ENERGY YIELD REPORT

PV Plant Webinar Amperecloud
2024/10/29

Prepared for: Amperecloud

DISCLAIMER

This report ("Report") is provided by Rated Power S.L. ("RatedPower") for the use of the Client, which has entered into a separate written agreement with RatedPower. However, RatedPower makes no representations or warranties of any kind, expressed or implied, as to the accuracy, completeness, suitability or reliability of the Report, and shall not be liable or responsible for any damages of any kind arising out of or in connection with the Client's use of the Report.Client may provide RatedPower with its logo for its placement in the Report. The Client represents and warrants that it has all necessary rights and permissions to use and include the logo in the Report, and shall hold RatedPower harmless from any claim deriving from the use of any such logo in the Report.

TABLE OF CONTENTS

1. INTRODUCTION

The purpose of this report, produced by RatedPower, is to describe the methodology used to compute the energy yield of the photovoltaic plant and present the results obtained.

A summary of these results is provided in Table 1.

Table 1. Summary of the results.

Description	Value
Solar resource	
Global horizontal irradiance	1888.4 kWh/m2
Average temperature	18.13 °C
Data source	PVGIS
Energy yield (year 1)	
Specific production	2155.3 kWh/kWp
Performance ratio	86.40 %
Energy injected to grid	78.42 GWh
Nighttime consumption	-272.85 MWh
Net energy yield	78.2 GWh
Energy yield (25 years average)	
Specific production	2092.2 kWh/kWp
Energy yield	1903.2 GWh
Performance ratio	83.87 %

The energy yield results were computed considering all the losses incurred up to and including the substation level.

The main features of the photovoltaic plant are shown in Table 2.

Table 2. Project Characteristics

Webinar Amperecloud Project	
Location	Spain, Andalucía
Rated power (AC)	30.0 MWac
Peak power (DC)	36.4 MWdc
Ratio DC/AC	1.21
Structure type	One-axis tracker
PV Modules (610.0 Wp)	59650
Power station (up to 4620.0 kW)	7
Number of inverters (up to 2310.0 kVA)	13
Suitable plot area	54.15 ha

The complete layout is shown in Figure 1.

Figure 1. General layout

2. SITE

2.1. Location

The PV Plant location has the characteristics shown in Table 3

Table 3. Location characteristics

PV Plant location characteristics	
City / Town	Carboneras
Region	Andalucía
Country	Spain
Latitude	+36.99 °
Longitude	-2.04 °
Altitude	204.79 m a.m.s.l.
Timezone	UTC +1

The project location is shown in Figure 2. A closer view of the region is shown in Figure 3.

Figure 2. Location of PV Plant in the region of Andalucía, in Spain

Figure 3. Closer view of the PV plant in the region of Andalucía

2.2. Plot Areas

The area where the PV plant is to be built consists of 4 available areas, with a total surface area of 54.15 ha.

The size of each area and the total suitable area for installation purposes is shown in Table 4.

Table 4. Size of plot areas of the project.

Area name	Surface
Available areas	
Area 1	5.59 ha
Area 2	12.03 ha
Area 3	27.12 ha
Area 4	9.68 ha
Interconnection facility areas	
ST	
Area 1	0.28 ha
Total available area	**54.15 ha**

The substation(s), the plot area(s) and, if any, the restricted area(s) are shown in Figure 4.

Figure 4. Plot Areas of the Webinar Amperecloud PV Plant

2.3. Topography

A preliminary terrain topography analysis was performed to study the suitability of the terrain for the construction of a photovoltaic plant. The North-South and East-West slopes were calculated and are shown in Figure 5.

The elevation data was uploaded by the user in CSV (XYZ) format.

The analysis of the terrain slopes results in three differentiated areas:

- Zones where the slope is lower than 5.00 %.
- Zones where the slope is between 5.00 % and 10.00 %.
- Zones where the slope is greater than 15.00 %.

NOTE: The slopes measured on site when performing a detailed topographical analysis could be greater than the slopes obtained using this analysis.

The map shown in the Figure 5 represents the slopes of the terrain, with the following colors representing:

- Slopes <5.00 %
- Slopes >5.00 % and <10.00 %
- Slopes >10.00 % and <15.00 %
- Slopes >15.00 %

Using the previously mentioned elevation data, the position of the mounting structures in the terrain was calculated. The slope of the terrain in the North-South and East-West directions under the structures was calculated. The position of the structure posts was also calculated, including ground elevation and post height.

For some structures, earth works were performed to adequate the terrain to the limits set by the mounting structure manufacturer. The conditions required to perform earth works were as follows:

- The slope in the North-South direction is between 25.00 % and 15.00 %.
- The slope in the East-West direction is between 20.00 % and 10.00 %.

The structures which did not meet the following requirements were removed from the layout:

- The structure must be within the bounds of the Digital Elevation Model (DEM).
- The slope of the structure in the North-South direction must be lower than 15.00 %.
- The slope of the structure in the East-West direction must be lower than 10.00 %.

