OPEN ACCESS

International
Journal
Of Modern Engineering Research (IJMER)

Performance of photovoltaic installations according to the climatic and geographical conditions of northeastern Morocco.

Abdelkader DOUDOU
Mohammed First University of Oujda, Laboratory of Mechanics and Energetics, Multidisciplinary Faculty of Nador, BP 300, 62702 Selouane, Morocco.
Corresponding Author: Abdelkader DOUDOU, a.doudou@ump.ac.ma,

ABSTRACT: *Moroccan authorities have legalized the connection of photovoltaic installations to the national low-voltage network, and they will probably adopt the net billing method (Law N0. 58/2015). Knowing that the national electricity distributor ONEE (National Office of Electricity and Water) will only be able to purchase a small part of the electricity produced by private installations, oversized photovoltaic installations become a crucial issue for promoters and investors. In this situation, it is important to know the electrical productivity and efficiency of the photovoltaic installations obtained on each site. Thus, in each of the first 20 sites, including the Multidisciplinary Faculty of Nador, a photovoltaic installation with three silicon technologies: monocrystalline, polycrystalline and amorphous, each of 2kWp is installed and connected to the national electricity network. The installation is coupled to a weather station. The installation is acquired as part of the PROPRE.MA project supported by IRESEN (Institute for Research in Solar Energy and New Energies). The work carried out here focuses on the experimental analysis of the electrical productivity of technologies based on meteorological data by evaluating the performances. The results of the three technologies are then compared to the simulations of the PVsyst software.*

KEY WORDS: *Solar energy, Silicon technology, Power production, Meteorology, Metrology, Efficiency.*

Date of Submission: 05-03-2025 Date of acceptance: 16-03-2025

I. INTRODUCTION

Experts around the world are researching strategies to reduce energy demand, methods to secure energy supplies, technologies to increase power grid efficiency, new and renewable energy sources to replace limited and harmful fossil fuels. Renewable sources are the effective choice to reduce energy dependence, environmental pollution and global warming. Morocco is a country rich in renewable energy sources (wind, hydraulic and solar), but these are little exploited [1]. Since 2009, sustainable development has been a leitmotif of Moroccan policies. Renewable energies, energy efficiency and environmental preservation permeate political discourse. Indeed, in a context of high oil prices having a significant impact on the trade balance, renewable resources constitute the most interesting alternative to help Morocco support its economic vulnerability.

The Moroccan renewable energy strategy aims to achieve an electricity production of 6 GW by 2030 equivalent to 52% of installed capacity from renewable resources, which will allow an annual saving in greenhouse gas emissions equivalent to 3.7 million tons of CO_2. In 2009, Morocco put in place several instruments; A Moroccan Solar Plan with a budget of 9 billion dirhams (0.9 billion American dollars) and a dedicated MASEN agency (Moroccan Solar Energy Agency) were set up in 2009. In the building sector, ADEREE (National Agency for development of renewable energies and energy efficiency) contributes to promoting renewable energies, while IRESEN contributes to promoting scientific research in the field of renewable energies.

To meet its energy needs, Morocco inaugurated in 2010 a thermodynamic combined cycle power plant located in Ain Beni-Mathar in the Oriental region of 20 MW out of 470 MW of the complete project. In 2013, the

Ouarzazate NOOR solar complex was inaugurated. At present, CSP parabolic trough plants; NOOR I at 160 MW and NOOR II at 200 MW are already operational. NOOR III is the third CSP complex in the complex and the first tower. The latter plant has a molten salt storage capacity of 7.5 hours and is expected to be commissioned by the end of 2018. The phase I of the NOOR Midelt project was launched soon in May 2019; the commissioning date is planned for 2024. Its phase I should include two hybrids concentrated solar (CSP) and photovoltaic (PV) power plants of 400 MW each. For each project, CSP would provide 150 to 190 MW with minimum storage duration of 5 hours. At the end of 2018, the Kingdom had a solar capacity of 700 MW, also thanks to the Noor Laayoune (85 MW) and Noor Boujdour I (20 MW) power plants. Furthermore, the ONEE has developed a program of medium-sized photovoltaic (PV) solar power plants through 3 projects; Noor Tafilalet-Erfoud (120 MW) commissioned in 2020, Noor Atlas (200 MW) launched in 2021, commissioning is planned for 2024 and Noor Argana (200 MW) commissioned in 2020. Regarding wind power, Morocco currently has a capacity of 900 MW, including the Khalladi private park, with an installed capacity of 120 MW, operational since December 2017. The Taza wind farm (150MW) launched in 2020 and will be commissioned in 2024, as well as the 850 MW integrated wind project: Tanger II (100 MW), Jbel Lahdid (200 MW) and Midelt (150 MW), Tiskrad (300 MW) and Boujdour (100 MW) and will be commissioned in 2024. And that's not all, other projects have been carried out, including Aftissat (201.6 MW). The project is located south of Boujdour; it will be commissioned in 2019.

In the same sense, the connected photovoltaic network can be a means for the emergence of decentralized production of DC photovoltaic energy. Anyone owning a residential house, a municipal building or another establishment can build a photovoltaic generator and become a producer of renewable energy by injecting all or part of the DC photovoltaic energy produced into the public distribution network. ONEE can systematically purchase the energy produced at preferential rates, defined in the regulatory framework decided by the government.

The PROPRE.MA project supported by IRESEN constitutes a modest contribution to these national efforts. The project is based on the use of soil calibration by DC photovoltaic production measurements on around twenty sites uniformly distributed across the national geography for three silicon technologies whose objectives can be summarized as follows:

- Integration of time measurements to obtain monthly (kWh/Wp/Month) and annual (kWh/Wp/Year) productivity.
- Use of on-site measurements to carry out an experimental calibration of a productivity chart based on that of solar radiation and temperature.
- Proposal of a correlative method which would be easily extended to other regions of Morocco.

The innovation of the project lies in the creation of a national network of measurement sites and updated data essential for future projects in the photovoltaic sector. The contribution of this article to the PROPRE.MA project is to measure electricity production from solar radiation using three silicon-based photovoltaic technologies; mc-Si, pc-Si and a-Si according to meteorological data obtained from the meteorological installation located near the photovoltaic installation. The two facilities are located on the roof of the research block of the Multidisciplinary Faculty of Nador (PFN), in the province of Nador, in the northeast of Morocco. The measurements will be used to analyze DC photovoltaic production based on meteorological data, then to compare DC photovoltaic production obtained by the three silicon technologies by estimating the performance of each. Finally, a comparison of the experimental data will be carried out with the simulation results obtained by the commercial software PVsyst.

II. BASIC THEORETICAL BACKGROUND

2.1 Solar radiation

Solar energy is nothing other than the light energy emitted by the sun (Figure 1). Light energy is composed of several monochromatic rays; each of a specific wavelength. The curve of light energy versus wavelength is the solar spectrum. The average solar spectrum on the ground depends on GPS (Global Positioning System) coordinates. In this case, the same spectrum at a given position of the ground depends on the inclination of the sun and climatic conditions. The spectrum is characterized by a coefficient, called Air Mass (AM), corresponding to the thickness of the atmosphere crossed by the solar rays [2].

The light at the outer edge of the Earth's atmosphere, corresponding to the so-called zero air mass (AM0), is defined as the extraterrestrial insolation (Go), variable quantity, but generally taken as 1366.1 W/m^2 for practical applications [3]. When the sun's rays pass through the Earth's atmosphere, they are attenuated by various atmospheric constituents; notably in descending order of their relative effects on solar rays under a clear (cloudless) sky: Aerosols (Die Light Scattering), particles (Rayleigh scattering), Water Vapor, Ozone, Carbon Dioxide and Oxygen.

