Integration of PV in the Moroccan Buildings: Simulation of a Small Roof System Installed in Eastern Morocco

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Abstract- This study presents the simulation results of a small rooftop photovoltaic (PV) system with a nominal power of 2kWp under the climate of Oujda city (North East of Morocco) using high quality data measured at ground level for a period of one year. The results show that for an annual global horizontal irradiance of 1891kWh/m², the system is able to provide a yearly electrical production of 3230.1 kWh for a total load of 1538 hours/year and with a mean system efficiency of 8.6%. Generally, the integration of PV systems for small utility scale in Eastern Morocco and especially in the building is very promising, and the results of this study can help the local political and economical actors in the field of solar energy to develop strategies and programs to enhance the PV integration on buildings.

Keywords Photovoltaic, Simulation, Performance, Eastern Morocco, Buildings.

1. Introduction

The use of solar energy, in large or small scale, has become an important issue for the countries with scarce fossil sources, such as Morocco, for decreasing their energy bill. Indeed, with an irradiation of 5630 Wh/m²/day [1], Morocco can produce a high electrical potential from solar and therefore, cover his energy needs and export a part to Europe as well.

From many solar technologies, photovoltaic is very promising. In fact, according to the Internal Energy Agency (IEA) last report [2], the total PV capacity installation during 2014 exceeded 150 Giga-watts per day. Furthermore, the IEA foresees that this capacity will reach 4600 GW by 2050, which means that PV's share of global electricity will reach 16%, where the utility-scale and rooftop systems will each have roughly half of the global market.

For this reason, and in order to encourage Moroccan policymakers and the actors in the field of solar energy to push forward PV's integration, especially in the buildings and rooftops, a simulation of the performance of a small system is very important. This paper discusses the simulation results of a 2kW rooftop PV system under the climate of Oujda, a city located in the North East of Morocco. The results show that for an annual global irradiation of 1891 kWh/m², the system can produce a gross energy of about 3230 kWh with an efficiency of 8.6%. These results show that the integration of small PV systems in buildings can be very efficient and reduces the electricity consumption as well as the pollution and CO_2 emissions by producing a climate friendly and sustainable energy.