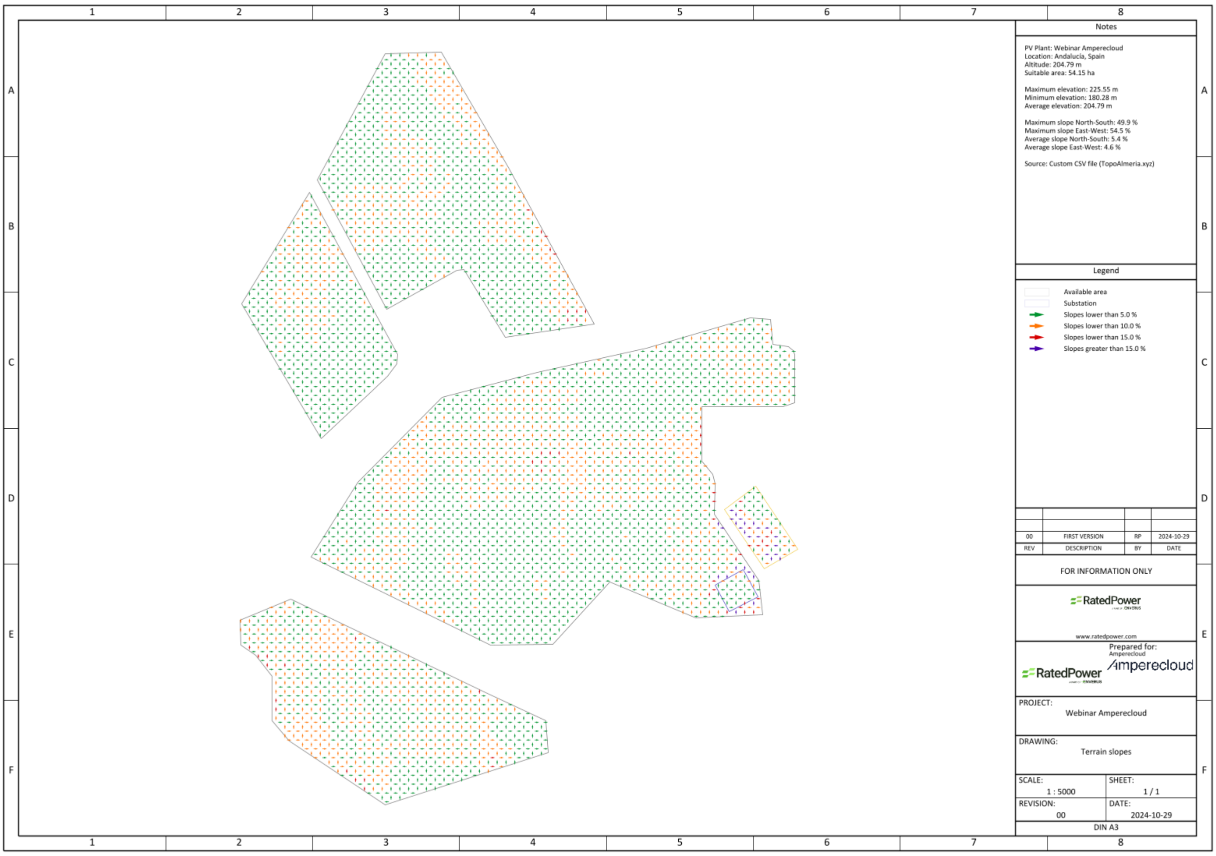

Figure 5. Slopes of the plot areas (source: SRTM)

The north-south direction is considered to be the direction parallel to the axis of the structure (row slope). The east-west direction is considered to be the direction perpendicular to the axis of the structure (pitch slope). Rotating the layout may have an impact in the topography analysis, due to the rotation of the axis of the structure.

2.4. Horizon profile

The solar irradiance reaching the photovoltaic modules will change if there are hills or mountains on the horizon. These physical obstructions will block the beam component of the irradiance during some periods of the day and will have an impact on the diffuse component as well. Therefore, the horizon profile directly impacts the energy yield of the photovoltaic plant.

The horizon line has an average elevation of 1.9° and a maximum elevation of 3.4°. Throughout the year, the Sun will be blocked by the horizon line for a total of 126 hours. The data source for the horizon line was PVGIS 5.2.

The blocked elevations over the complete azimuth range are shown in Figure 6.

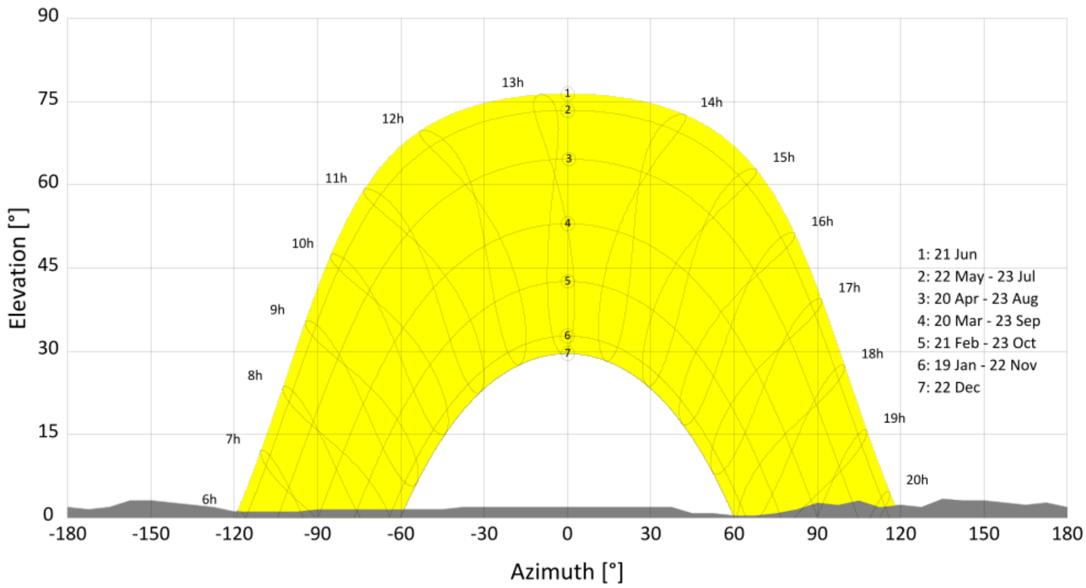

Figure 6. Horizon profile (data source: PVGIS 5.2)

3. SOLAR RESOURCE

3.1. PVGIS data source

PVGIS has been in continuous development for more than 10 years at the European Commission Joint Research Centre. The focus of PVGIS is solar resource assessment research, photovoltaic (PV) performance studies, and the dissemination of knowledge and data about solar radiation and PV performance.

The latest version of PVGIS (PVGIS 5.2) has extended the capabilities of the system and improved the coverage of the meteorological database. PVGIS 5.2 uses PVGIS-SARAH-2, PVGIS-NSRDB and PVGIS-ERA5 databases.

The main features of the PVGIS 5.2 database are:

- Source: satellite.
- Spatial coverage: Worldwide.
- Time period: at least ten years starting in 2005 or 2006 depending on the region.
- Spatial resolution: site dependent, with an average value of 4 km x 4 km.
- Temporal resolution: hourly.
- Uncertainty: site dependent, ±3% to ±10% on average.

In Figure 7 the spatial coverage of the PVGIS 5.2 database is shown.

