Available online at www.elixirpublishers.com (Elixir International Journal)

Renewable Energy

Elixir Renewable Energy 120 (2018) 51212-51218

ISSN: 2229-712X

Comparative Study of the Performances of Different Silicon-Based Photovoltaic Technologies

Ladifata MOGMENGA[1,*], Bouchaib HARTITI[2,3], Brahima SORGHO[4], A.BATAN[5], Sala FADILI[2], Abderrazack LFAKIR[6], Philipe THEVENIN[7] and Dieudonné Joseph BATHIEBO[1]

[1]Laboratory of Renewable Thermal Energies, Department of Physics, University Ouaga I Professor Joseph KI-ZERBO, 03 BP 7021 Ouagadougou 03, Burkina Faso.

[2]ERDyS Laboratory GMEEM & DD group, Department of Physics, Hassan II University, FST Mohammedia, BP 146, 20800 Mohammedia, Morocco.

[3]Senior Associate. ICTP-UNESCO-IAEA, Trieste, Italie.

[4]Laboraory of molecular Chemistry and Materials, Department of Chemistry, University Ouaga I Professor Joseph KI-ZERBO, 03 BP 7021 Ouagadougou 03, Burkina Faso.

[5]FST Errachidia, University Moulay Ismail, Errachidia Morocco.

[6]FSTBM Sultan Moulay Sliman University, Beni Mellal, Morocco.

[7]LMOPS Laboratory, University of Lorraine, BP57070, Metz, France.

ARTICLE INFO

Article history:

Received: 05 June 2018;
Received in revised form: 25 June 2018;
Accepted: 7 July 2018;

Keywords

Solar energy,
Photovoltaic Productivity (PV),
PVSyst,
Burkina-Faso,
Morocco.

ABSTRACT

In a dynamic of protection of the environment and sustainable development, solar energy is one of the essential solutions to the energy problems of developing countries and to limiting greenhouse gas emissions. In this work, we compare the energy productivities of photovoltaic installations in four cities of two countries (Morocco and Burkina Faso). Government energy policies in both countries place a strong emphasis on solar photovoltaics. We then chose to make a detailed evaluation of the performances of the various photovoltaic technologies under various climatic conditions in these countries. PVsyst software is used to model the performance of a photovoltaic solar power plant connected to the 6kWc network (2kWc per technology) using three silicon-based photovoltaic technologies, namely: polycrystalline (pc-Si), monocrystalline (mc-Si) and amorphous (a-Si) in two cities per country. The comparative analysis included annual energy efficiency, performance ratio, annual energy density and system efficiency. From these performances, it can be observed that PV installations with a-Si have the highest energy yields and performance ratios (Er-Rachidia, Ouagadougou and Bobo-Dioulasso), while in Mohammedia, energy efficiency and maximum performance ratio are given by pc-Si technology. The mc-Si installation has the maximum overall efficiency of the system as well as the annual energy density in the cities selected for this study. The production of the city of Mohammedia is validated by the actual production of a 6kWc installation (2kWc per technology) made up of three mini-power plants, one with polycrystalline silicon, one with monocrystalline silicon and the other with amorphous silicon. Comparing the data validates our results.

1. Introduction

Today, one of the major concerns of government policies is global warming. In fact, about 70% of the electricity produced in the world is based on fossil fuels **[1].** The use of these fossil fuels is at the root of climate change because it produces greenhouse gases. In order to respond to global energy problems, government energy policies place a high priority on renewable energies, including solar energy **[2-3].** Solar energy has experienced strong growth in the last decade and is identifying to play an important role in global energy security **[4].** There are several types of solar energy that are: passive energy, solar thermal energy, photovoltaic energy and thermodynamic energy. Photovoltaic energy is today among promising, sustainable energies and can meet the energy needs of a home **[5].** Commercially mature PV module technologies are silicon (crystalline), thin film, and multi-junction. 90% of the available solar cells are crystalline silicon **[6].** These include monocrystalline silicon (mc-Si), polycrystalline silicon (pc-Si) and amorphous silicon (a-Si).

Thin film technology includes one or more thin PV layers deposited on a surface such as metal, glass or plastic. Multi-junction cells are characterized by multiple p-n junctions from different materials,each producing electricity at different wavelengths **[7].** The popularization of photovoltaic solar energy in a country requires a good knowledge of the field. The production of a photovoltaic installation (performance) depends on several parameters, most importantly on the site **[8],** the location of the installation which is characterized by its geographical coordinates. In addition to climatic conditions, the type of solar cell (technology) also affects the overall performance of the PV system due to differences in solar cell efficiency, sensitivity to environmental factors such as shading and dust, and the temperature coefficient **[9].**

Tele: + 226 70 95 86 65
E-mail address: ladifata.mogmenga@yahoo.fr

The evaluation of the performance of solar PV technologies then becomes relevant for the design of a PV system and its control **[10].** In literature, there are several studies on the performance of solar PV technologies. Studies have been carried out on the impact of climate conditions on the energy efficiency of a solar PV system **[11 - 13].** Some researchers have focused on evaluating the performance of a PV plant using a single module technology **[14-19],** while others have analyzed PV systems for several installed module technologies **[20-25]**. Several studies have already been carried out on the performance of photovoltaic installations connected to the internal network of a building or in the national network **[26 - 28].** We find that in all cases, PV module technology plays a key role in the performance of PV systems. As far as Morocco is concerned, studies have already been made on the performance of solar installations. However, according to our knowledge, there are very few studies on the performance of different solar photovoltaic technologies in the prevailing climatic conditions in Burkina Faso, which has a huge solar potential. It is in this context that we have chosen in this work to compare the energy productivity of a network-connected PV installation in four cities in two countries with almost opposite climatic conditions.They are Mohammedia and Er-Rachidia in Morocco, Ouagadougou and Bobo-Dioulasso in Burkina Faso.

