loss	IAM Losses	Auxiliaries
Ageing	Unavailability		Spectral correction		

☒ Use spectral correction in simulation

FirstSolar model

☒ According to PV module technology

C0:	0.8409000	Coefficient Set Polycrystalline Si	Default <input checked="" type="checkbox"/>
C1:	-0.0275390		
C2:	-0.0079224		
C3:	0.1357000		
C4:	0.0380240		
C5:	-0.0021218		

Meteo input Relative humidity is available in the Meteo variables. It will be used to estimate the precipitable water column

PV modules PV module model: Q,PLUS L-G4.1 340

Spectral correction: to take in account changes in the solar spectrum due to scattering and absorption in the atmosphere that changes its characteristics.

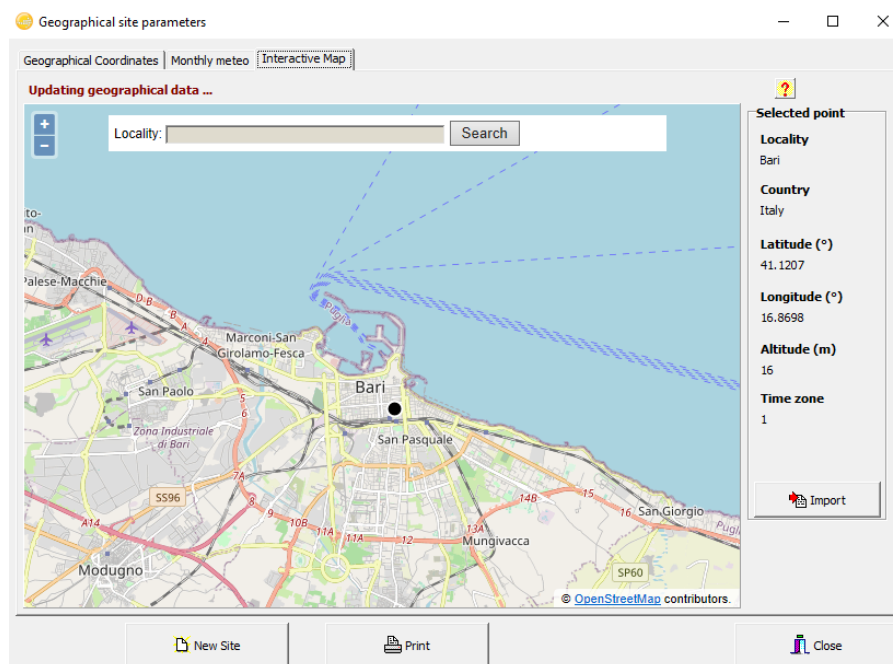
Shadow losses are not taking into the account.

INPUTS OF THE SECOND REPORT

1. Location: the location was set in Bari, the bigger country in the South of the Italy, and the meteorological values are already provided by the map of PVSyst.
2. PV system components: as an overview the system will include PV modules and inverter taken from database.
3. User's needs: a planned power of 55kWp and daily profile of consumption with a seasonal modulation.

PROCEDURE OF THE SECOND REPORT

1. *Set the project's destination (Name, Geographical location and weather file):* in this case country was not already present into the database. So, it was added during the simulation as new site;



Geographical site parameters

Geographical Coordinates | Monthly meteo | Interactive Map

Site: **Bari (Italy)**

Data source: **Meteonorm 7.2 (1986-2005, Sat=100% (Modified by user))**

	Horizontal global irradiation kWh/m².mth	Horizontal diffuse irradiation kWh/m².mth	Temperature °C	Wind Velocity m/s	Linke Turbidity [-]	Relative Humidity %
January	61.2	27.4	8.0	3.29	2.645	73.0
February	72.7	31.7	8.0	3.49	2.866	69.5
March	122.6	54.1	11.1	3.40	3.008	67.2
April	161.1	62.2	13.6	3.20	3.209	70.8
May	209.5	74.7	18.9	3.10	3.399	66.2
June	219.4	81.7	22.7	3.09	3.399	64.4
July	236.0	62.4	25.7	3.50	3.399	59.1
August	201.8	60.8	25.2	3.10	3.459	63.1
September	148.8	50.4	20.4	3.20	3.143	70.2
October	109.2	38.9	17.0	2.90	3.008	74.1
November	68.9	29.2	12.5	3.10	2.866	74.3
December	53.0	22.7	9.3	3.19	2.720	75.4
Year	1664.2	596.2	16.0	3.2	3.093	68.9