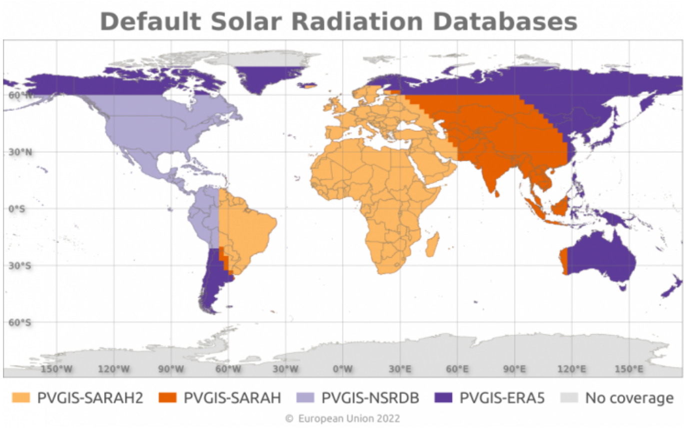

Figure 7. Spatial coverage of the PVGIS 5.2 database.

The solar irradiance data of PVGIS has been calculated using satellite data. There are three satellite databases available:

- PVGIS-SARAH-2 is a database based on data provided by the EUMETSAT CM SAF. It uses the images of the METEOSAT geostationary satellites covering Europe, Africa and Asia. The temporal period is 2005 to 2020.
- PVGIS-NSRDB is a collaboration between PVGIS and the NREL (National Renewable Energy Laboratory), and it consists of the implementation of the NSRDB in PVGIS. The temporal period is from 2005 to 2015.

- PVGIS-ERA5 is a reanalysis product from ECMWF, combining historical observations into global estimates using advanced modelling and data assimilation sysetms. It provides coverage in areas where there is no satellite data, such as some parts of South America, Australia, and Japan. The temporal period is 2005 to 2020.
- PVGIS-SARAH-1 is a database based on a new algorithm developed by CM SAF. It provides coverage in Asia. The temporal is from 2005 to 2016.

3.2. Typical Meteorological Year (P50)

The Typical Meteorological Year (TMY) is a set of representative values of any given meteorological parameter, for some given location. It is given in hourly resolution and is derived from long-term meteorological data.

In Table 5 a monthly summary of the TMY data is shown. A chart representing the data of Table 5 is shown in Figure 13

Table 5. TMY monthly irradiation and temperature.

Month	GHI [kWh/m2]	DHI [kWh/m2]	Temperature
1	90.3	28.3	11.95 °C
2	96.2	36.4	13.29 °C
3	159.5	50.2	14.15 °C
4	160.8	66.1	14.6 °C
5	227.7	64.3	20.68 °C
6	236.6	64.3	23.01 °C
7	248.9	62.8	25.5 °C
8	210.1	62.6	25.29 °C
9	166.4	53.5	23.29 °C
10	117.0	46.3	18.51 °C
11	94.9	30.4	15.58 °C
12	79.9	25.0	11.36 °C
Year	**1888.4**	**590.1**	**18.1 °C**

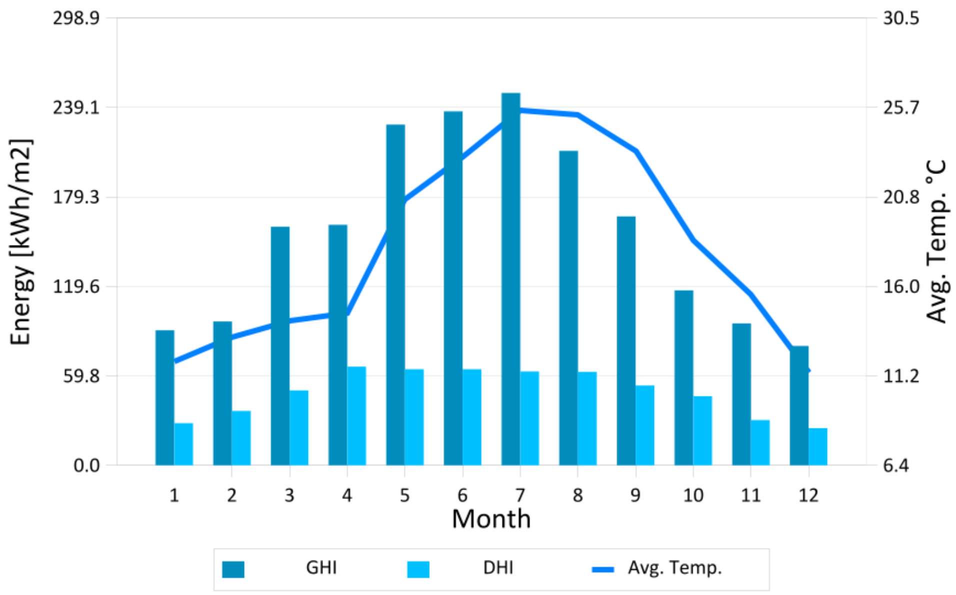

Figure 8. Solar resource chart

3.3. Surface albedo

The surface albedo data used in the simulation was obtained from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor, which is a key instrument aboard the NASA Terra and Aqua satellites.

The data has a monthly temporal resolution and is derived from long term measurements taken from 2000 to 2017. The albedo value for each month is the average of all the available data values for that month.

The spatial resolution is 0.1 degrees in latitude and 0.1 degrees in longitude, which is equivalent to a grid of 11x11km at the equator. At locations further from the equator, the resolution in kilometers increases.

The average albedo value for the whole year was 16.95 %. The monthly albedo values are shown in Table 6.

Table 6. Monthly albedo values

Monthly albedo values	
January	16.34 %
February	16.59 %
March	16.67 %
April	16.70 %
May	17.03 %
June	17.59 %
July	17.99 %

August	18.09 %
September	17.36 %
October	16.78 %
November	16.19 %
December	16.07 %
Yearly mean value	**16.95 %**

4. DESCRIPTION OF THE PV PLANT

4.1. General description

The rated power of the PV Plant is 30.0 MWac and the Peak Power is 36.4 MWdc resulting in a DC/AC ratio of 1.21. The present description of the project could be subject to changes in the next stages of the project development. The main characteristics of the project are shown in Table 2.

The main equipment used to convert the solar energy to electricity is:

- Photovoltaic modules, which convert the solar radiation into direct current.
- The single-axis tracker, which supports and orients the PV modules to minimize the angle of incidence between the incoming sun rays and the PV modules surface during the day.
- The string combiner boxes, which consolidate the output of the strings of photovoltaic modules before reaching the inverter.
- Central inverters, which convert DC from the solar field to AC.
- Power Transformers, which raise the voltage level from low to medium.
- Power Stations, which hold the necessary equipment to convert the DC power to AC.