The level of attenuation depends on the concentration of atmospheric components and the length of the path traveled by the sun's rays. If the sun is directly overhead, the path length is minimum, and the air mass is one air mass (AM1). As the sun's elevation above the horizon decreases, the sun's rays must travel a greater distance before reaching the ground. Thus, the air mass will increase. For many solar PV applications, an air mass of 1.5 (AM1.5) with an associated irradiation of 1000 W/m^2 (1 sun) is considered a standard atmospheric condition. The precise definition of standard atmospheric conditions AM1.5 (ASTM G-173) can be found in articles [4-12].

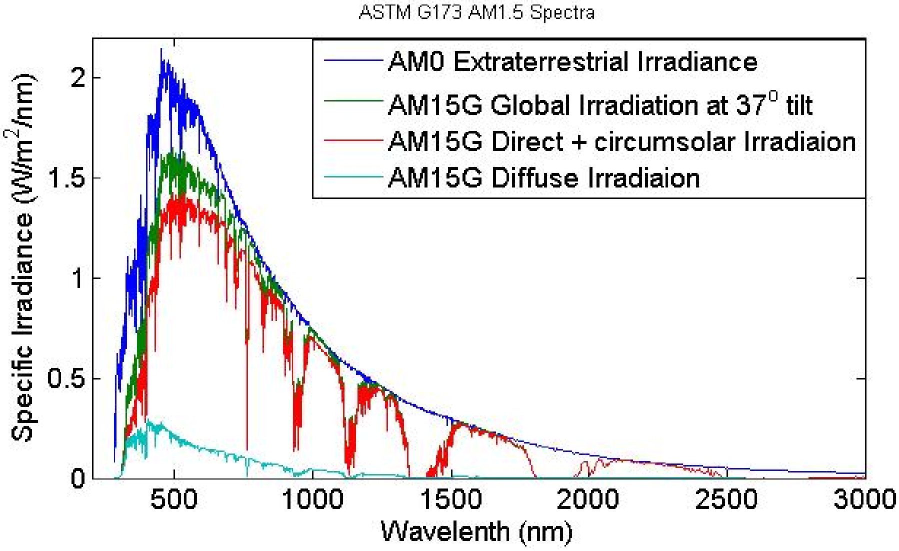

Figure 1: Solar energy spectrum

Morocco with solar radiation of 320 days/year (3000 hours/year) and average solar radiation of 5.5 kWh/m²/day (figure 2) [13] can be a leading country in the installation of photovoltaic power plants connected to the network. and produce electricity on an industrial scale.

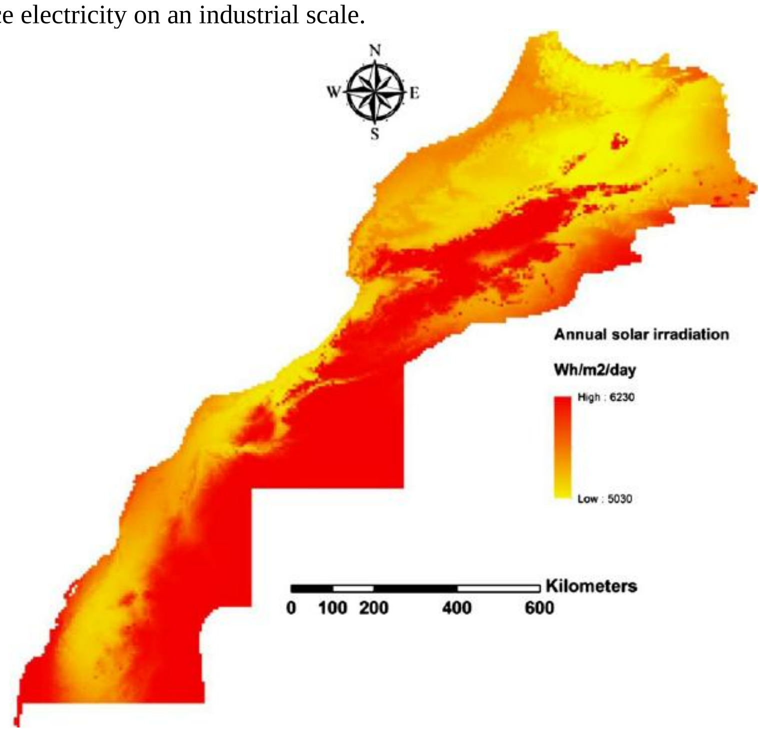

Figure 2: Annual mean solar irradiation map of Morocco as obtained by the ANN aboriginal technique [13].

2.2 Photovoltaic Solar Energy

The term "photovoltaic" can refer to the physical phenomenon or the associated technology. Photovoltaic solar energy is electricity produced by transforming part of solar radiation using a photovoltaic cell. The photovoltaic cell is the elementary component of a photovoltaic panel. Photovoltaic cells exploit the photoelectric effect to produce direct current by absorbing solar radiation. The photoelectric effect was first noticed by a French physicist, Edmund Becquerel, in 1839, who discovered that certain materials produced small amounts of electric current when exposed to light [14,15]. This effect allows cells to directly convert the light energy of photons into electricity using a semiconductor material carrying electrical charges. A photovoltaic cell is made of two types of semiconductor materials, one with an excess of electrons and the other with a deficit of electrons. These two parts are called n-type and p-type "doped" respectively. Doping silicon crystals involves adding other atoms to improve the conductivity of the material. A silicon atom has four peripheral electrons. One of the layers of the cell is doped with phosphorus atoms, which themselves have five electrons (1 more than silicon). We speak of n-type doping as negative because the electrons (of negative charge) are in surplus. The other layer is doped with boron atoms which have three electrons (1 less than silicon). We speak of p-type doping as positive because of the electronic deficit thus created. When the first is brought into contact with the second, the excess electrons in the n material diffuse into the p material. As they pass through the photovoltaic cell, the photons snatch electrons from the silicon atoms of the two n and p layers. The released electrons then move in all directions. After leaving the p layer, the electrons then take a circuit to return to the n layer. This movement of electrons is nothing other than electricity (figure 3). The effect therefore relies on the semiconductor properties of the material and its doping, to improve the conductivity [16].

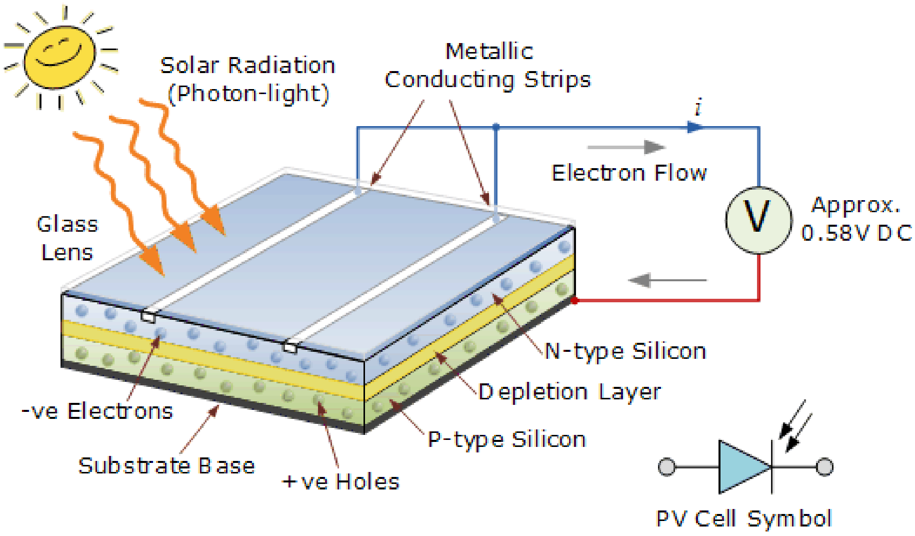

Figure 3: Equivalent circuit of the photovoltaic effect. (http://www.alternative-energy-tutorials.com)

