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Performance comparison between Low Concentration Photovoltaic and fixed angle PV systems

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Abstract

This paper focuses on the comparison between two different Photovoltaic systems. Both of them are located in the same place in the south part of Italy - Sicily. The first system is a photovoltaic system (PV) with a fixed tilt angle of 30° and an azimuth orientation of 0° South; its peak power is about 1.63 kWp and its 10 modules are made up of polycrystalline silicon for a total area of 13.13 m^2. The second system is a low concentration photovoltaic system (LCPV) with a biaxial suntracker and a concentration of 25 suns; its peak power is about 4.65 kWp and its modules are made up of monocrystalline Silicon for a total area of 44.6 m^2. In order to analyse the behaviour of these two different systems the most common Performance Indexes (YR, Yf, PR and η) has been used for the comparison, starting from the measured radiation data for both systems. The experimental data were treated for almost one year. Moreover it was analysed the thread of these indexes for two typical days in different seasons. Analysis results showed that LCPV has better performances (according the PR index) during the summer months thanks to a greater percentage of direct irradiation, while the efficiency of the fixed angle PV system is higher during the other months.

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Keywords: Low Concentration; sun-tracker; Photovoltaic; Performance Ratio.

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1. Introduction

The conversion of solar radiation into electrical energy by using photovoltaic technologies has occupied a role more important in energy production during these last years; despite the high cost of modules does not still allow the achievement of the grid parity. This high cost is mostly due to the materials that constitute the modules such as Si, GaAs or many other semiconductors. With the aim at decreasing these costs many researches have been conducted on Concentration Photovoltaic systems (CPV). These technologies presents the important advantage to reduce the active photovoltaic surface used for the photoelectric conversion exploiting an optical system [1] that concentrates on it the direct solar radiation. The disadvantage of this technology is derived by an architecture more complex and fragile due to the need to catch perfectly the direct radiation. The most important parts of CPV are the optical concentrator, the heat sink and the sun-tracker. The optical concentrator is made up of lenses, mirrors or a combination of both, that allows to concentrate the solar light on the photovoltaic cells. The mostly used lens is The Fresnel lens [2]. The tracker is an electro-mechanical part of the system used to keep the modules perpendicular to the direct solar radiation: it could be mono-axis or bi-axis. The complex architecture of this type of systems needs a heat sink in order to keep low the temperature of cells to minimize the losses of performance caused by the thermal drift [3]. CPV systems can be classified according the level of concentration of solar radiation: low Concentration photovoltaic systems (LCPV) can concentrate the radiation up to 40 times and usually are made up of high efficiency Silicon cells [4]; High Concentration photovoltaic systems (HCPV) can concentrate radiation even 500 times and usually are constituted by multi-junction cells [5]. The major hindrance in high concentration is as follows:

- The cell temperature increases with increase in concentration of light and being a semiconductor material it has a negative temperature coefficient of open-circuit voltage. As a result the solar cell loses its efficiency;
- Concentrating system uses direct sunlight, so they require an accurate sun tracking system. With the increase in concentration a higher precision in tracking and optics is required [6].

Low concentration photovoltaic (LCPV) systems with a concentration ratio below 40 suns present the following advantages:

- LCPV systems can make use of conventional high performance silicon solar cells [7];
- LCPV systems are less demanding in terms of tracking accuracy as compared to high concentration systems [8].

In this paper two systems have been compared according many performance indexes: a LCPV system and a plane photovoltaic system.

Nomenclature

T	Air Temperature [°C]
Y_R	Reference Yield [kWh/m^2/kW/m^2]
Y_f	Array Yield [kWh /kWp]
P_0	Peak power [kWp]
PR	Performance Ratio [%]
η	Efficiency of the system [%]

2. Performances indexes

The comparison between different PhotoVoltaic Systems has to consider the differences that may income among all the possible PV technologies, considering the different size, tilt and azimuth angle, irradiation received due to different latitudes and weather conditions. The use of these indexes helps to evaluate the single causes of efficiency loss and to better work on it for further improvements. The aim is the normalization of the measurements of solar irradiation and electrical power production [9]. The best standardized index is the Performance Ratio (PR) that compares the real production of the system with the attended one.