4.2. Photovoltaic module

The selected photovoltaic module is the General610 Bifacial model, manufactured by Generic (default). It has a peak power of 610.0 W, and the technology of the cells is Si-mono.

The features of the photovoltaic module are shown in Table 7.

The module has a bifaciality factor of 80.00 %.

Table 7. Photovoltaic module characteristics

Photovoltaic module characteristics	
Main characteristics	
Module model	General610
Manufacturer	Generic (default)
Technology	Si-mono
Type of module	Bifacial
Maximum voltage	1500 V
Standard test conditions (STC)	
Peak power	610.0 W
Efficiency	21.85 %
MPP voltage	45.7 V
MPP current	13.37 A
Open circuit voltage	55.3 V

Short circuit current	14.03 A
Temperature coefficients	
Power coefficient	-0.300 %/°C
Voltage coefficient	-0.278 %/°C
Current coefficient	0.046 %/°C
Mechanical characteristics	
Length	2465.0 mm
Width	1134.0 mm
Thickness	30.0 mm
Weight	34.6 kg

An example picture of a Bifacial Si-mono module is shown in Figure 9.

Figure 9. Example of a Bifacial Si-mono photovoltaic module

4.3. Single axis N-S tracker

The PV solar modules will be mounted on North-South oriented one-axis solar trackers, integrated on metallic structures combining galvanized steel and aluminum parts, forming a structure fixed to the ground. An example of a single-axis tracker is shown in Figure 10.

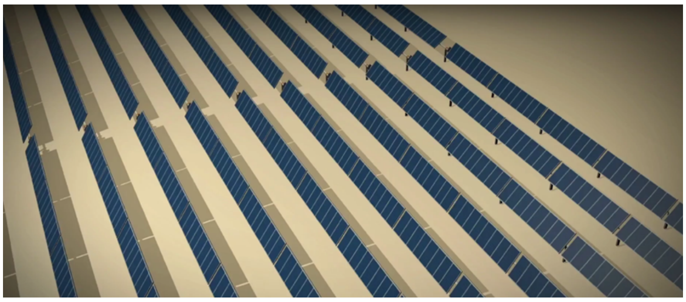

Figure 10. Example of single-axis tracker

Single-axis trackers are designed to minimize the angle of incidence between the incoming sun rays and the photovoltaic panel plane of array. The tracking system consists of an electronic device capable of following the sun through the day. The main features of the tracking system are summarized in Table 8.

Table 8. Main characteristics of the single-axis trackers

Single-axis tracker characteristics	
Model	Generic tracker
Manufacturer	Generic (default)
Technology	Single-row
Configuration	1P (Portrait)
Tracking angle limits	+60 / -60 °
Number of modules per row	50 modules (maximum 60 modules)
Minimum ground clearance	0.5 m
Designed for	MONOFACIAL modules
Motor gap	0.0 mm
Torque beam gap	0.0 mm
Gap between modules in the axis direction	20.0 mm
Gap between modules in the pitch direction	0.0 mm

The number of single-axis trackers installed are summarized in Table 9.

Table 9. Number of single-axis trackers installed

Strings per structure	Modules per structure	Length	Quantity
2	50	57.68 m	1017
1	25	28.83 m	352

Additional structure information can be found in Table 10.

Table 10. Civil Characteristics

Area Name	Pitch	Clearance	GCR	Distance between consecutive	Azimuth angle	Tilt angle

			rows			
Area 2	6.2 m	3.74 m	39.76%	0.5 m	0.0 °	[-]
Area 4	6.2 m	3.74 m	39.76%	0.5 m	0.0 °	[-]
Area 3	6.2 m	3.74 m	39.76%	0.5 m	0.0 °	[-]
Area 1	6.2 m	3.74 m	39.76%	0.5 m	0.0 °	[-]

The details for the low voltage electrically grouped areas are shown in Table 11.

Table 11. Electrical configuration characteristics per group of areas

Group of Areas	Rated Power	Peak Power	DC/AC Ratio
Area4	4620.0 kWac	6222.0 kWdc	1.35
Area3	16.2 MWac	18.8 MWdc	1.17
Area2, Area1	9240.0 kWac	11.3 MWdc	1.22

4.4. String combiner box

The string boxes collect the power generated by the DC array, connect the strings in parallel to the inverter, and provide electrical protection to the PV field. To match the number of inputs of the inverters, several parallel strings will be concentrated to function as a single circuit. Junction boxes shall be installed with a fuse per string to protect each array. Overvoltage DC dischargers will be installed, and one DC switch will be situated in the output line. Additionally, a communication system may be installed to monitor the string current and voltage.

An example of a string box is shown in Figure 11.

Figure 11. Example string box (Schneider Electric)

The string boxes will be installed in a shaded area and shall be easily accessible to facilitate maintenance. They will be placed behind the PV modules and use existing structure poles if possible, so that they remain shaded and to prevent damage caused by rainwater or other meteorological phenomena.

The main features of the string box are shown in Table 12.

Table 12. Main string box characteristics

String box	Quantity	Inputs	Power	Fuse Current	Switch current	Overvoltage Arrester
1	116	16 string	244.0 kW	25 A	315 A	Yes
2	19	8 string	122.0 kW	25 A	315 A	Yes
3	13	15 string	228.8 kW	25 A	315 A	Yes
4	9	10 string	152.5 kW	25 A	315 A	Yes
5	7	9 string	137.3 kW	25 A	315 A	Yes
6	1	7 string	106.8 kW	25 A	315 A	Yes
7	1	12 string	183.0 kW	25 A	315 A	Yes
8	1	11 string	167.8 kW	25 A	315 A	Yes

4.5. Central inverter

The inverter converts the direct current produced by the photovoltaic modules to alternating current. It is composed of the following elements:

- One or several DC-to-AC power conversion stages, each equipped with a maximum power point tracking system (MPPT). The MPPT will vary the voltage of the DC array to maximize the production depending on the operating conditions.

- Protection components against high working temperatures, over or under voltage, over or under-frequencies, minimum operating current, mains failure of transformer, anti-islanding protection, protection against voltage gaps, etc. In addition to the protections for the safety of the staff personnel.
- A monitoring system, which has the function of relaying data regarding the inverter operation to the owner (current, voltage, power, etc.) and external data from monitoring of the strings in the DC array (if a string monitoring system is present).

In Figure 15 a commonly used photovoltaic inverter for utility-scale PV plants is shown.