2. Methodology: simulation tool & input data

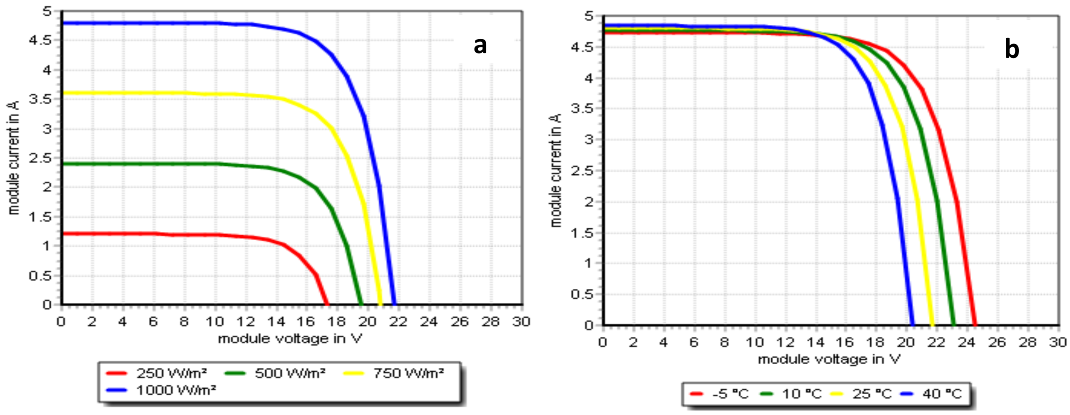
2.1. Simulation software

In order to predict the performance of a PV technology in a region or a country, the use of simulation software is fundamental. Several simulation tools are available in the market, we can mention for instance, PVsyst, SOLDIM, PV*SOL, System Advisor Model (SAM), The Green Energy System Analysis Tool (Greenius), etc. Also, many studies used the Simulink library included in Matlab, or Labview to simulate the electrical and characteristics behavior of PV modules [3,4]. In this study, the Greenius software developed by the German Aerospace Center (DLR) was used to simulate the rooftop PV system. Greenius is a powerful and friendly simulation environment that gives to the user the opportunity to simulate the performance of many energy systems like PV, Concentrating solar power plants (CSP) and wind plants [10,11]. For the simulation, Greenius uses empirical equations and requires the integration of a one-year meteorological file with the resolution of one-hour step. It is also developed in a way that allows the user to easily change the important simulation parameters (such as the size or the location). Greenius was used in many studies. Quashning et al, simulate the performance of a 50MWe power plant based on parabolic troughs collectors and they claim that Greenius is a comfortable simulation tool [5]. The same think has been mentioned by the developers of the software [6] and with Liqreina [11] that studied the dry cooling option in concentrating solar plant and compare it to the wet scenario using this software.

2.2. Grid connected PV System

2.2.a. PV module

The PV module used in this study is the Siemens SP75 mono-crystalline silicon PV panel. In the nominal conditions (Irradiance of 1000W/m², Air mass AM=1.5 and a cell temperature t_{cell}=25°C) the SP75 module had a nominal MPP power of 75 Wp, an open circuit voltage V_{oc}= 21.7 V and a Short-circuit current I_{SC}=4.80 A. Figure 1, represents the most important module characteristics. In fact, figures (1-a) and (1-b) represent the current's variation as a function of voltage by varying the irradiation and the temperature respectively. Where, the figures (1-c) and (1-d) represent the module's power variation as a function of the voltage by varying the irradiation and the temperature respectively



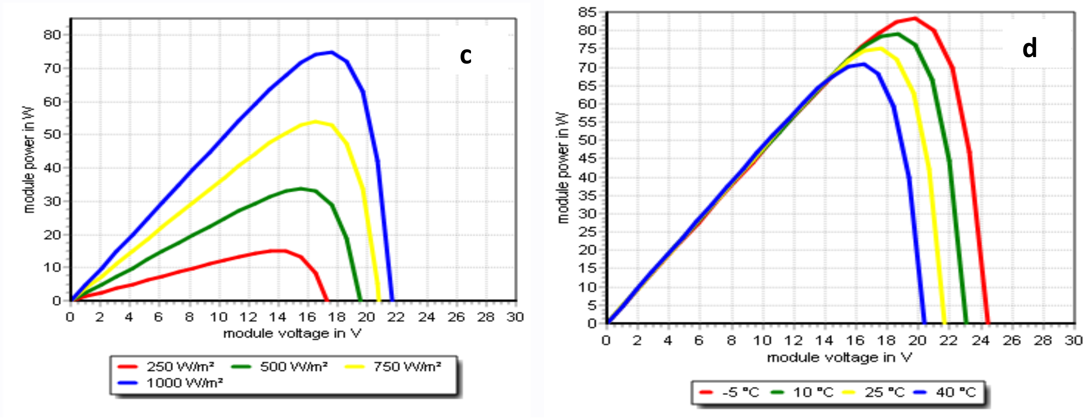


Fig. 1. The Siemens SP75 characteristics.(a) Current over voltage (irradiance), (b) current over voltage (temperature), (c) power over voltage (irradiance), power over voltage (temperature).

2.2.b. Inverter

The inverter is a very important element in PV system installation. The choice of the suitable DC-AC converter with the right reliability and efficiency features is essential. These elements are responsible of the operation of a PV system continuously near its maximum power point. In this study, the Aixcon PS 2500 inverter is used. The Aixcon PS 2500 had a nominal DC and AC power of 2.5kW and 2.38kVA.

The voltage range is between 125 and 500V and the maximum current reaches 12 A. The efficiency at 50% and 10% part load are 95% and 94.7% respectively and the nominal efficiency is of 95% (figure 2).

2.2.c. The roof PV system

The PV system modeled in this paper has a nominal DC power of 2kWp. It is composed by two strings of fourteen SP75 PV-modules each (28 modules on totality) and one inverter. The modules are mounted with a fix tilted angle of 30° (close to the latitude of Oujda city 34°) and they cover an area of 17.71m². The system’s efficiency is of 9%, see figure 3. The efficiency will be discussed in details in the result section.