Photovoltaic model

The *I-V* characteristic of the solar cell changes with the global solar radiation intensity G (W/m^2) and the cell temperature *t*(ºC), i.e. $I = f(V,S,t)$. According to electronics theory, when the load is pure resistance, the actual equivalent circuit of the solar cell corresponds to that in Figure 5 [17]. I_L is the current supplied by a solar cell.

$$I = I_L - I_0\left[e^{\left(\frac{q(V+IR_s)}{AkT}\right)} - 1\right] - \frac{V+IR_s}{R_{sh}} \tag{1}$$

I_d: the junction current of the diode, is estimated as:

$$I_d = I_0\left[e^{\left(\frac{q(V+IR_s)}{AkT}\right)} - 1\right]$$

where:

I: Load current,
I_L: Photovoltaic current,
I_0: Reverse saturation current,
q: Electronic charge,
k: Boltzmann constant,
T: Absolute temperature,
A: Diode quality factor,
R_s: Series resistance,
R_{sh}: Parallel resistance

Another important parameter is the open circuit voltage V_{OC}:

$$V_{OC} = \frac{kT}{q} In\left(\frac{I_L}{I_o} + 1\right) \approx \frac{kT}{q} In\left(\frac{I_L}{I_o}\right) \tag{2}$$

Figure 5 illustrates an IV function with the power curve, to illustrate the position of the maximum power point

[18]. The equivalent diagram (figure 4) of the real photovoltaic cell includes a current generator, which models the lighting and a diode in parallel which models the PN junction, and two resistors, one in series R_s and the other in parallel R_{sh} [19].

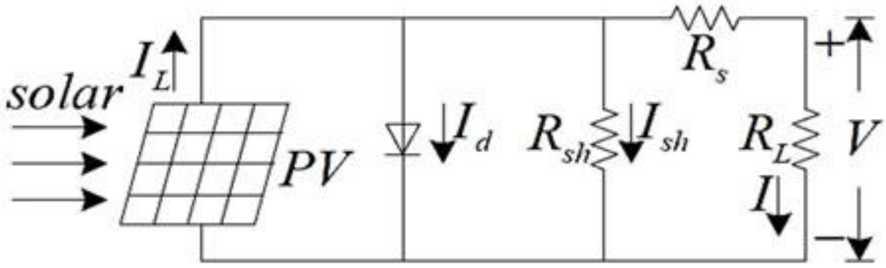

Figure 4: Equivalent circuit diagram of a real PV cell.

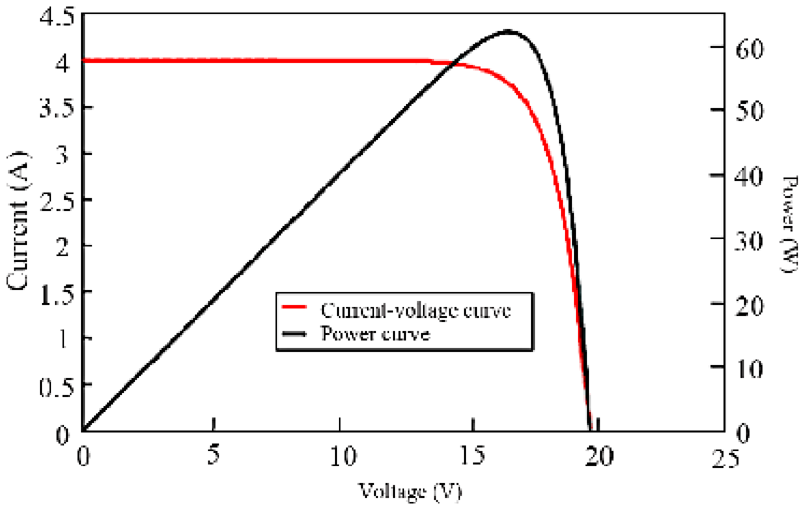

Figure 5: Typical I-V characteristic of a module with the variation of power [18]

a) Photovoltaic system efficiency

The efficiency of the PV system is the efficiency of the entire system, including the PV generator and the inverter [20]. It is the ratio of the AC energy injected into the network to the overall incident irradiance G on the surface inclined at 30° of 1 m^2 times the surface of row A [21]. The analytical expression allowing the efficiency of the system to be expressed is written [22]:

$$e = \frac{E_{AC}}{G \cdot A} \tag{3}$$

b) Photovoltaic cells

Currently on the market, there are three predominant and recognized technologies: mc-Si, pc-Si and a-Si (Fig. 6). The definitions of each of them are reported here below:

<u>mc-Si cells:</u>

The silicon is melted twice to solidify and form a large single crystal. The crystal is then cut into thin slices to form cells. These cells are usually uniformly blue. Their efficiency is around 14 to 16% and they are more expensive than pc-Si cells.

Use: Its high efficiency can make it possible to integrate a 2kWp photovoltaic field on a small roof with a small surface area.

<u>pc-Si cells:</u>

These are currently the most used. They are made up of a block of crystalline silicon made up of several crystals of different orientations. The photovoltaic cell is bluish but not uniform; the different crystals distinguish the patterns. Their efficiency is around 11-13%, but their cost is lower than that of mc-Si cell production.

Use: Less expensive than mc-Si these days, while having the same thermal resistance characteristics, pc-Si panels are perfectly suited to a project with a power of 3 kWp.

(a) mc-Si (b) pc-Si (c) a-Si

Figure 6: Three technologies of PV silicon cells

a-Si cells:

a-Si cells are made of a glass or synthetic material support on which a thin layer of silicon is spread; the organization of atoms is more regular than in a crystal. a-Si cells have the advantage of operating with little light (on cloudy days for example) and of being less sensitive to high temperatures than mc-Si or pc-Si cells. However, their yield is low; it's between 5 and 10%. The flexibility of a-Si cells allows them to be mounted on curved supports. In addition, neither the lightness of the panels (nor the weight of the device must be greater than 5kg/m²), nor the stability of the supports must be reinforced. The guarantee of the nominal installed power after 20 years of operation is 80% for the most recent products.

Use: a-Si cells are preferable when we have a large field and want to optimize our production. These cells are often used when strong heating of the modules is expected. These panels are often used for so-called "professional" projects whose power exceeds 3 kWp.

2.3 Grid-connected photovoltaic power systems

A mini photovoltaic solar installation is made up of modules, each made up of silicon photovoltaic cells most often. These generators convert solar energy directly into DC (direct current) electricity. The power is expressed in Watt-peak unit (Wp) which defines the power available at the generator terminals in optimal sunshine conditions. Then a Sunny Boy inverter converts direct current (DC) into alternating current (AC) at 50 Hz and 220 V. Depending on the choice, all or part of the production is injected into the public network, and the rest is consumed by the producer. When photovoltaic production is insufficient, the network provides the necessary electricity. In special cases, mainly in regions subject to regular power outages, it may be advantageous to add batteries for energy storage to the photovoltaic generator fleet. We are then talking about a secure system for producing electricity, even in the event of a breakdown in the power supply from the public network (bad weather, devastating cyclone, …etc.).