2.1. The Reference Yield (Y_R)

The Reference Yield (Y_R) is the ratio between the solar radiation directed perpendicularly to the active surface E_{DNI} *[kWh/m²]* and the Direct Normal Irradiance DNI (i.e. 850 *[W/m²]* for concentrated PV systems). It represents the number of working hours at the DNI considered.
The unit is hours [h]:

$$Y_R = \frac{E_{DNI}}{DNI_{ref}} \tag{1}$$

The Reference Yield is a function of: location, orientation, monthly or yearly weather conditions. It helps to compare systems that receive different percentage of radiation from the sun.

2.2. The Array Yield (Y_f)

The Array Yield (Y_f) is the ratio between the energy production E *[kWh]* and the peak power of the system P_0 *[kW$_p$]*

The unit is hours [h]. It is possible to define two different kinds of Y_f before and after the inverter, using the energy in DC and in AC respectively:

- The DC array yield Y_{f_DC} represents the number of hours that the system needs in order to produce the energy E_{DC} working at the peak power P_0:

$$Y_{f\_DC} = \frac{E_{DC}}{P_0} \tag{2}$$

- The AC final yield Y_{f_AC} represents the number of hours that the system needs in order to produce the energy E_{AC} working at the peak power P_0:

$$Y_{f\_AC} = \frac{E_{AC}}{P_0} \tag{3}$$

The Array Yield normalizes the energy production on the system size, helping to compare systems with different peak power P_0.

2.3. The Performance Ratio (PR)

Using the first two parameters defined before, it is now possible to evaluate the value of the Performance Ratio as the ratio between those. The PR can also be defined before and after the inverter using the two different values of the Array Yield (Y_f):

$$PR_{\_DC} = \frac{Y_{f\_DC}}{Y_R} \tag{4}$$

$$PR_{\_AC} = \frac{Y_{f\_AC}}{Y_R} \tag{5}$$

The PR helps to define the losses of the system due to:

- spectral mismatch;
- back temperature;
- inverter efficiency;

- transmission losses in DC or in AC;
- system malfunction.

It is possible to evaluate the energy losses:

$$L_C = Y_R - Y_{f\_DC} \tag{6}$$

This index includes the thermal losses due to a module temperature higher than 25 °C, the transmission losses of the cables, the bypass diodes losses, the MPPT, mismatch, spectral losses and inverter malfunction. By considering the Y_{f_AC} it is possible to obtain the losses of energy conversion.

$$L_S = Y_R - Y_{f\_AC} \tag{7}$$

2.4. The Efficiency of the system (η)

The efficiency is the ratio between the produced Energy and the Irradiation received:

$$\eta = \left[\frac{E_{PROD}}{(E_{DNI} \cdot A)}\right] \cdot 100 \tag{8}$$

From the definition of PR it is obtained:

$$PR = \frac{Y_f}{Y_R} = \frac{\left(\frac{E_{PROD}}{P_0}\right)}{\left(\frac{E_{DNI}}{DNI}\right)} \tag{9}$$

i.e.

$$PR = \left(\eta \cdot \frac{A}{100} \cdot \frac{DNI}{P_0}\right) \cdot 100 \tag{10}$$

Or

$$\eta = \left|\frac{PR}{\left(\frac{A}{100}\right) \cdot \left(\frac{DNI}{P_0}\right)}\right| \cdot 100 \tag{11}$$

By using the efficiency it is possible to compare systems with the same peak power, same conversion technology and same received irradiation. It is more accurate if we consider the conversion of the module, but it is more restrictive for a study of various systems, as in this case.

3. Systems description

The two systems compared are a Low Conentration PhotoVoltaic (LCPV) system with biaxial suntracker and a photovoltaic system (PV) with a fixed tilt angle of 30° and an azimuth orientation of 0° South.