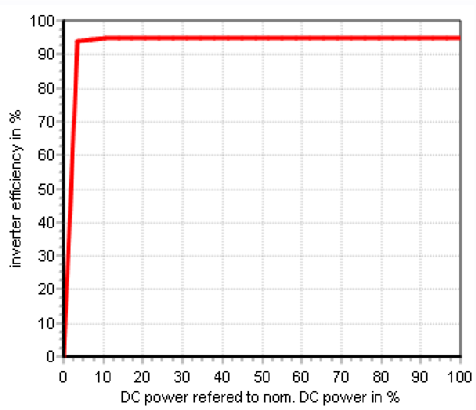


Fig. 2. The nominal inverter efficiency over the DC power.

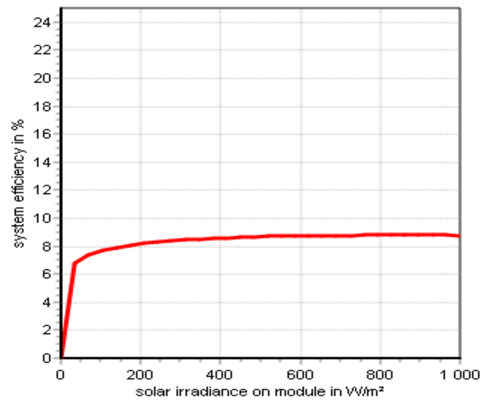


Fig. 3. The nominal PV system efficiency

2.2.d. Cabling and system optimisation

In addition to the ordinary simulations output, such as electricity generation, the efficiency of the field…Greenius gives to the user the opportunity to choose the shadowing and the cleanliness factors as well as optimizing the cable cross-sections of the DC lines. Indeed, these factors have a high influence on the system performance and can highly affect the electricity production. Soiling of PV panels, especially in arid regions (such as Oujda city), decreases the transmission of the PV panels, thus, the electricity production [7,8]. In this study the default cleanliness value of 95% has been chosen.

Cabling losses, on the other hand, can be very important if the wrong cable cross-section is chosen. Therefore, the amount of electricity injected on the grid will decrease. Figure 4 presents the hourly cable losses of the same system before and after the optimization of the cable's cross-section. In Greenius the optimization is done automatically by the software [9]. In the first time (default value), the cable has a cross-section of 4mm² and a specific resistance of 0.01750 Ω mm²/m, the cable losses at 1000W/m² and -10°C are of 279.3W (14.7%). After optimizing the cross-section, with the help of the software, it becomes 2.5mm², the losses of the same cable with the same condition reduce to 44.7W (2.4%).

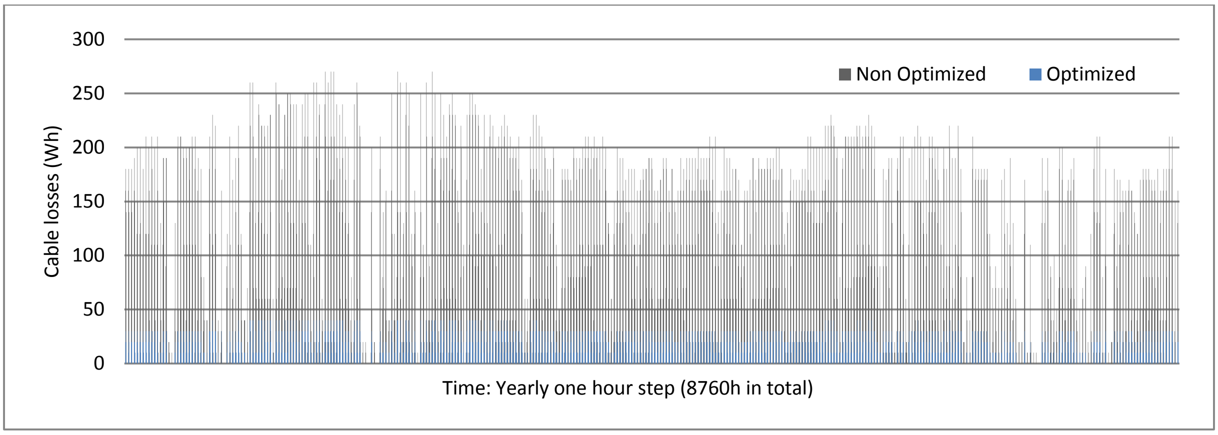


Fig. 4. The hourly cable losses of the system before and after the optimization of the cross-section.