III. EXPERIMENTAL DETAILS

The photovoltaic system (Figure 7), mounted with a meteorological station on the roof of the Research Block of the Multidisciplinary Faculty of Nador (PFN) (north latitude 35°3'53.751", west longitude 2°54'37.504", altitude 29m) province of Nador in the northeast of Morocco, belongs to the PROPRE.MA project. The project supported by IRESEN, in which twenty national academic institutions plus three others (Figure 8) and one company are involved, aims to establish a table where photovoltaic productivity will be compiled to guide future photovoltaic projects [24-29]. The weather station provides air temperature, wind speed and direction as well as solar radiation in horizontal and 30° inclined planes [30-33]. The installation consists of three rows of independent panels of three different silicon-based photovoltaic technologies: mc-Si, pc-Si and a-Si of 2 kWp of power each. All three inverters of the same brand and model convert direct current (DC) to alternating current (AC). To reduce losses on the DC side, the inverters are mounted outside, just in the shade of the modules. DC photovoltaic productivity measurements are carried out based on meteorological data. The characteristics of the three technologies are presented in Table 1. In Table 2 the nominal specifications of the photovoltaic modules are summarized, as extracted from the standard technical data sheets of the manufacturers.

Table 3 shows the nominal specifications of each PV row, calculated from the manufacturer's standard data sheets, according to the system configuration shown in Figure 7. It is important to note that the tilt angle (30°) is almost equal to the latitude of Nador, almost the optimal value for capturing maximum solar energy each year

Table 4 shows the nominal specifications of the inverters, taken from the manufacturer's standard data sheet.

No instructions were given for cleaning the modules. Like all other Moroccan cities in the project, the modules should only be cleaned (with soap and water) when visual inspection of the site reveals unacceptable clogging of the modules. As a result, the AC efficiencies that will be presented below more closely resemble what they should be for common silicon-based PV technologies connected to a home PV grid. Therefore, AC efficiencies may even be slightly higher for professionally maintained installations.

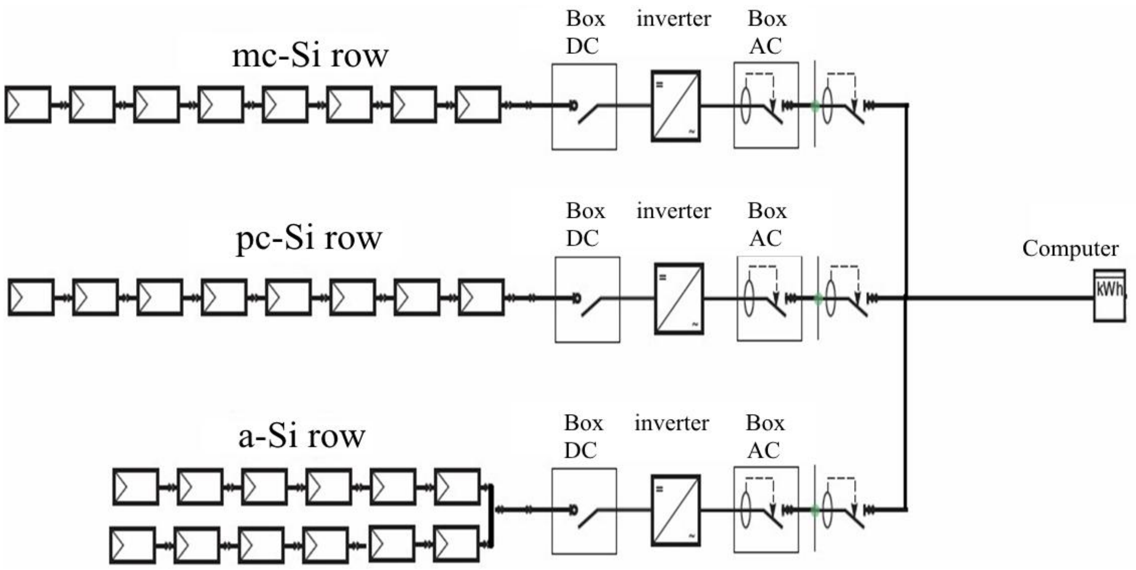

Figure 7: Diagram of PV generators duplicated in 21 cities

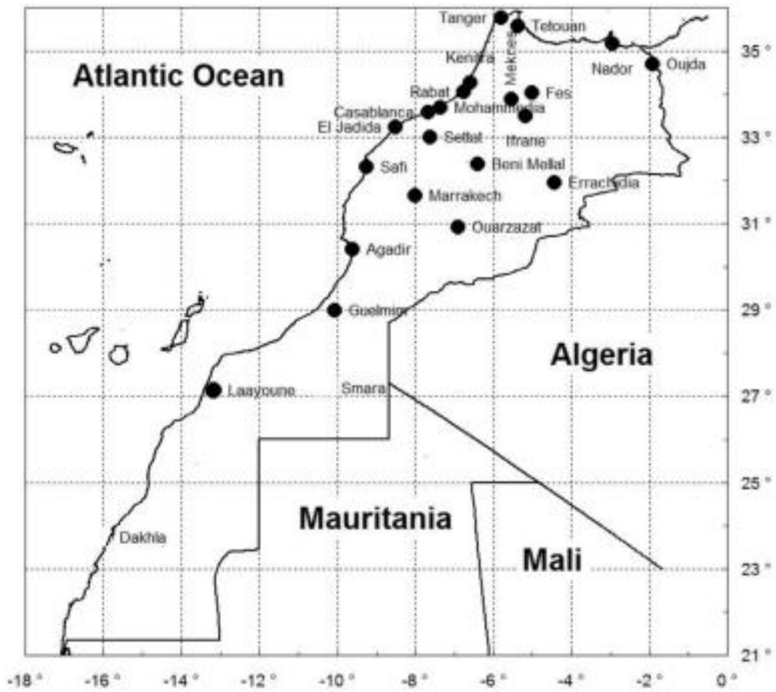

Figure 8: Position of the calibration points in 21 academic sites.

IV. RESULTS AND DISCUSSIONS

The production of photovoltaic installations is not stationary over time; and it may depend on several factors as follows:

4.1 Solar radiation

In Figure 9, it is possible to represent the solar radiation captured in the horizontal plane and the 30° inclined plane of the weather station for certain winter and summer days. There is an obvious gap between the solar radiation of horizontal and inclined planes in summer, but in winter the gap becomes minimal. Another important note is that solar radiation is greatest in the middle of the day in winter with short daylight hours. Concerning the two irradiations, we note that the irradiation of the inclined panel is slightly higher than that of the horizontal panel and is close to the behavior of the energies released by three silicon technologies compared to the irradiation of the horizontal panel [34].