3.1. LCPV MONOCRYSTALLINE - 25 SUNS

The LCPV system analyzed has a peak power of 4.65 kW_p (4 strings with 13 modules each), a biaxial sun-tracker and a low concentration systems of 25 suns (Fig. 1). The 52 modules are made of monocrystalline Silicon (with laser grooved buried contact), each of a peak power of 89.4 W_p and an area of 0.036 m^2 (total area is 44.6 m^2), with a stated efficiency in CSTC of 16.7% at 25 suns. The module datasheet is described in Tab. 1.The strings are connected to the inverter in two different parallel couples on two different channels. The concentrating system ("swallow concentrator") is made of plastic truncated cones covered by a metal film that reflects the radiation directly on the basis of the lenses where is the PV cell. The efficiency of this optical transmission is of 80 % . This optical concentration, even if low concentration, permits high acceptance angles tolerance of 4°, that means a lower precision of the tracking system, i.e. a less expensive tracker. Each module is made by 160 optical elements that focus the sunbeams each one on an area of 14x16 mm^2 on a single mono-Si PV cell. Thanks to the lenses it is possible to use only 5 % of silicon compared to a traditional PV system with the same peak power. The cells are connected with thermo conductive substrates that maintain a dissipative heat exchange. This dissipation keeps the temperature difference between the cells and the back module under 10 °C. For ulterior heat dispersion everything is buried in a metallic box with a design that optimizes natural convection dispersion with the wind on the back of the PV module.

Figure 1. LCPV monocrystalline system 25 suns.

Table 1. LCPV module.

Characteristics	Value
Concentration geometric/optical (suns)	25/20
Number of cells	160
Cell dimensions (mm x mm)	14 x 16
Cell efficiency (%)	16.7
Panel efficiency (%)	11.8
Pmax in CSTC1 (W)	89.4
Voc (V)	27
Isc (A)	4.5
Vmpp (V)	23
Impp (A)	4.14
FF (%)	78
NOCT (°C)	45
Panel dimension (mm x mm x mm)	1160 x740 x 185
Vout (V)	12
Angle acceptance (°)	±4
ΔVoc/ΔT (V/°C)	-0.008
ΔPmax/Pmax ΔT (%/°C)	-0.45

3.2. Sun tracking system

Every concentrating PV system needs a sun tracker that permits the modules to be always orthogonal to the sun beams. The LCPV analyzed has a sun tracker with the characteristics shown in Tab. 2.

Table 2. Sun trakers

Characteristics	Value
Length (mm)	10582
Vertical position height (mm)	5171
Horizontal position height (mm)	2807
Height over the base (mm)	850
PV surface (m^2)	44.6

The sun-tracker is strongly cemented on the ground in order to resist at wind speed up to 100 km/h in working position, up to 150 km/h in safety position. The two electrical engines are activated by a time-dependent solar pointing system.

3.3. PV Policrystalline

The second PV system analyzed is a fixed plane photovoltaic system with a peak power of 1.62 kWp. The 10 modules are made of polycrystalline for a total area of 13.13 m^2. The tilt angle of the array is 30°, with an azimuth angle of 0° South. The datasheet of the module are shown in Tab. 3.

Table 3. PV module.

Characteristics	Value
Cell type	polycrystalline
Number of panels	10
Number of cell per panel	48
Panel Area (m x m)	1.32 x 0.99
System Area (m^2)	13.13
Voc (V)	28.4
Isc (A)	7.92
Vmpp (V)	228
Impp (A)	7.11
FF (%)	0.71
Panel Efficiency (%)	12.16
Power at STC (W)	162
Temperature Coefficient of Isc (%/°C)	0.053
Temperature Coefficient of Voc (%/°C)	-0.35
Temperature Coefficient of Pmp (%/°C)	-0.49
NOCT (°C)	47.5

4. Data Analysis

The comparison between the two PV systems has been made during almost one year (data losses for LCPV in April are due to system maintenance). In the analysis it has been made a comparison between the values of the received radiation from the two systems and the PVgis data. As shown in Fig. 2, at low latitudes the DNI is higher than the GNI during some good weather periods (mostly during summer).