II-3- Meteorological data

As mentioned before, the simulation in Greenius requires a one year-meteorological file with one-hour step. In our study, the meteorological file has been built based on the measurements of a meteorological high precision station installed at the rooftop of the University of Oujda. This station, and in addition to the ordinary meteorological parameters (humidity, pressure, temperature, wind velocity and direction), measures the three component of solar irradiation separately and on one minute step. The global and the diffuse irradiance (GHI, DHI) are measured using secondary standard Kipp&Zonen CMP21 pyranometers, while the direct normal irradiation (a very important parameter that is measured in only five sites in Morocco, including Oujda) is measured with the first class CMP1 pyrheliometer.

Furthermore, the station is very well maintained and the sensors are cleaned on a daily purpose (except the weekends and holidays). Therefore, the data used in this study can be considered as of high quality. Those data were collected in a daily purpose, analyzed, corrected and converted from one minute to one-hour step for a period of one year in order to prepare the meteo-file for the simulation.

Figure 5, presents the daily values of the global and the diffuse horizontal irradiance (GHI and DHI) measured by our station for a period of one year. The one can clearly see that the amount of the daily GHI received by Oujda city can be considered as high, especially during spring and summer, where the maximum daily values can reach 400 W/m². During winter and autumn the GHI is quite good and the daily values vary between 50 and 300 W/m².

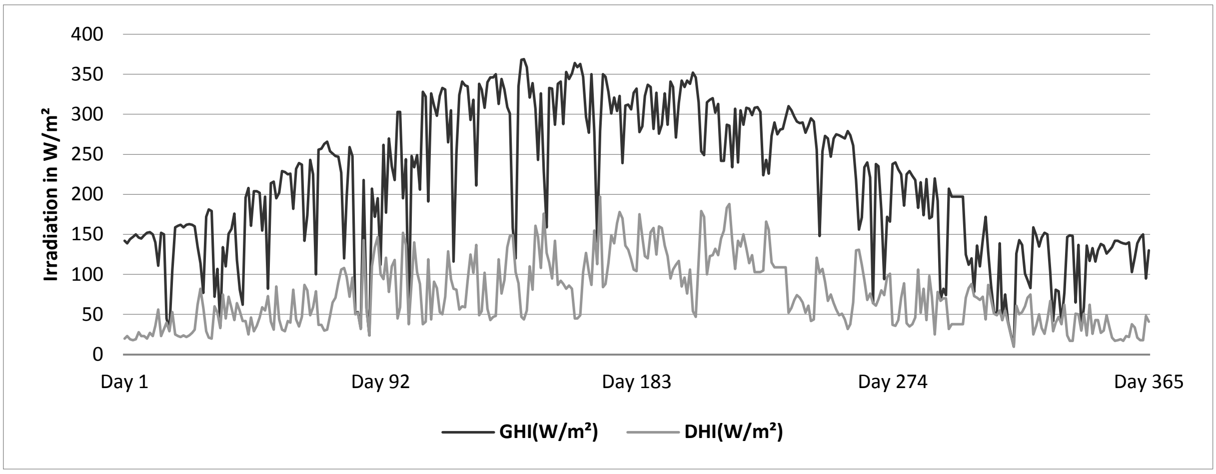


Fig. 5. The daily values of the GHI and the DHI measurements for a period of one year.

An additional important parameter, which influences the PV efficiency in a location, is the temperature [12]. Since Oujda is an arid region, the investigation on the temperature distribution is important. Figure 6 presents the hourly frequencies distribution of the ambient temperature measurements during a whole year in Oujda.

It's clear that the high temperature values (above 30°C) are scares in comparison with the other ones. Indeed, the number of hours with a temperature values above 30°C represents only 1040 from 8760 (the number of hours in one year).