Horizontal global irradiation year-to-year variability 4.7%

Required Data

☒ Horizontal global irradiation

☒ Average Ext. Temperature

Extra data

☒ Horizontal diffuse irradiation

☒ Wind velocity

☒ Linke Turbidity

☒ Relative Humidity

Irradiation units

☐ kWh/m².day

☒ kWh/m².mth

☐ MJ/m².day

☐ MJ/m².mth

☐ W/m²

☐ Clearness Index Kt

New Site | Print | Close

2. *Set the orientation of the PV module:* as specified before the tilt and azimuth angle will be taken as the optimal, as optimization method was chosen the one that take an average between winter and summer needs (called: *yearly irradiation yield*) this because a grid connected system aims to produce all the possible energy and feed the electrical grid and not perfectly satisfy a building demand;

Orientation, Variant "New simulation with self consumption"

Field type: Fixed Tilted Plane

Field parameters

Plane Tilt: 38.0 [°]
Azimuth: 0.0 [°]

Optimization by respect to

☒ Yearly irradiation yield ?
☐ Summer (Apr-Sep)
☐ Winter (Oct-Mar)

Tilt 38°

Azimuth 0°

West East
South

Yearly meteo yield

Transposition Factor FT: 1.19
Loss By Respect To Optimum: 0.0%
Global on collector plane: 1979 kWh/m²

Show Optimization

Cancel OK

Orientation, Variant "New simulation with self consumption"

Field type: Fixed Tilted Plane

Field parameters

Plane Tilt: 38.0 [°]
Azimuth: 0.0 [°]

Optimization by respect to

☒ Yearly irradiation yield ?
☐ Summer (Apr-Sep)
☐ Winter (Oct-Mar)

Tilt 38°

Azimuth 0°

West East
South

Yearly irradiation yield graph

Year

Plane Tilt

FT_{Transpos.} = 1.19
Loss/opt. = 0.0%

Azimuth graph

Plane orientation

Cancel OK

- Set the user's need: in this case a planned power of 55kWp and the daily consumption are added like the previous case with, of course, a seasonal modulation.

Set the system in terms of: array and pre-sizing of inverter, define system components and define losses;

- Array and inverter pre-sizing:* typically, there is an oversizing of the PV panels' total power respect to inverter power about 10-20% because inverter allows overload. In the first time the inverter was selected as an intersection of its operative voltage with the voltage of an array of PV panels in serial connection (V_{mpp} 20 Celsius degree).

After this, the minimum voltage of a single array dependent on the higher temperature of the location (V_{mpp} 60 Celsius degree) and it has to be higher respect the minimum voltage of the inverter

The maximum voltage of a single array dependent on the minimum temperature of the location (V_{oc} -10 Celsius degree) and it has to be lower than input maximum voltage of the inverter;

- Define system component:*

Chosen inverter	It was given, this to have a low number of degrees of freedom in the problem
Chosen PV	It was given, this to have a low number of degrees of freedom in the problem

So, as follows:

Grid system definition, Variant "New simulation with self consumption"

Global System configuration
1 Number of kinds of sub-arrays
Simplified Schema

Global system summary
Nb. of modules 165 Nominal PV Power 56.1 kWp
Module area 329 m² Maximum PV Power 52.6 kWdc
Nb. of inverters 1 Nominal AC Power 50.0 kWac

PV Array

Sub-array name and Orientation
Name PV Array
Orient. Fixed Tilted Plane
Tilt 38°
Azimuth 0°

Presizing Help
No sizing Enter planned power 55.0 kWp
Resize ... or available area(modules) 323 m²