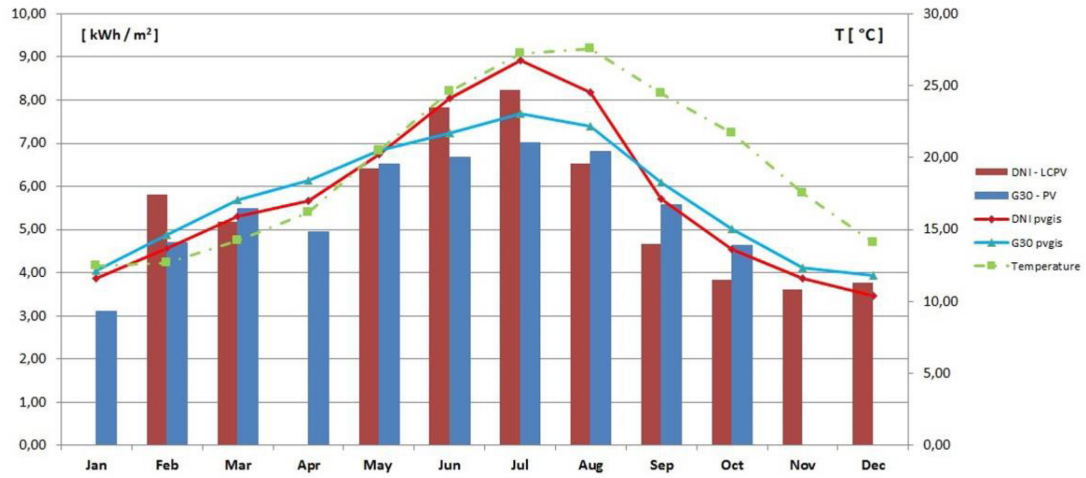


Figure 2. Radiation comparison

A first comparison has been made in two typical days in summer and in winter (Fig. 3 and Fig. 4). It is possible to see the different time of sunrise and sunset looking at the radiation (DNI or GNI). During the summer the sun-tracker allows LCPV to receive more energy following the sun, so that the DNI is higher than the GNI on fixed angles of tilt and azimuth. When the sun gets high enough, the GNI and DNI are received almost at the same angles, so that there is more global irradiation on the fixed roof than the DNI (from 09:00 to 15:00 in Fig. 3). It is obvious that during a bad weather condition (as shown in the winter analysis) that the GNI is higher than the DNI, so that the PV system has a better Y_f, as well as a better energy production.