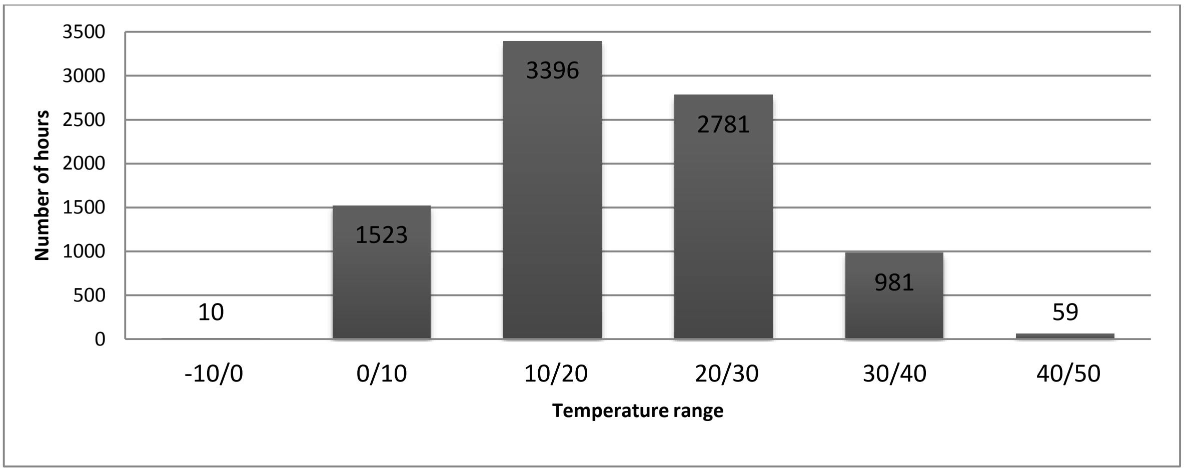


Fig. 6. The hourly ambient temperature frequencies distribution.

Therefore, we can say that Oujda's ambient temperature is somewhat suitable for the PV cells and doesn't affect much the efficiency of the module. Indeed, and as illustrated in figure 7, during the warm periods of the year the modules daily's efficiency are almost constant and equal 9%. This efficiency increases during the cold days and reaches 10%. The cell temperature on the other hand changes with the ambient temperature and it fluctuates during the warm period between 20 and 32°C. Greenius calculates the cell temperature using the equation (1), where t_{amb} is the ambient temperature (°C), I_{module} is the current irradiation (W/m²), while C represents an empirical value that refers to the temperature coefficient [9]. In this study, the default value used in the software (0.022°C/W/m²) has been chosen.

$$t_{\text{cell}} = t_{amb} + c \cdot I_{\text{module}} \quad (1)$$

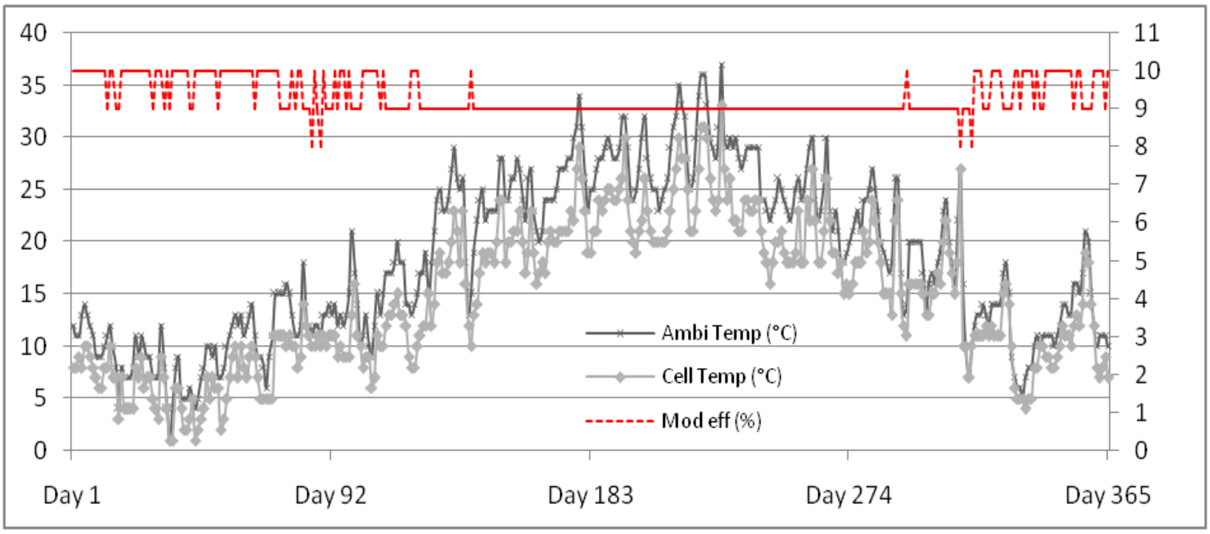


Fig. 7. The daily ambient temperature, cell temperature and module efficiency.