Table I. **Manufacturer cell nominal specifications.**

Cell	a-Si	pc-Si	mc-Si
Yield at standard conditions* (%)	7–8	11–13	14–16
Normal operating cell temperature (°C)	45	45	NC
Panel area per 1 kWp** (m²)	16	8	7
Power produced (kWh/y)	900	750	750
Energy produced (kWh/m²/y)	55–60	90–95	90–95
Emission of CO_2 saved (kg/kWp/y)	390	325	325
Emission of CO_2 saved (kg/m²/y)	25	40	45

* Standard Test Conditions: 25°C, light intensity of 1000W/m^2
** kWp = kilowatt 'peak'

Table II. **Manufacturer module nominal specifications.**

Module	pc-Si	mc-Si	a-Si
IEC standard certification	IEC 61,215	IEC 61,215	IEC 61,646
Number of cells per module	60	60	127
Cells size	6	6	~ 1/3
Nominal power (W)	255	255	155
Temperature coefficient of power (/K)	−0.410%	−0.450%	−0.280%
Tolerance on power	0 to + 2%	0 to + 2%	0 to + 3%
Nominal open circuit voltage (V)	38	37.8	85.5
Temperature coefficient open circuit voltage (/K)	−0.310%	−0.300%	−0.320%
Nominal voltage at maximum power (V)	30.9	31.4	65.2
Nominal short circuit current (A)	8.88	8.66	2.56
Temperature coefficient short circuit current	0.051%	0.004%	0.070%
Nominal current at maximum power (A)	8.32	8.15	2.38

Table III. **Row nominal specifications as calculated from the standard manufacturers' datasheets.**

PV row	pc-Si	mc-Si	a-Si
Number of strings per row	1	1	2
Number of modules per string	8	8	6
Nominal power (W)	2040	2040	1860
Nominal open circuit voltage (V)	304	302.4	513
Nominal voltage at maximum power (V)	247.2	251.2	391.2
Nominal short circuit current (A)	8.88	8.66	5.12
Nominal current at maximum power (A)	8.32	8.15	4.76
Modules orientation	Facing south		
Modules tilt angle (°)	30		

4.2 Temperature

Figure 10 shows four graphs of panel temperature and weather station air temperature near the panels for two days in winter and summer; the first is poorly sunny and the second is perfectly sunny. Typically, panel temperatures are higher than nearby air temperatures during the day. However, at night or on cloudy days, the panel and air temperatures are the same. In addition, the temperature of a-Si panels is always higher than that of pc-Si panels. The temperature of the mc-Si panels is always lower than that of the other two.

4.3 Power production

Figure 11 shows the energy productivity of the three types of solar panel rows with solar radiation tilted at 30° in winter and summer, with the first and third graphs for cloudy days and the second and fourth graphs for sunny days. On bad days, energy productivity is very strongly affected and disrupted [35]. Power generation on good days is supported by slightly elevated power generation in winter during the middle of the day. However, in summer, production extends to sunnier hours. Moreover, the energy productivities of mc-Si and pc-Si panel rows are almost equal, slightly higher for pc-Si panel rows. The energy production of the rows of a-Si panels is always lower than that of the other two. In the same figure we can see that the rows of panels start producing energy even though the sun has not yet risen in the morning, so the power is greater than the solar radiation. According to these graphs, photovoltaic energy production mainly depends on solar irradiation [36,37].

***Table IV.* Inverter nominal specifications as extracted from the standard manufacturer's datasheet.**

	Inverters	All systems
power (W)	Nominal	2000
	Maximum	2100
Efficiency	Maximum	96.3%
	European	95.0%
DC voltage (V)	Minimum	175
	Maximum	560
DC current (A)	Maximum	12
AC voltage (V)	Nominal	230
	Minimum	180
	Maximum	280
AC current (A)	Maximum	11.4
Frequency (Hz)	Nominal	50
	Minimum	45.5
	Maximum	54.5

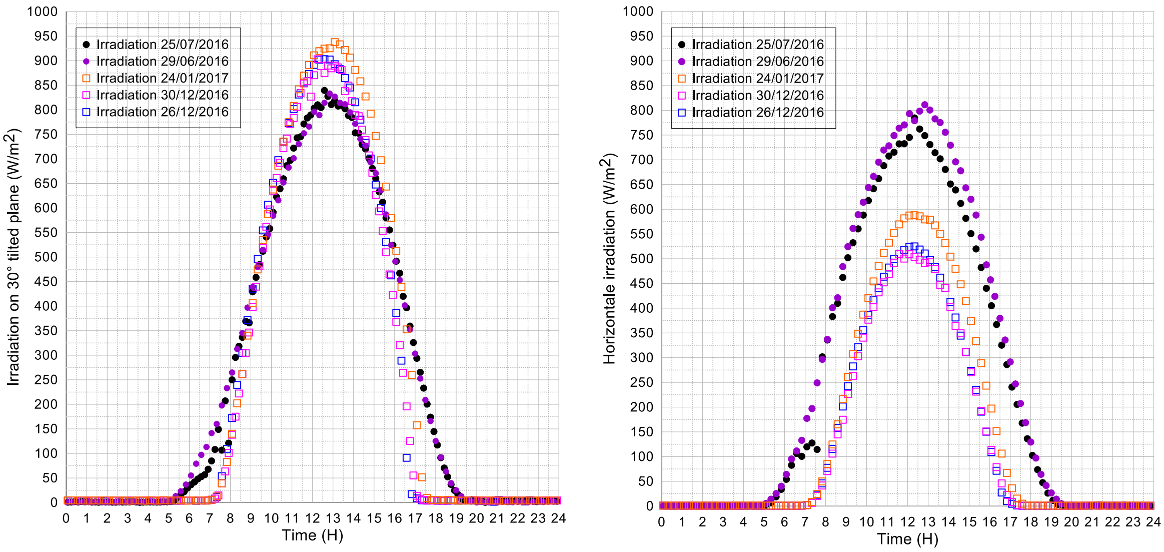

Figure 9: *Daily solar irradiation in winter and summer for 30°-inclined and horizontal planes.*

Figure 12 shows the electricity production for the three technologies during the year 2015. Production is higher in July but also in May and March. This means that electricity production depends on solar radiation and is independent of the seasons. However, in winter and autumn the days are cloudier. This condition implies low energy production during these two seasons.

A comparison made between the experimental power generation results for mc-Si panel rows and the theoretical results obtained using the PVsyst software is shown in Figure 13. Both give similar results [38], and the small differences (April for example) are due to the fact that the experimental results are attenuated by cloudier days in April 2015 than in normal years. However, other factors can alter the energy production of the rows of panels, such as dust and bird droppings.

4.4 Efficiency

Figure 14 shows the time-dependent efficiency of three silicon PV solar arrays. Efficiency is calculated from measured data as a ratio of electricity production to solar radiation on a 30° inclined plane, like equation 2, for the two good sunny days only. The yield is stable in general but low at the start and end of the day. The a-Si yields are respectively 9 and 10% in winter and summer while for the rows of mc-Si and pc-Si panels it is around 15% all year round. It can also be noted that pc-Si lines start producing earlier than mc-Si and a-Si technologies. It can be noted that the experimental efficiency values are in perfect agreement with the manufacturers' values [22].