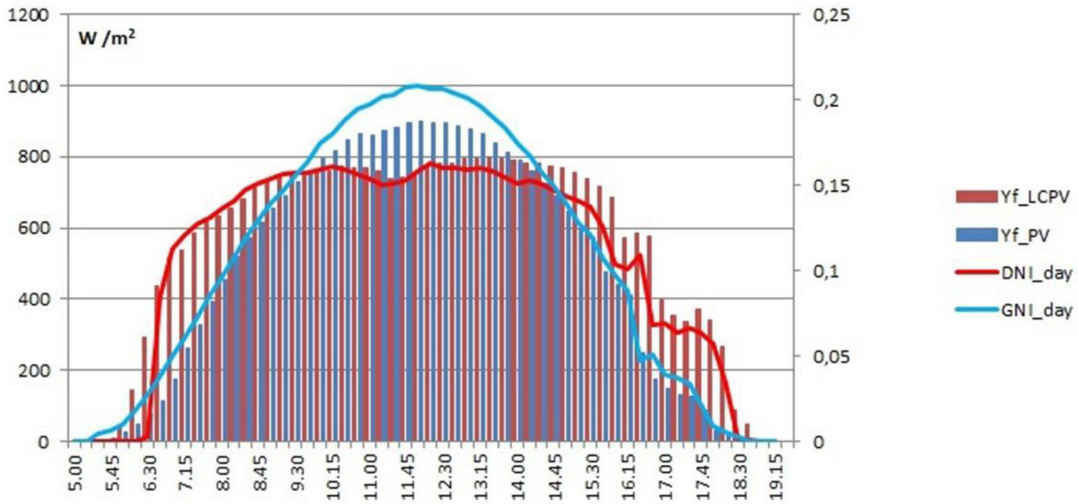


Figure 3. Summer/sunny day analysis

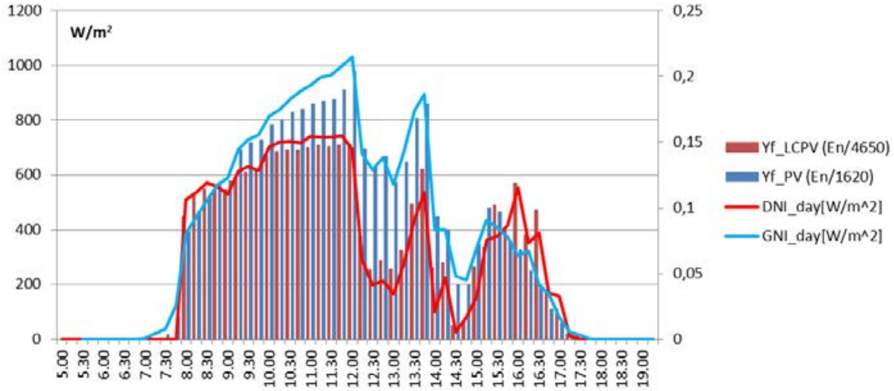


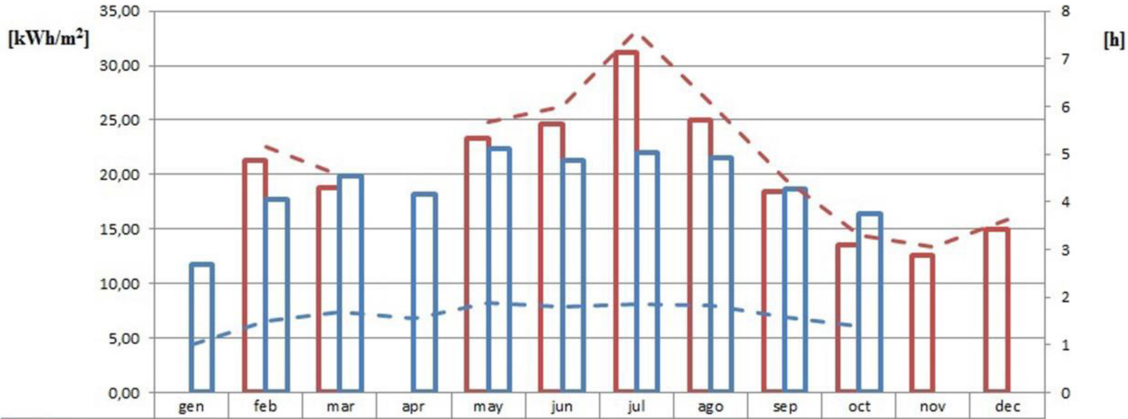
Figure 4. Winter/cloudy day analysis

By looking at the year analysis (Fig. 5), it is possible to see that the sun-tracker allows higher values of Y_R; this means that thanks to the tracking system it is possible to receive more radiation from the sun.

	gen	feb	mar	apr	may	jun	jul	ago	sep	oct	nov	dec
YR - LCPV		6,84	6,11		7,54	9,20	9,68	7,69	5,48	4,51	4,24	4,44
YR - PV	3,11	4,70	5,48	4,95	6,53	6,68	7,00	6,82	5,57	4,64		
DNI month - LCPV		5,82	5,19		6,41	7,82	8,23	6,54	4,66	3,84	3,60	3,77
GNI 30° month - PV	3,11	4,70	5,48	4,95	6,53	6,68	7,00	6,82	5,57	4,64		

Figure 5. Radiation and Reference Yield comparison

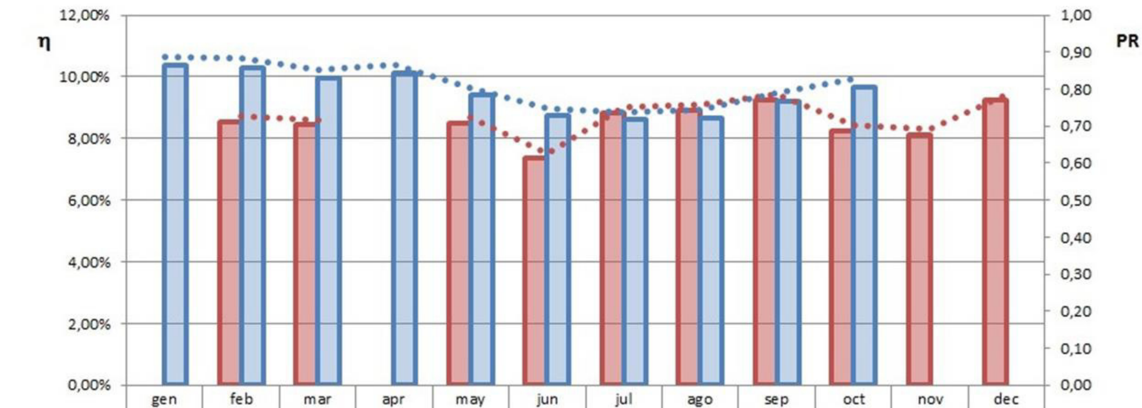
The energy production mostly is better for the LCPV than the PV (Fig. 6).