3. RESULTS AND DISCUSSION

In this section we will discuss the main results of the 2kW PV system simulated under the climate of Oujda. As illustrated in figure 8, the system's monthly electricity production (E_{syst}) depends on the amount of the GHI, and can be considered as high.

During the winter, the system produces an electricity amount between 250 and 300 kWh, whereas, the production during spring and summer reaches 350 kWh. The minimum electricity production value is observed during November, which is completely reasonable, because of the low GHI value measured during this month. Nevertheless, a production of 161 kWh can still be considered as high.

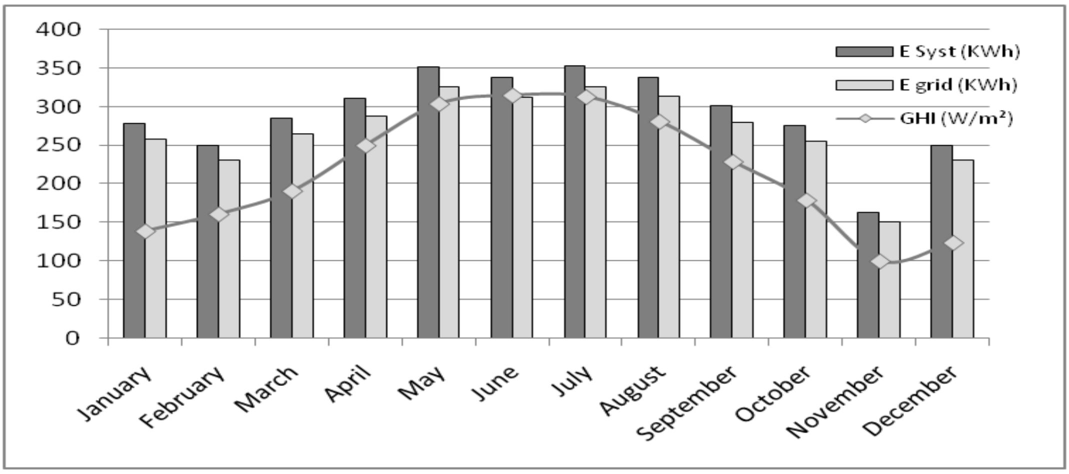


Fig. 8. Monthly electricity produced and injected on the grid.

On the other hand, and due to the losses caused by the cables, the inverter etc, the amount of electricity injected on the grid (E_{grid}) is a little bit smaller than E_{syst}. The highest differences are observed on May and July with a decrease of 26 kWh, while the lowest difference was on November with 12kWh. Table1, shows the monthly differences between E_{syst} and E_{grid}.

This can be explained by the fact that the temperature influences less the efficiency of the modules as well as the inverter and the system, hence, the amount of electricity produced and injected on the grid. Indeed the efficiency of the module increases during winter and autumn, and can reach 10%, while a drop of 1% in the module efficiency is observed during summer, see figure 9.

Table1, The monthly electrical losses between the production and the injection on the grid in kWh.

January	February	Marsh	April	May	June	July	August	September	October	November	December
21	19	21	23	26	25	26	25	22	20	12	19

Greenius uses the equation 2 to calculate the module efficiency where I is the current irradiance (W/m²), I_0 is the nominal irradiance (I_0=1000W/m²) and t_0 refers to the nominal temperature (t_0=25°C).

$$\eta(I, t_0) = a_1 + a_2 \ln(\frac{I}{I_0}) + a_3(\frac{I}{I_0} - 1) \quad (2)$$

The parameters a_1, a_2 and a_3 are the part load parameters that characterize the SP75 module. Greenius gives the opportunity to the user to change those parameters in order to define the nominal efficiency of the module. In our case, the default values of the SP75 panel (a_1 = 0.11900, a_2 = 0.009990 and a_3=0) were used.