Select the PV module
Available Now Filter All PV modules Approx. needed modules 162
Hanwha Q Cells 340 Wp 32V Si-poly Q.PLUS L-G4.1 340 Since 2016 Manufacturer 2017 Open
Sizing voltages : Vmpp (60°C) 32.5 V
Voc (-10°C) 52.2 V
Use Optimizer

Select the inverter
All inverters Output voltage 400 V Tri 50Hz 50 Hz
Ingeteam 50 kW 405 - 750 V LF Tr 50/60 Hz Inoecon Sun 50 Until 2013 60 Hz Open
Nb. of inverters 1 Operating Voltage: 405-750 V Global Inverter's power 50.0 kWac
Input maximum voltage: 900 V

Design the array
Number of modules and strings
Mod. in series 15 between 13 and 17
Nb. strings 11 between 10 and 11
Overload loss 0.0 % Show sizing
Pnom ratio 1.12
Nb. modules 165 Area 329 m²

Operating conditions
Vmpp (60°C) 487 V
Vmpp (20°C) 578 V
Voc (-10°C) 782 V
Plane irradiance 1000 W/m²
Imp (STC) 98.9 A
Isc (STC) 105 A
Isc (at STC) 105 A
Max. operating power at 1000 W/m² and 50°C 50.5 kW
Array nom. Power (STC) 56.1 kWp

System overview Cancel OK

- Define losses: will be taken in account losses to obtain more realistic results, such as: *Thermal parameter, Voltage drops across series diode, Light Induced Degradation, Yearly soiling loss factor, Yearly soiling loss factor, Incidence Angle Modifier, Ageing, Unavailability of the system and Spectral correction*. They will be the same as the losses of the first project.