	gen	feb	mar	apr	may	jun	jul	ago	sep	oct	nov	dec
Yf - LCPV		4,86	4,29		5,34	5,63	7,12	5,70	4,21	3,10	2,87	3,41
Yf - PV	2,68	4,04	4,55	4,17	5,11	4,86	5,03	4,93	4,27	3,74		
E prod - LCPV		22,58	19,95		24,83	26,20	33,11	26,52	19,59	14,43	13,37	15,88
E prod - PV	4,35	6,54	7,36	6,75	8,28	7,87	8,16	7,98	6,92	6,05		

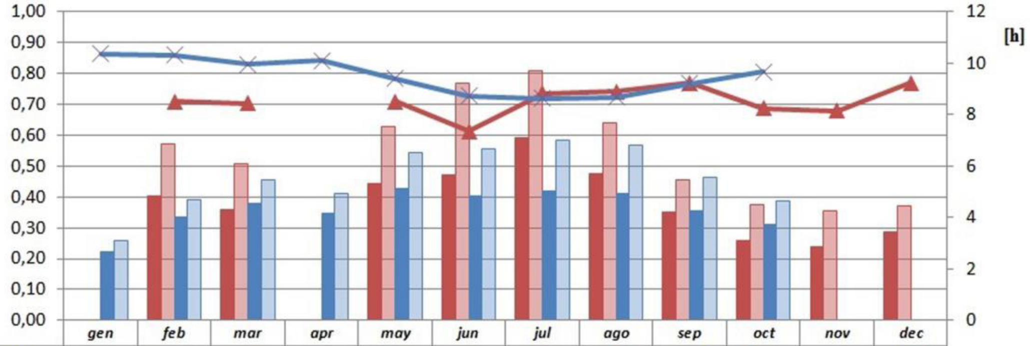
Figure 6. Energy production and Energy Yield comparison

Analyzing the Performance Ratio (Fig. 7 and Fig. 8) it is possible to see that the "fixed plane PV system" has a PR higher than the LCPV's during most of the year. This is due to the fact that even if the LCPV catches more radiation than the PV system, the energy production should be higher to justify the use of this technology.



	gen	feb	mar	apr	may	jun	jul	ago	sep	oct	nov	dec
PR - LCPV		0,71	0,70		0,71	0,61	0,74	0,74	0,77	0,69	0,68	0,77
PR - PV	0,86	0,86	0,83	0,84	0,78	0,73	0,72	0,72	0,77	0,81		
η - LCPV		8,71%	8,62%		8,69%	7,51%	9,03%	9,10%	9,43%	8,44%	8,32%	9,44%
η - PV	10,66%	10,60%	10,23%	10,39%	9,67%	8,98%	8,87%	8,92%	9,46%	9,95%		

Figure 7. Performance Ratio and efficiency comparison.



	gen	feb	mar	apr	may	jun	jul	ago	sep	oct	nov	dec
Yf - LCPV		4,86	4,29		5,34	5,63	7,12	5,70	4,21	3,10	2,87	3,41
YR - LCPV		6,84	6,11		7,54	9,20	9,68	7,69	5,48	4,51	4,24	4,44
Yf - PV	2,68	4,04	4,55	4,17	5,11	4,86	5,03	4,93	4,27	3,74		
YR - PV	3,11	4,70	5,48	4,95	6,53	6,68	7,00	6,82	5,57	4,64		
PR - LCPV		0,71	0,70		0,71	0,61	0,74	0,74	0,77	0,69	0,68	0,77
PR - PV	0,86	0,86	0,83	0,84	0,78	0,73	0,72	0,72	0,77	0,81		

Figure 8. Performance indexes comparison.

5. Conclusions and future work

As seen, at low latitudes the DNI gets higher values than GNI during some good weather periods (mostly during summer). The comparison has shown that the higher received DNI at low latitudes helps the LCPV to receive much more energy from the sun, and more than compensate the higher losses due to a higher mean temperature during the year. However by analyzing the Perfomance Ratio comparison of the two systems in the experimental site in the city of Catania it has been possible to see that the "fixed plane PV system" has reached higher PR than the LCPV during most of the year. This is due to the fact that even if the LCPV is able to catch much more radiation than the PV system, the energy production should be higher to have an higher value of PR and so justify the use of this technology. More than this, a further analysis about economical prices and failure rate of the two systems should confirm that the only way to make LCPV system economical interesting in a global market production is by enhancing the energy production per square meter and using at best the higher Yf reached thanks to the by-axial suntracking.

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