Furthermore, from figure 9 it's clear that the efficiency of the power conversion from DC to AC is more or less steady with a monthly value of 94%, while the whole system efficiency varies between 9% during winter and autumn and 8% for the rest of the year.

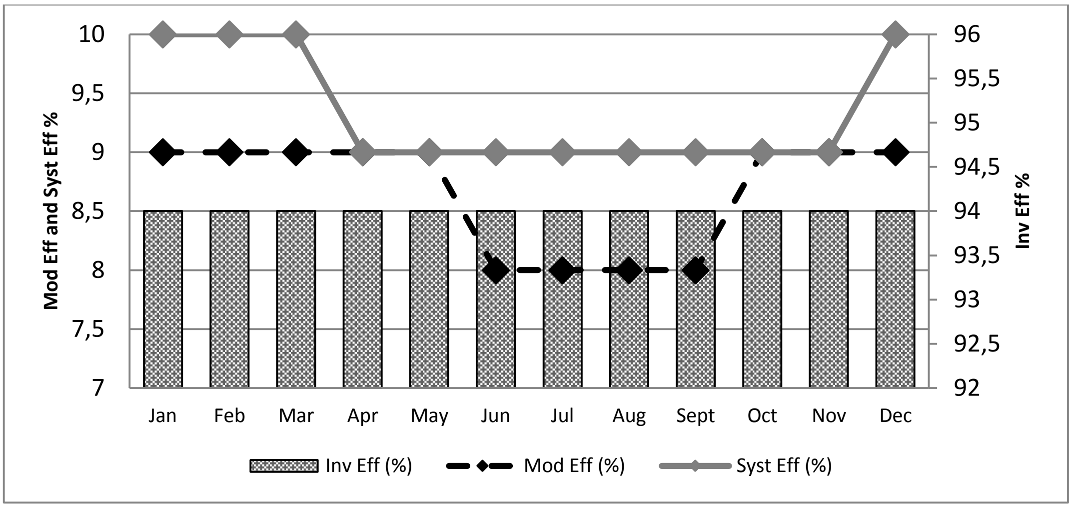


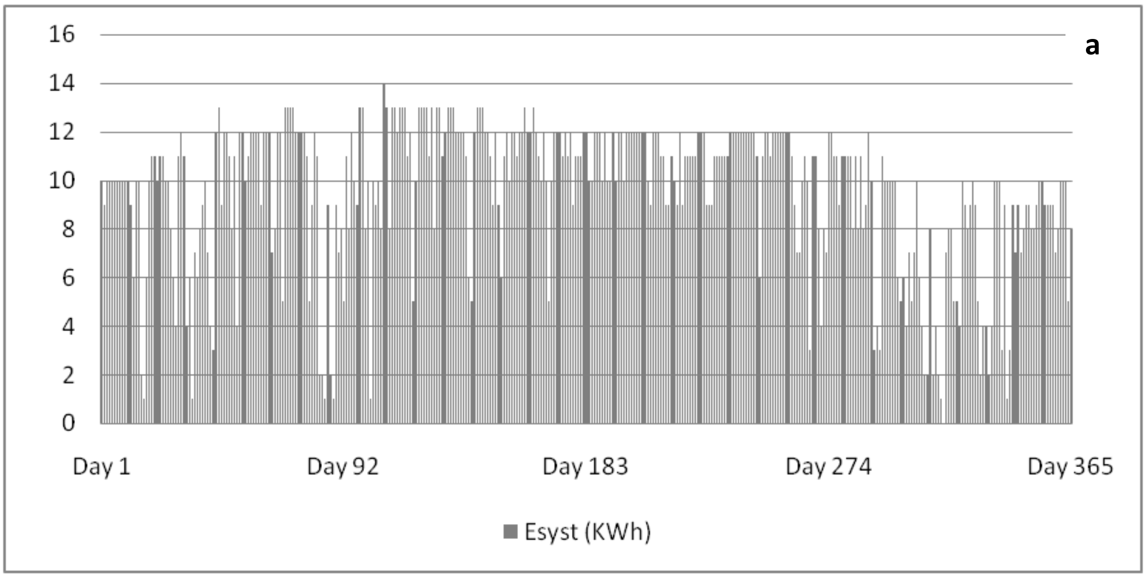
Fig. 9. Monthly efficiencies: system and module (left axis), inverter (right axis).