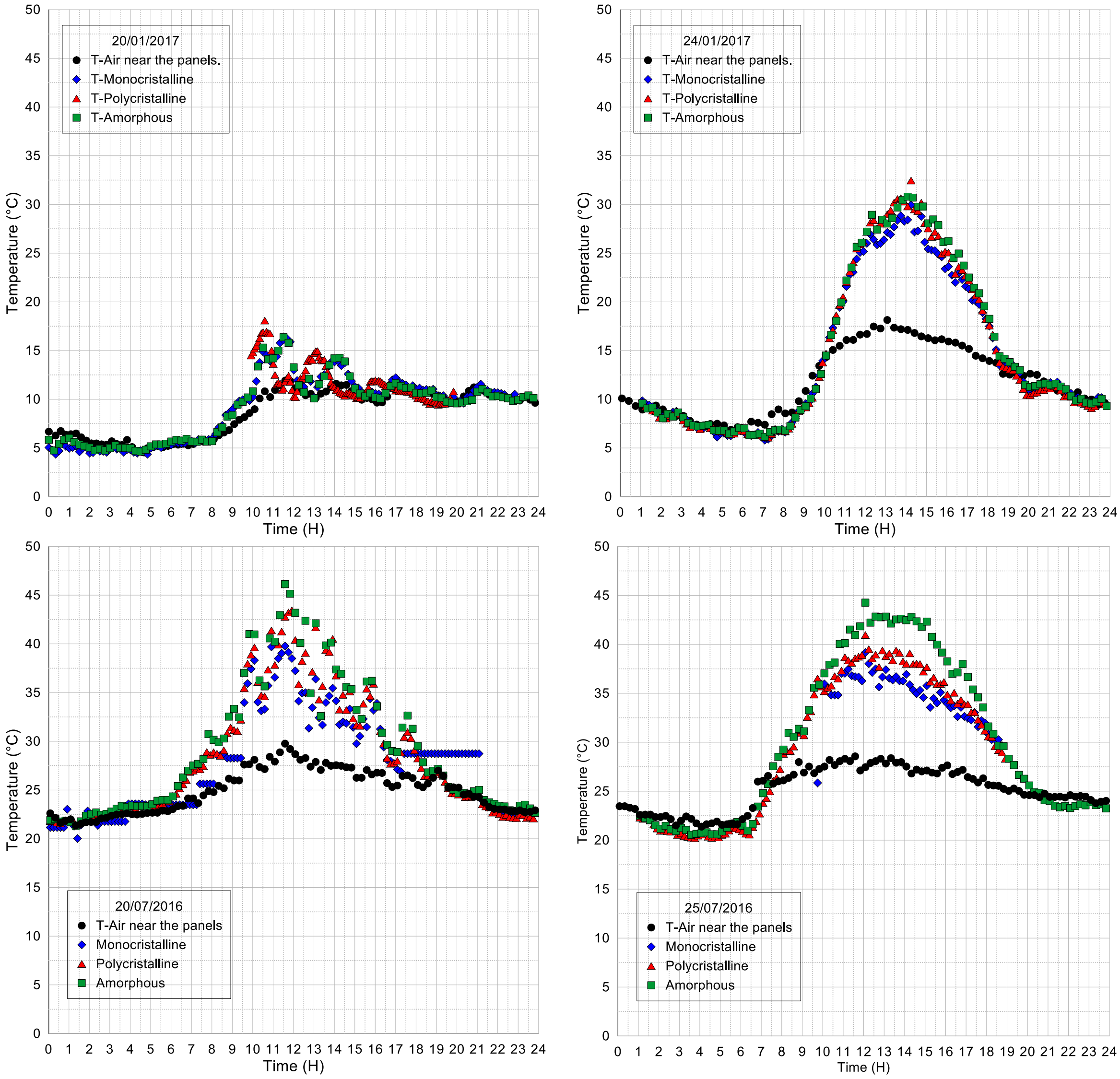

Figure 10: Daily temperature for sunny days in winter and summer.

V. CONCLUSIONS

The analysis of the results of the photovoltaic installation with the data from the meteorological station led to important remarks:

- The climatic conditions and geographical position of the Nador site are favorable to pc-Si technology because its production is better than that of mc-Si and a-Si.
- The energy produced in spring is maximum; however, the rest of the year it does not undergo significant attenuations (does not exceed 30%).
- The efficiency of the installation depends initially on the irradiation received at the level of the rows of panels and secondly on the ambient temperature. The mc-Si and pc-Si panel arrays have equivalent and higher outputs than a-Si.
- In the event of bad weather (opaque clouds, rain, etc.) production is greatly reduced (approximately 20% of production in good conditions).
- The yields of pc-Si and mc-Si technologies are almost the same 15% but better than those of a-Si technology 9% (winter) and 10% (summer).

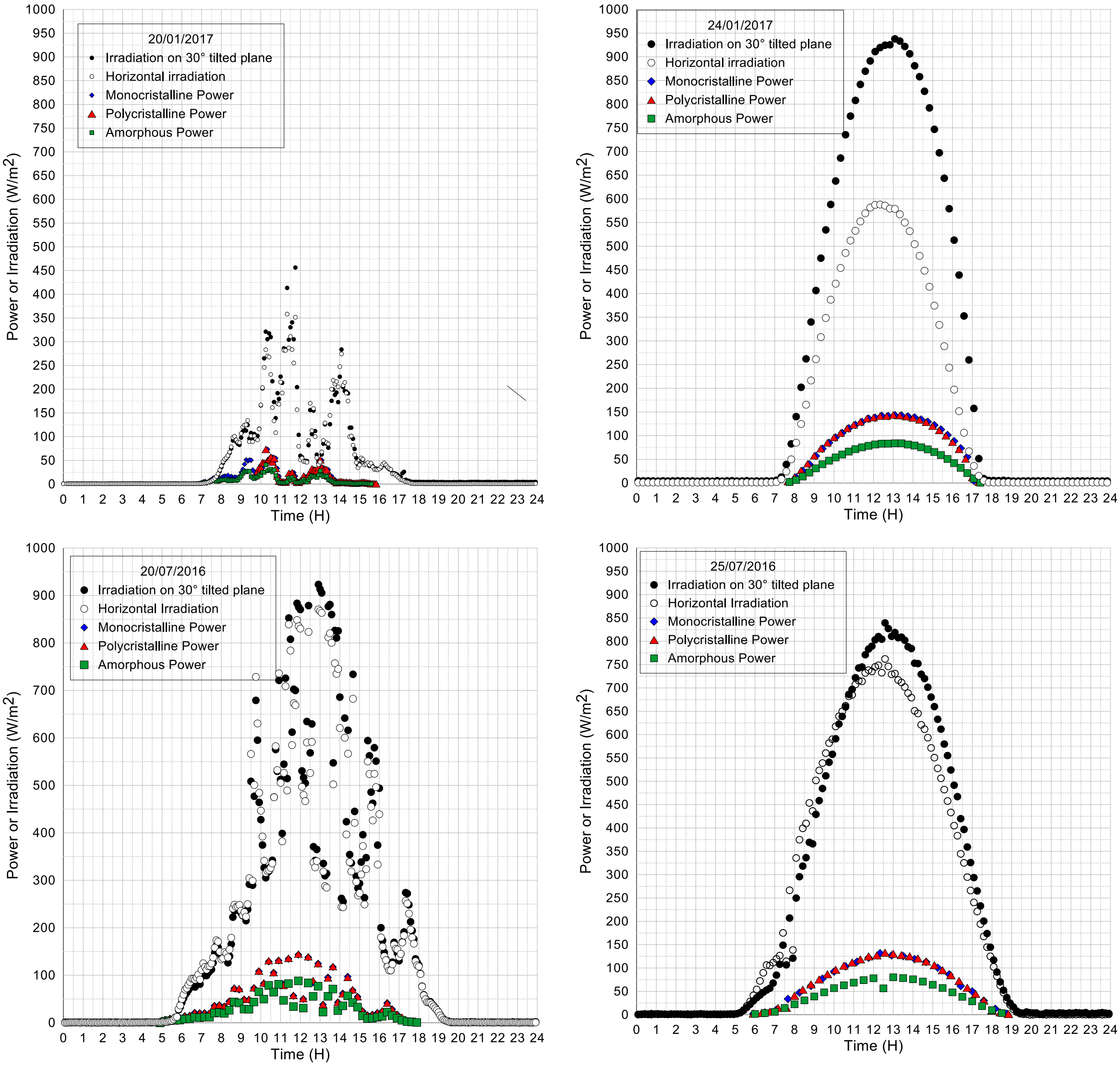

Figure 11: Daily power production in winter and summer.