Figure 12. Example of central photovoltaic inverter (ABB)

The main characteristics of the selected inverter are shown in Table 13.

Table 13. Inverter characteristics

Inverter characteristics	
Main characteristics	
Inverter model	Generic 2310
Inverter type	CENTRAL
Manufacturer	Generic (default)
Maximum DC to AC conversion efficiency	98.72 %
Input side (DC)	
MPPT search range	891 - 1310 V
Maximum input voltage	1500 V
Output side (AC)	
Rated power	2310.0 kVA
Maximum Power (datasheet)	2310.0 kVA
Nominal Power (datasheet)	2310.0 kVA
Output voltage	630 V
Output frequency	50 Hz

Table 14. Inverters

Inverter	Quantity	DC inputs	Power DC	DC/AC ratio
Generic 2310 (2310 kWac)	2	1 String Box of 15 string 1 String Box of 10 string 3 String Box of 8 string 8 String Box of 16 string	2699 kW	1.169
Generic 2310 (2310 kWac)	2	1 String Box of 9 string 1 String Box of 8 string 1 String Box of 15 string 9 String Box of 16 string	2684 kW	1.162
Generic 2310 (2310 kWac)	1	1 String Box of 8 string 1 String Box of 10 string 1 String Box of 12 string 10 String Box of 16 string 1 String Box of 15 string	3126 kW	1.353
Generic 2310 (2310 kWac)	1	1 String Box of 11 string 12 String Box of 16 string	3096 kW	1.340
Generic 2310 (2310 kWac)	1	1 String Box of 8 string 2 String Box of 9 string 10 String Box of 16 string	2837 kW	1.228
Generic 2310 (2310 kWac)	1	1 String Box of 15 string 1 String Box of 9 string 1 String Box of 8 string 1 String Box of 10 string 9 String Box of 16 string	2837 kW	1.228
Generic 2310 (2310 kWac)	1	2 String Box of 10 string 7 String Box of 16 string 1 String Box of 8 string 3 String Box of 15 string	2821 kW	1.221
Generic 2310 (2310 kWac)	1	1 String Box of 9 string 1 String Box of 10 string 1 String Box of 8 string 2 String Box of 15 string 8 String Box of 16 string	2821 kW	1.221
Generic 2310 (2310 kWac)	1	1 String Box of 9 string 2 String Box of 8 string 1 String Box of 10 string 1 String Box of 15 string 8 String Box of 16 string	2715 kW	1.175

Generic 2310 (2310 kWac)	1	1 String Box of 10 string 2 String Box of 8 string 1 String Box of 7 string 9 String Box of 16 string	2699 kW	1.169
Generic 2310 (2310 kWac)	1	1 String Box of 15 string 2 String Box of 8 string 9 String Box of 16 string	2669 kW	1.155

4.6. Power transformer

The power transformer raises the voltage of the inverter AC output to achieve a higher efficiency transmission in the power lines of the photovoltaic plant. An example of a power transformer is shown in Figure 13.

Figure 13. Example of power transformer

4.7. Power Station

The power stations or transformer stations are indoor buildings or containers. The voltage of the energy collected from the solar field is increased to a higher level to facilitate the evacuation of the generated energy.

The inverters and power transformers will be housed in the power station.

An example of an Indoors power station is shown in Figure 14.

Figure 14. Example of an Indoors power station

The power station shall be supplied with medium voltage switchgears that include one transformer protection unit, one direct incoming feeder unit, one direct outcoming feeder unit and electrical boards. Particularly, for the first power station of each MV line, a direct incoming unit will not be installed.

The common features of the power stations are shown in Table 15.

Table 15. Power station common characteristics

Power station characteristics	
Voltage ratio	0.63/20.0kV
Transformers cooling system	ONAN
Transformers tap changer	2.5%, 5%, 7.5%, 10%
Service	Indoors

The characteristics of the different power stations according to their AC configuration are shown in Table 16.

Table 16. Power stations according to the AC configuration

Power stations	Quantity	Num Inverters	Transformers configuration	Short circuit (Zcc)
1	6	2(4.62 MVA)	1 two-winding transformer of 4.62 MVA	0.080
2	1	1(2.31 MVA)	1 two-winding transformer of 2.31 MVA	0.080

The different types of power stations according to the DC field associated to them are shown in Table 17.

Table 17. Power stations according to the DC field

Power stations	Quantity	Num Inverters	Power AC	Power DC	DC/AC ratio
1	1	2	4.62 MW	6.222 MW	1.347
2	1	2	4.62 MW	5.658 MW	1.225
3	1	2	4.62 MW	5.658 MW	1.225
4	1	2	4.62 MW	5.383 MW	1.165
5	1	2	4.62 MW	5.383 MW	1.165
6	1	2	4.62 MW	5.368 MW	1.162
7	1	1	2.31 MW	2.714 MW	1.175

5. CALCULATION METHODOLOGY

The methodology used to compute the energy yield is described in the ENERGY YIELD METHODOLOGY document, available in the following link:

Download the energy methodology report

The methodology requires the following inputs:

- The typical meteorological year.
- The parameters of the electrical equipment to be used.
- The electrical configuration of the photovoltaic plant.
- Simulation parameters such as losses or calculation settings.

With these inputs the following steps are performed sequentially to compute the final value of the energy yield:

- The transposition of the radiation components to the tilted plane.
- Using a library to compute the sun position.
- The sun-tracking algorithm used in single-axis trackers (backtracking).
- Computation of the effects of shadows on the irradiance received by a tilted plane.
- Electrical generation of a photovoltaic module being irradiated, and its associated losses.
- Estimating the effect of partial shading on strings of modules.
- Performance of an electrical inverter and window of operation.
- Electrical losses in a utility-scale photovoltaic plant.

6. LOSSES

6.1. Transposition of GHI to the plane of array

The irradiance seen by the plane of array is computed by transposition of the global horizontal irradiance to the tilted plane. Because of the tilt angle, the transposition results in an irradiance gain with respect what would be received by a horizontal plane. This gain will be greater if the mounting structure is sun-tracking.

The transposition to the plane of array for the front-face resulted in a gain of +32.10 %.

In the back-face, the ground reflected irradiance was transposed to the tilted plane of array. The tilted plane also perceives diffuse and beam irradiance. The transposition resulted in a gain of +12.96 %.