Obviously, a 2kWp system if installed in Oujda will work efficiently. Moreover, the daily electrical production of this system can reach 12kWh in the majority of the days of the year, whereas, the daily amount of electricity injected in the grid fluctuates between 9 and 11 kWh in most days of the year, see figure 10.

Finally, the most relevant simulation results are summarized in table 2.

Table 2: Simulation’s key results

Meteorological Data		
Global horizontalirradiance (GHI)	1891	kWh/(m²·a)
Diffuse horizontalirradiance (Diff)	652.6	kWh/(m²·a)
Meanannualambienttemperature	18.3	°C
Simulation results		
Electricitygeneration	3230.1	kWh/a
Mean system efficiency	8.6	%
Mean module efficiency	9.3	%
Meaninverterefficiency	94	%
Annualyield factor (YF)	1538.1	kWh/kWp
Full loadhours	1538	h/a



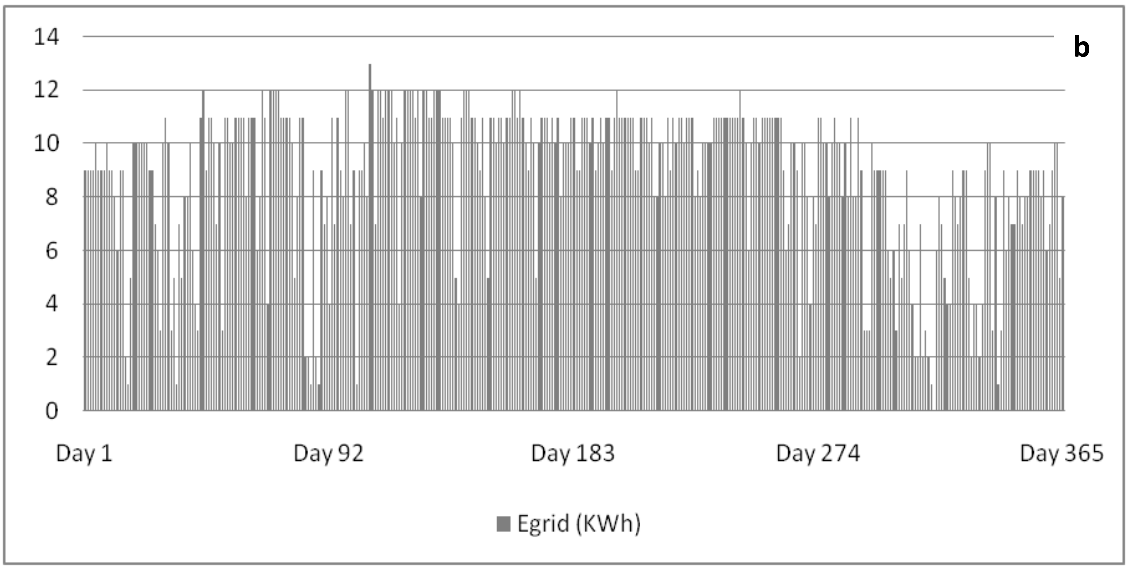


Fig. 10. The daily electricity produced (a) and injected on the grid (b)

4. CONCLUSION

In this paper, a simulation of the performance of a 2kWp rooftop PV system under the climate of Oujda city has been done using Greenius software and a full year of meteorological data (with one hour step). Those data were measured using high precision devices especially the irradiation.

With a GHI annual value of 1891 kWh/m²/year this system can produce 3230.1 kWh/year of electricity with a full load of 1538 hour per year.

The module's, the inverter and the system efficiencies are of 9.3%, 8.6% and 94% respectively and the annual yield factor is about 1538 kWh/kWp. These results are very encouraging and can give an idea for policymakers as well as for actors in the field of solar energy to move forward the integration of the small PV systems on buildings, which will undoubtedly decrease the energy bill and protect the environment in the Eastern region of Morocco.

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