- Production of pc-Si starts earlier in the morning than the other two technologies. The other mc-Si and a-Si technologies are slow to start production in the morning.

Of all the above findings, pc-Si technology is the most favorable in the climatic conditions of the province of Nador. We therefore recommend the use of pc-Si technology rather than the other two for the province of Nador.

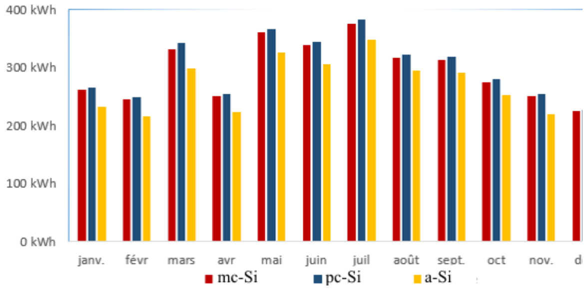

Figure 12: Monthly power production for the three technologies

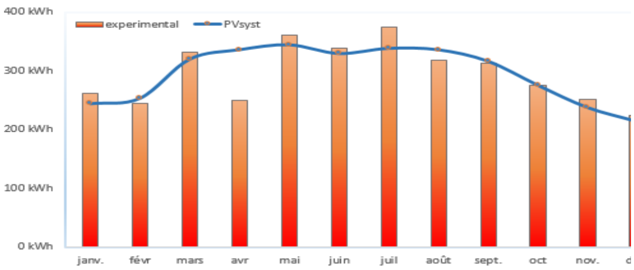

Figure 13: Monthly power production with PVsyst predictions for the mc-Si technology.

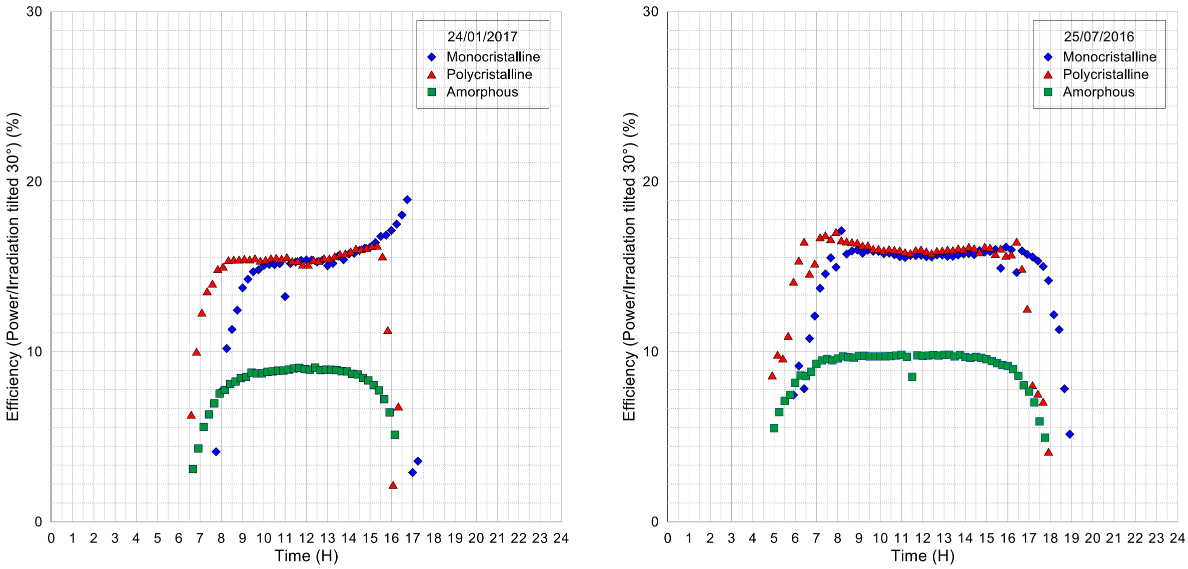

Figure 14: Daily efficiency for the three technologies in winter and summer.

REFERENCES

[1] J. Jäger, Étude du potentiel de développement de l'énergie photovoltaïque dans les régions de Meknès-Tafilalet, Oriental et Souss-Massa-Drâa, *la Coopération maroco-allemande Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH* (2011). http://www.abhatoo.net.ma/

[2] M. Hadrami, Conversion Photovoltaïque, *Master Course*, Mohammed First University 2013.

[3] C.A. Gueymard, The sun's total and spectral irradiance for solar energy applications and solar radiation models, *Solar Energy 2004*, 76(4), 423-453, https://doi.org/10.1016/j.solener.2003.08.039

[4] D.G. Collins, W.G. Blattner, M.B. Wells, H.G. Horak, Backward Monte Carlo Calculations of Polarization Characteristics of the Radiation Emerging from Spherical Shell Atmospheres, *Applied Optics* 1972, 11(11), 2684-2696. https://doi.org/10.1364/AO.11.002684

[5] R.E. Bird, R.L. Hulstrom, L.J. Lewis, Terrestrial Solar Spectral Data Sets, *Solar Energy 1983,* 30(6), 563-573. https://doi.org/10.1016/0038-092X(83)90068-3

[6] C. Gueymard, Parameterized transmittance model for direct beam and circumsolar spectral irradiance, *Solar Energy 2021*, 71 (5), 325-346. https://doi.org/10.1016/S0038-092X(01)00054-8

[7] C; Gueymard, D. Myers, K. Emery, Proposed reference irradiance spectra for solar energy systems testing, *Solar Energy* 2002, 73(6), 443-467. https://doi.org/10.1016/S0038-092X(03)00005-7

[8] N. Kata, D. Diouf, A. Darga, and A.S. Maiga, The effect of the recombination mechanisms location on the temperature sensitivity of thin-film photovoltaic cells, EPJ Photovoltaics 2019, 10(8), https://doi.org/10.1051/epjpv/2019008.

[9] S.R. Kurtz, D. Myers, T. Townsend, C. Whitaker, A; Maish, R. Hulstrom, K. Emery, Outdoor Rating Conditions for Photovoltaic Modules and Systems, *Solar Energy Materials* 2000, 62(4), 379-391. https://doi.org/10.1016/S0927-0248(99)00160-9

[10] D.R. Myers, S.R. Kurtz, C. Whitaker, T. Townsend, Preliminary Investigations of Outdoor Meteorological Broadband and Spectral Conditions for Evaluating Photovoltaic Modules and Systems, Program and Proceedings: *NCPV Program Review Meeting* 2000, 16-19, Denver, Colorado.

[11] D.R. Myers, S.R. Kurtz, K. Emery, C. Whitaker, T. Townsend, Outdoor Meteorological Broadband and Spectral Conditions for Evaluating Photovoltaic Modules, *Conference Record of the Twenty-Eighth IEEE Photovoltaic Specialists Conference* 2000, 15-22 September, Anchorage, Alaska. https://doi.org/10.1109/PVSC.2000.916104.

[12] United States Committee on Extension to the Standard Atmosphere, U.S. Standard Atmosphere, 1962: ICAO extension to 32 kilometers. Committee on Extension to the Standard Atmosphere, U.S. Government Printing Office, Washington, D.C., 1962.

[13] A. Ouammi, D. Zejli, H. Dagdougui, R. Benchrifa, Artificial neural network analysis of Moroccan solar potential, *Renewable and Sustainable Energy Reviews* 2012, 16(7), 4876-4889. https://doi.org/10.1016/j.rser.2012.03.071

[14] http://www.rise.org.au/info/Education/ SAPS/sps003.html, February 2010.