6.2. Ground shades effect in the back-face

The shades cast on the ground by the structures result in a loss of irradiance for the back-face. Parameters such as the pitch distance between structures, the minimum ground clearance and the transparency fraction affect the value of this loss.

A value of 0.00 % was considered to model the transparency of the photovoltaic module and the mounting structure.

The loss due to the ground shades was of -59.96 %.

6.3. Far shading

The presence of obstacles in the horizon line (such as hills or buildings) will negatively impact the irradiance reaching the photovoltaic modules. This will occur in the times of day when the sun elevation is lower. An obstacle is usually considered to be part of the horizon profile if the size of its shade is more than ten times greater than the size of the photovoltaic plant.

The far shading loss is computed against a hypothetical plant with no horizon obstacles. In Figure 15 the horizon profile of the photovoltaic plant is shown.

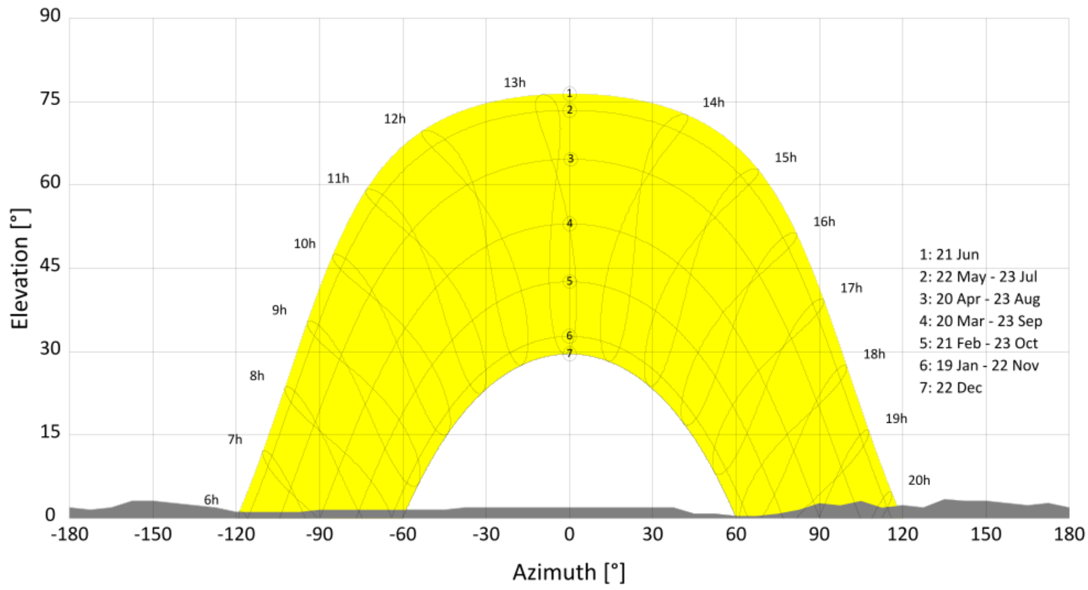

Figure 15. Horizon profile (source: PVGIS).

This horizon profile results in front-face irradiance loss of -0.36 %.

In the back-face, the horizon profile is only considered for the beam component shading, which results in a loss of 0.00 %.

6.4. Near shading

Contiguous rows of photovoltaic modules will block the sunlight to nearby rows whenever the sun elevation is low. These shades will negatively impact the irradiance received by the photovoltaic modules.

The yearly loss due to front-face near shadings was of -2.40 %. It was caused due to the shades cast from one structure to the next.

The back-face near shading loss was caused by the ground reflected irradiance blocked by the structures themselves, and by the torque beam. Its value was of -13.69 %.

6.5. Soiling

The deposition of dirt and dust on the surface of the module causes a direct loss of irradiance known as soiling loss. This impact is greater for oblique sun rays than for perpendicular rays.

The soiling loss is easily minimized by regularly cleaning the photovoltaic modules. It also is reduced whenever the atmospheric conditions result in the removal of dirt from their surface (through rain or wind). However, in transient conditions of high pollution the loss may be as high as 8 %, e.g. in between cleaning operations. Other conditions which influence the soiling loss are the proximity of roads, the terrain characteristics, or the tilt angle of the modules.

The front-face soiling loss is modeled as an average value constant throughout the whole year, with a value of -2.00 %.

The back-face soiling is modeled as an average value constant throughout the whole year, with a value of 0.00 %.

6.6. IAM effect

A loss is incurred due to the non-zero angle of incidence of the sun rays on the plane of array, in addition to the cosine effect. A fraction of the light reaching the surface of the modules is reflected by the glass cover protecting them. This loss is computed using an Incidence Angle Modifier (IAM) coefficient, which is a function of the glass used.

The front face glass was modeled according to the manufacturer specifications, using a custom IAM profile found in the PAN file.

The back-face glass was modeled using the air-glass model for normal glass, with an index of refraction value of 1.526 (n parameter).

The losses due to the IAM effect caused by the front-face glass were of -0.22 %, and the back-face glass caused a loss of -7.83 %.

6.7. Photovoltaic module degradation

An initial degradation of the module performance occurs in the first hours of exposure to sunlight, known as the Light Induced Degradation loss (LID).

However, after this initial degradation, a more long-term process takes place which results in a yearly loss of performance.

This degradation occurs due to corrosion of the conductors and a gradual failure of the back-sheet seal of the module. Atmospheric conditions such as high temperature swings, rain, ambient humidity, and salinity may accelerate the corrosion.

The value of the yearly degradation considered was -0.30 % for the first year of operation, and -0.30 % for subsequent years.

6.8. Irradiance level

The loss due to the irradiance level refers to the lower production of the photovoltaic module whenever the irradiance is lower than 1000 W/m2 (STC conditions).

The irradiance level loss was +0.30 %.

6.9. Temperature loss

The production of photovoltaic cells is negatively affected by high operation temperatures. The loss is a consequence of the photovoltaic module characteristics. The cell temperature is always higher than the ambient temperature.

A value of 29.00 W/m2/K was considered as the heat transfer coefficient constant component. The heat transfer coefficient wind component was of 0.00 W·s/m3/K.

The yearly loss due to the module cell temperature was -4.34 %.

6.10. Photovoltaic module quality

The rated power of mass-produced photovoltaic modules varies on a module-to-module basis. This dispersion of the module performance is usually modeled as percentage of the variation against the rated power in STC conditions. The dispersion often results in a net gain, as the manufacturers usually aim for tighter tolerances with a bias towards a slightly higher than rated performance.