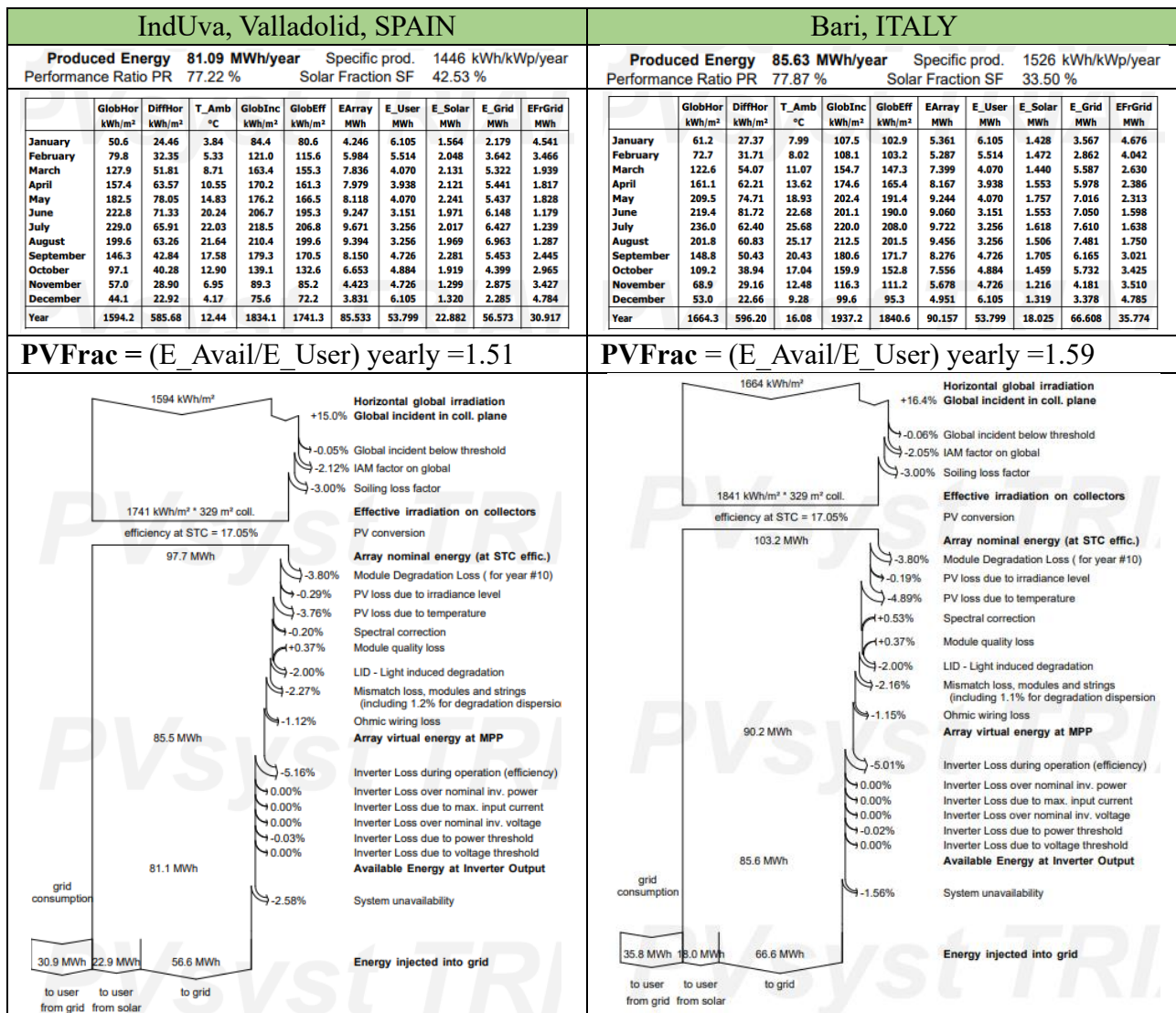
OUTPUTS

The main important results are, the same of the previous report and some **new**:

1. Produced energy;
2. Specific production: The produced energy divided by the Nominal power of the array (P_{nom} at STC). This is an indicator of the potential of the system, taking into account irradiance conditions (orientation, site location, meteorological conditions).
3. Performance Ratio: is the ratio of the energy effectively produced (used), with respect to the energy which would be produced if the system was continuously working at its nominal STC efficiency. Unlike the "Specific energy production" indicator, expressed in [kWh/kWp/year], this indicator is not directly dependent on the meteo input or plane orientation. This allows the comparison of the system quality between installation in different locations and orientations;
4. **Solar fraction**: is the division of Energy Solar by Energy Available, that mean the average between the energy produced by PV modules and used by users without excess and the energy present at the exit of the inverter (so, what PV modules produce taking into account losses until the energy reaches the inverter). If it is equal to 1 all the needs are covered by PV panels.
5. **Balances and main results**: this table shows parameters as follow:

E_Avail	The PV produced energy (output of the inverter, after eventual AC losses)
E_User	The energy needs (consumed by the user)
E_Grid	The excess energy injected into the grid,
EfrGrid	The energy drawn from the grid for the internal consumption (when PV is not sufficient), and during night.
E_Solar	$(E_User - EfrGrid)$ The PV energy internally consumed.
SolFrac	(E_Solar / E_User) Ratio of the user's consumption covered by the solar production
PVFrac	(E_Avail / E_User) Ratio between annual user's consumption and annual solar production.

6. **Loss diagram over the whole year**: that allow us to recognize the most affecting losses on our systems and now, it displays some other information like: the amount of energy taken from the grid to the user, the amount of energy taken from the PV modules to the users and the amount of energy taken from the PV modules to the grids as unused from the users.



Comparing the two locations only by the higher value of specific energy production, Bari is the best location for this type of system because of higher value of horizontal global and horizontal diffuse irradiation.

Taking into the account the performance ratio: Bari is also the best location because of a higher value of performance ratio independently of meteo input or plane orientation.

But, looking for losses, Bari has the higher losses due to the temperature. This is maybe because the colder temperature reached in Valladolid morning allows the PV modules to work better instead higher average temperature in the south of the Italy.

The previous results converge in better working condition for Valladolid instead Bari. In fact, Valladolid has a better value of Solar Fraction than Bari despite in all the other values it has lower performance.

For example, the PVFrac is higher in Bari than Valladolid and is more than 1. It doesn't mean that Bari's installation covers all the needs because it is a yearly evaluation and this covering doesn't happen every time on every day. So, is better to evaluate the Solar Fraction as done before. This value will never be equal to one, without batteries, because of the high needs simulated during the night when PV modules not work.