[15] http://science.nasa.gov/headlines/y2002/ solarcells.html, February 2010.

[16] A. Benhmed, M. Temimi, Études des propriétés électriques des cellules photovoltaïques organiques, *Master Memory*, Abou-bakr Bekaid University, Tlemcen 2011.

[17] X.J. Ma, J.Y. Wu, Y.D. Sun, S.Q. Liu, The Research on the Algorithm of Maximum Power Point Tracking in Photovoltaic Array of Solar Car, *Vehicle Power and Propulsion Conference IEEE* 2009, 1379-1382. https://doi.org/10.1109/VPPC.2009.5289450

[18] N.M. Pearsall, R. Hill, Photovoltaic Modules, Systems and Applications, *Series on Photoconversion of Solar Energy: Clean Electricity from Photovoltaics* (2001) 671-712. https://doi.org/10.1142/9781848161504_0015

[19] J.F. Reynaud, Recherches d'optimums d'énergies pour charge/décharge d'une batterie à technologie avancée dédiée à des applications photovoltaïques, PhD Thesis, Toulouse University 2011.

[20] S. Sundaram, J.S. Chandra Babu, Performance evaluation and validation of 5 MWp grid connected solar photovoltaic plant in South India, *Energy Conversion and Management*, 2015, 100, 429-439. https://doi.org/10.1016/j.enconman.2015.04.069

[21] M. Malvoni, A. Leggieri, G. Maggiotto, P.M. Congedo, M.G. De Giorgi, Long term performance, losses and efficiency analysis of a 960 kWp photovoltaic system in the Mediterranean climate, *Energy Conservation and Management*, 2017, 145 169-181. https://doi.org/10.1016/j.enconman.2017.04.075

[22] M. Zaimi, H. El Achouby, A. Ibral, E.M. Assaid, M.S. EL Maliki, R. Saadani, Temporal monitoring of temperature and incident irradiance for predicting photovoltaic solar module peak power and efficiency using analytical expressions of model physical parameters, 6th International Renewable and Sustainable Energy Conference (IRSEC) 2018. https://doi.org/10.1109/IRSEC.2018.8702973

[23] A. Bennouna, N. Aarich, N. Erraissi, M. Akhsassi and M. Raoufi, Improving grid-connected PV dc yields obtained with daily models, *Environmental Risk Assessment and Remediation* 2017, 1(3). https://doi.org/10.4066/2529-8046.100021

[24] A. Doudou, Y. Tahiri, Cas d'une installation PV équipée d'une station météo sur le site de la faculté pluridisciplinaire de Nador, *13ème Congrès de Mécanique*, Meknès Maroc 2017, 11-14 Avril.

[25] Y. Tahiri, Montage et Caractérisation d'une installation Photovoltaïque installée à la Faculté Pluridisciplinaire de Nador, *Master Memory*, Université Mohammed Premier 2016.

[26] A. Doudou, Y. Allouch, Simulation and Experimental Study of Grid-Connected PV Systems (3×2kWp) at the Faculté Pluridisciplinaire de Nador, *1ère Edition de l'Ecole de Printemps; Matériaux, Propriétés & Applications* (MPA-1), Selouane, Nador, Morocco, 2015, June.

[27] Y. Allouch, Etude par modélisation, simulation et par voie expérimentale d'une installation photovoltaïque raccordée au réseau de la faculté pluridisciplinaire de Nador, *Master Memory*, Faculté des Sciences Aïn Chock-Casablanca, Université Hassan II Casablanca 2015.

[28] N. Aarich, N Erraissi, M. Akhsassi, A. Bennouna, A. Asselman, A. Barhdadi, L. Boukhattem, A. Cherkaoui, Y. Darmane, A. Doudou, A. el Fanaoui, H. el Omari, M. Fahoume, M. Hadrami, D. Moussaid, B. Hartiti, A. Ihlal, M. Khaidar, M. Aboufirass, Photovoltaic DC yield maps for all Morocco validated with ground measurements, *Energy for Sustainable Development*, 2018, 41, 158-169. https://doi.org/10.1016/j.esd.2018.10.003.

[29] A. Bennouna, N. Aarich, N. Erraissi, M. Akhsassi, A. Asselman, A. Barhdadi, L. Boukhattem, A. Cherkaoui, Y. Darmane, A. Doudou, A. El Fanaoui,, H. El Omari, M. Fahoume, M. Hadrami, B. Hartiti, A. Ihlal, M. Khaidar, A. Lfakir, H. Lotfi, K. Loudiyi, M. Mabrouki, D. Moussaid, M. Raoufi, A. Ridah, R. Saadani, I. Zorkani, M. Aboufirass and A. Ghennioui, Energy performance of 3 silicon-based PV module technologies in 20 sites of Morocco, *Energy for Sustainable Development*, 2019, 53, 30-56. https://doi.org/10.1016/j.esd.2019.09.002.

[30] N. Erraissi, N. Aarich, M. Akhsassi, M. Raoufi, A. Bennouna, Preliminary developments of a low-cost data acquisition system For The 3x20 Grid-Connected Pv Plants Of The Propre.Ma Project, *31st European Photovoltaic Solar Energy Conference and Exhibition* 2015, September.

[31] A. Elamim, B. Hartiti, A. Haibaoui, A. Lfakir, Ph. Thevenin, Performance evaluation and economical analysis of three photovoltaic systems installed in an institutional building in Errachidia, Morocco, *Energy Procedia* 2018, 147, 121-129. https://doi.org/10.1016/j.egypro.2018.07.041

[32] El M. Karami, M. Rafi, A. Ridah, B. Hartiti, Ph. Thevenin, Analysis of Measured and Simulated Performance Data of Different PV Modules of Silicon in Casablanca, *SSRN Electronic Journal* 2018, January. http://dx.doi.org/10.2139/ssrn.3127646

[33] N; Aarich, M.Raoufi, A.Bennouna, N.Erraissi, Outdoor comparison of rooftop grid-connected photovoltaic technologies in Marrakech (Morocco), *Energy and Buildings* 2018, 173, 138-149. https://doi.org/10.1016/j.enbuild.2018.05.030

[34] D.O. Akpootu, Y.A. Sanusi, A new temperature-based model for estimating global solar radiation in Port-Harcourt, south-south Nigeria. *The International Journal of Engineering and Science*, 2015, 4(1), 63-73.

[35] A. Purohit, Anshu Sharma, Arvind, S.P. Nehra, M.S. Dhaka, A study on photovoltaic parameters of monocrystalline silicon solar cell with cell temperature Subhash Chander, *Energy Reports*, 2015, 1, 104-109. https://doi.org/10.1016/j.egyr.2015.03.004.

[36] A. Khelifa, K. Touafek, Etude de l'influence des paramètres externes et internes sur le capteur hybride photovoltaïque thermique (PVT), *Revue des Energies Renouvelables* 2012, 15(1), 67-75.

[37] J.K. Copper, A.B. Sproul, S. Jarnason, Photovoltaic (PV) performance modelling in the absence of onsite measured plane of array irradiance (POA) and module temperature, *Renewable Energy*, 2016, 86, 760-769. https://doi.org/10.1016/j.renene.2015.09.005

[38] A. Chouder, F. Cherfa, A. Hadj Arab, S. Silvestre, R. Oussaid, Etude comparative de simulation entre PVsyst3 et PSpice de la centrale photovoltaïque connectée au réseau du CDER, *Revue des Energies Renouvelables* CER'07 Oujda 2007, 131-136.