The gain due to module quality dispersion was of +0.70 %.

6.11. Light induced degradation

The light induced degradation occurs in the first hours of exposure the photovoltaic module is exposed to sunlight. After these initial hours, the degradation sets in and is constant for the remaining lifetime of the module. This effect is not usually reflected in the module datasheet.

The value of the LID loss was -2.00 %.

6.12. Bifacial mismatch

The bifacial mismatch is caused by heterogeneous illumination of the back-face. It is more pronounced in 1V single axis trackers where the torque beam casts a shade on the back face and there are photovoltaic cells in the shaded area.

A value of 3.00 % of bifacial mismatch was considered. This value does not directly translate into the final loss result, as it is applied proportionately to the ratio of front to back irradiance.

The resulting bifacial mismatch loss was of -0.14 %.

6.13. Electrical mismatch

The mismatch loss occurs because of the variation of electrical characteristics between photovoltaic modules connected in series in an array. This means the modules are not always able to operate at their maximum power operating point.

The value of the loss was constant throughout the whole year, -1.00 %.

6.14. Shading mismatch

The presence of partial shadings in an array gives rise to a mismatch between the partially (or completely) shaded modules and the unshaded ones. This loss can be minimized by increasing the pitch distance between rows, or by using a backtracking system in one-axis trackers.

The shading mismatch loss was 0.00 %.

6.15. DC cable losses

There is a loss due to the ohmic effect incurred in the electrical transmission of DC power. This loss occurs in the cables connecting the photovoltaic module strings to the string boxes and inverters (or directly to the inverters if the plant is designed using a DC bus system).

The value of the transmission losses depends on the cable cross sections and cable lengths, which are usually calculated by specifying a value for the voltage drop in STC conditions.

The average hourly loss on DC cables was -1.15 %.

6.16. Inverter loss

The main loss incurred in the electrical inverter is the conversion of DC to AC, usually known as the efficiency loss. Additional losses may occur if the sizing of the DC array with respect to the rated power of the inverter is not optimal (inverter operation window losses).

The combined losses in the inverter were -3.11 % (this value includes the efficiency loss, operation window losses and the auxiliary consumption loss).

6.17. AC cable losses from inverter to transformer

The losses incurred in the AC cables due to the ohmic effect depend on the cable cross sections and lengths. The loss is typically specified as a percentage of voltage drop in STC conditions. Because of the short length of the cables connecting inverter to transformer, this loss is usually low.

The AC cable losses in the cables connecting inverters to transformers were 0.00 %.

6.18. Power station transformer loss

The power transformer losses are two-fold: a constant loss value, known as the iron or core loss, and a converted power dependent loss, known as the copper or winding loss. Although these losses are usually very low, because the transformer has a very high efficiency, they must be considered.

The resulting losses for the iron and copper components were -0.16 % and -0.80 %, respectively.

The yearly average loss in the power station transformers was -0.96 %.

6.19. Medium voltage network losses (MV cables)

The losses incurred in the MV network due to the ohmic effect depend on the cable cross sections and lengths. The loss is typically specified as a percentage of voltage drop in STC conditions.

The medium voltage network consists of a series of lines connecting the power station transformers to the substation switch gears. The power loss in the network was -0.38 %.

6.20. Photovoltaic plant auxiliary consumptions

The photovoltaic plant will consume part of the power it generates to power its own systems, such as the security devices, cleaning equipment, or night lighting. These consumptions may also be present during nighttime.

The photovoltaic plant auxiliary consumptions resulted in a loss of 0.00 %.

6.21. Substation transformer

The substation power transformer raises the voltage of the power plant AC output to match the grid voltage.

The resulting losses for the iron and copper components were -0.16 % and -0.79 %, respectively.

The substation transformer loss was -0.95 %.

6.22. HV line to grid

The loss incurred in the AC line connecting the photovoltaic plant to the grid is due to the ohmic effect, and it depends on the cable cross sections and length. Usually the loss is specified as a percentage of voltage drop in STC conditions.

The AC high voltage line loss was -0.06 %.

6.23. Plant unavailability

The photovoltaic plant unavailability was estimated to be 0.00 %. The unavailability occurs because of scheduled maintenance operations, which may require the plant to be unproductive, and unscheduled stops due to unforeseen circumstances. The loss value is dependent on the plant location.

7. ENERGY YIELD RESULTS

A summary of the results for the first year is shown in Table 18. The performance ratio is calculated using the front-face plane of array irradiance, which may result in a PR value greater than 100% for bifacial simulations with very high back-face irradiance.

Table 18. Summary of results for the first year

Description	Value	Unit
First year production	78.42	GWh
Performance ratio	86.40 %	-
Specific production	2155.3	kWh/kWp
Bifacial gain	3.81 %	-

7.1. First year energy yield and losses (P50)

The front-face irradiance results are shown in Table 19, and the back-face results in Table 20. The losses after the conversion to electrical energy are shown in Table 21 for the first year.

Table 19. Front-face solar irradiance results

Description	Value	Unit	Loss
Solar resource			
Global horizontal irradiation	1888.4	kWh/m2	
Transposition to the plane of array	2494.6	kWh/m2	+32.10 %
Far shadings (horizon profile)	2485.7	kWh/m2	-0.36 %
Near shadings	2426.0	kWh/m2	-2.40 %
Soiling	2377.5	kWh/m2	-2.00 %
IAM loss	2372.2	kWh/m2	-0.22 %
Front-face effective irradiation	**2372.2**	**kWh/m2**	

Table 20. Back face solar irradiance results

Description	Value	Unit	Loss
Solar resource			
Global horizontal irradiation	1888.4	kWh/m2	
Ground reflected irradiance	324.1	kWh/m2	-82.84 %
Transposition to the plane of array	366.1	kWh/m2	+12.96 %
Effect of ground shades	146.6	kWh/m2	-59.96 %
Far shadings (horizon profile effect on beam)	146.6	kWh/m2	0.00 %
Near shadings	126.5	kWh/m2	-13.69 %
Soiling	126.5	kWh/m2	0.00 %

IAM loss	116.6	kWh/m2	-7.83 %
Back-face effective irradiation	**116.6**	**kWh/m2**	

Table 21. Yields and losses for the first year.

Description	Value	Unit	Loss
Solar resource			
Front face effective irradiation	2372.2	kWh/m2	
Back face effective irradiation	116.6	kWh/m2	
Global effective irradiation	**2488.8**	**kWh/m2**	
Photovoltaic conversion (nominal efficiency)			
Total receptive surface	166740	m2	
Effective solar energy reaching the photovoltaic cells	415.0	GWh	
Effective energy after the bifaciality factor	411.1	GWh	-0.94 %
STC photovoltaic module efficiency	21.85	%	
Energy with STC conversion efficiency	**89.83**	**GWh**	
Photovoltaic module losses			
Module degradation	89.56	GWh	-0.30 %
Irradiance level loss	89.83	GWh	+0.30 %
Temperature loss	85.93	GWh	-4.34 %
Spectral correction	85.93	GWh	0.00 %
Quality	86.53	GWh	+0.70 %
LID (Light Induced Degradation)	84.8	GWh	-2.00 %
Bifacial mismatch	84.68	GWh	-0.14 %
Electrical mismatch	83.83	GWh	-1.00 %
Shading mismatch	83.83	GWh	0.00 %
DC cable losses	82.87	GWh	-1.15 %
Energy at the inverter input	**82.87**	**GWh**	
Inverter DC to AC conversion			
Loss due to the inverter input voltage threshold	82.87	GWh	0.00 %
Loss due to the inverter maximum input voltage limit	82.87	GWh	0.00 %
Loss due to the inverter input power threshold	82.87	GWh	0.00 %
Loss due to the inverter output power limit	81.43	GWh	-1.74 %
Auxiliary consumption	81.43	GWh	0.00 %
Conversion efficiency loss	80.29	GVAh	-1.39 %
Energy at the inverter output	**80.29**	**GWh**	
Power station and MV System losses			
AC cable from inverter to transformer loss	80.29	GWh	0.00 %

Transformer iron loss	80.16	GWh	-0.16 %
Transformer copper loss	79.52	GWh	-0.80 %
MV network transmission loss	79.22	GWh	-0.38 %
Energy available at the MV system output	**79.22**	**GWh**	
Reactive energy at the MV system output	0.0	GVArh	
Power factor at the MV system output	1.000		
Substation losses			
Plant auxiliary consumption	79.22	GWh	0.00 %
Substation transformer iron loss	79.09	GWh	-0.16 %
Substation transformer copper loss	78.47	GWh	-0.79 %
Delivery point limitation loss	78.47	GWh	0.00 %
Energy available at the substation output	**78.47**	**GWh**	
Reactive energy at the substation output	0.0	GVArh	
Power factor the substation output	1.000		
Transmission to grid and availability			
HV line from substation to grid loss	78.42	GWh	-0.06 %
Plant unavailability loss	78.42	GWh	0.00 %
Grid unavailability loss	78.42	GWh	0.00 %
ENERGY INJECTED TO GRID	**78.42**	**GWh**	
REACTIVE ENERGY INJECTED TO GRID	0.0	GVArh	
POWER FACTOR AT GRID CONNECTION	1.000		

7.2. First year nighttime consumption

In Table 22 the nighttime consumption results of the photovoltaic plant are shown. The consumptions come from the night loss of the inverters, the transformer core (iron) losses, and the plant auxiliary consumption loss.

The total yearly nighttime power consumption was of -272.85 MWh, which represents a 0.35 % of the total yearly energy production of 78.42 GWh.

Table 22. Nighttime consumption results for the first year

Description	Value	Unit	Percentage of total
Inverter			
Nighttime loss	0.0	MWh	0.00 %
Power station			
Transformer iron loss	-136.43	MWh	50.00 %
Substation			
Plant auxiliary consumption	0.0	MWh	0.00 %

Substation transformer iron loss	-136.43	MWh	50.00 %
TOTAL POWER CONSUMPTION	**-272.85**	**MWh**	**100.00 %**

7.3. 25 years energy yield (P50)

The energy yield of the photovoltaic plant has been calculated for a period of 25 years. In Table 23 the energy yield, specific production and performance ratio are shown for each year.

Table 23. Results for the 25 year period.

Year	Energy yield [GWh]	Specific production [kWh/kWp]	Performance Ratio [%]
1	78.4	2155.3	86.40
2	78.3	2150.6	86.21
3	78.1	2145.8	86.02
4	77.9	2140.9	85.82
5	77.7	2136.1	85.63
6	77.5	2131.0	85.43
7	77.4	2125.9	85.22
8	77.2	2120.7	85.01
9	77.0	2115.4	84.80
10	76.8	2110.1	84.59
11	76.6	2104.8	84.37
12	76.4	2099.3	84.15
13	76.2	2093.8	83.93
14	76.0	2088.2	83.71
15	75.8	2082.6	83.49
16	75.6	2076.9	83.26
17	75.4	2071.2	83.03
18	75.2	2065.4	82.79
19	74.9	2059.5	82.56
20	74.7	2053.7	82.32
21	74.5	2047.7	82.09
22	74.3	2041.8	81.85
23	74.1	2035.8	81.61
24	73.9	2029.8	81.37
25	73.6	2023.8	81.13

Total	**1903.2**	**2092.2**	**83.9**

7.4. Probabilistic yield estimation

The probabilistic yield estimation is a statistical analysis. It can be used to ascertain the effect that some uncertainties have on production over the course of several years. The weight of these uncertainties is quantified using the standard deviation (sigma value), which represents the expected annual variability. It can used to consider uncertainties in meteorological data, equipment performance, or long-term degradation.

The analysis consists of assuming that production will follow a normal distribution throughout the PV plants lifetime. The mean of the normal distribution will be the production of the first year (78.42 GWh).

The standard deviation of the normal distribution was specified by the user, and its value was 3.00 %.

The results are shown in Table 24.

Table 24. Probabilistic yield estimation

Probability	Energy yield [GWh]
P50	78.4
P75	76.8
P90	75.4
P95	74.6
P99	73.0

7.5. Battery Energy Storage System

In addition to the PV Plant, an AC coupling BESS has been defined inside the green area of Figure 1. This battery system includes a set of 6 battery containers and 1 power conversion systems with a total apparent power of 5500.0 kVA and a total rated power of 5500.0 kW at a power factor of 1.000 and an energy capacity of 12.0 MWh, resulting in a storage capacity of 2.2 hours of discharge.

The loss due to the delivery point limit (curtailment) could be used to charge an AC-coupling BESS. This loss amounted to 0.0 Wh.