Morocco has proved its interest in solar energy by building the world's largest thermodynamic plant (580 MW in total) named Noor I in Ouarzazate, which phase I has already begun with a capacity of 160 MW in June 2017 **[29].** In its energy transition strategy, Marocco aims to increase the share of renewable energies from 42% in 2020 to 52% in 2030 **[30].** As part of its project Propre.ma, Morocco also intends to build a photovoltaic productivity map for the whole country. This map will allow it to make predictions as to the installation of a facility in a given city, to have the types of modules adapted to each city, the inclination and the optimal orientation of systems for each city **[31].**

Burkina Faso has just marked its ambition to make solar the solution to the energy problem it faces, by the inauguration of one of the largest photovoltaic solar power plants in West Africa with a capacity of 33 MW in Zagtouli, which will have to be brought to 50 MW by extension **[32].**

In its sectoral energy policy 2014-2025, the Ministry of Mines and Energy of Burkina Faso intends to make solar a solution to energy problems in his country **[33].**

This article analyzes and compares the performance indicators of a 6 kWp installation using three mini-power plants of different PV[monocrystalline (mc-Si), olycrystalline (pc-Si) and amorphous silicon (a-Si) technologies] operating in climatic conditions in Morocco and Burkina Faso. We determine the type of technology of modules adapted to each of the cities studied and perform a comparison of productivity. The impact of ambient temperature on plant production is also evaluated.

The results will certainly provide useful information to the actors working in the field of electricity in these countries, especially for Burkina Faso, which is trying to make solar the solution to its energy problems.

2. Methodology

2.1. Sites and components of the PV plant

Table 1 below shows the geographical coordinates of the different cities where the photovoltaic installations are located. There is also information on average annual temperatures as well as global horizontal irradiations.

The optimum inclination of the modules is 31 ° for the cities of Morocco and 15 ° for the cities of Burkina Faso. All countries being of the Northern Hemisphere, the optimal orientation is trait south, taken therefore equal to 0 °. The latitude of the places in relation to sea level is 23 m for Mohammedia, 1025 m for Er-Rachidia, 297 m for Ouagadougou and 445 m for Bobo-Dioulasso.

2.2. Components of PV plant

In order to determine the appropriate technology for each of the cities studied, in this article, we chose to use silicon technologies because they are the most popular and most accessible on the market. The simulations are then made with modules of monocrystalline silicon (mc-Si), polycrystalline silicon (pc-Si) and amorphous silicon (a-Si). All installations have a size of 2 kWc. Table 2 shows the characteristics of the modules and the inverter used.

2.3. PVsyst

Several simulation software exist and allow to estimate the production of a photovoltaic installation. So we chose to work with the PVsyst software, for our simulations because this software allows to create databases by introducing the irradiations on the horizontal level obtained from the software PVGis **[34]** by optimizing the inclination and the orientation as well as the average monthly temperatures calculated using the Wunderground website. PVsyst software is used to model the power generation of a grid-connected PV plant using three different types of silicon technologies (pc-Si, mc-Si, and a-Si) in four different cities including two in Morocco and two in Burkina Faso to understand the performance of each technology under the different climatic conditions of those countries. The energy output of each technology is used to estimate performance indicators that include the performance ratio, annual energy density, and overall system efficiency.

Table 1. Geographic coordinates, mean temperature and global horizontal irradiation of cities.

	Mohammedia	Er-Rachidia	Ouagadougou	Bobo-Dioulasso
Latitude	33°41' North	31°55' North	12°22' North	11°9' North
Longitude	7°23' West	4°25'West	1°30' West	4°18' West
Average temperature (°C)	18.98	21.06	29.18	28.32
Overall horizontal irradiation (kWh / m^2 / year)	1977.8	2071.4	2211.5	2153.7

Table 2. Characteristics of the modules and the inverter.

	mc-Si	Pc-Si	a-Si
Model, manufacturer	Mono 250Wc 60 cellules, Topray solar	ESP-250Wc 60 Cells, Einnova Solarline	DA100-A5 100Wc, Dupont Apollo
Number of modules	8	8	20
Cell efficiency (%)	17.13	17.13	6.94
Module efficiency (%)	15.37	15.38	6.44
Module surface (mm^2)	1640*992	1640*992	1409*1110
Field surface (m^2)	8*1.627=13	8*1.627=13	20*1.564=31.3
Rated power (Wc)	8*250=2000	8*250=2000	20*100=2000
Inverter	GES2-2KTL 1.8kW, GESolar	GES2-2KTL 1.8 kW, GESolar	GES2-2KTL 1.8 kW, GESolar

PVsyst is a software for evaluation, sizing and data analysis of entire PV solar systems. With this software, network-connected systems, stand-alone and pumping systems can be simulated and studied **[35].** PV system simulation in the PVsyst software requires specification of the weather profile of the chosen location, the type of PV technologies and other components of the PV system. In this software it is possible to use the meteorological data contained in the database or to import data from other software such as PVgis. The energy output of the PV modules is affected by the declination angle and the azimuth angle, hence the need to provide them.

2.4. Performance indicators

2.4.1. Energy production

Annual Energy Output (Eg) is the total amount of energy that can be generated from the system in one year. This is one of the key factors in analyzing the performance of a PV plant. It can also be used to analyze the degradation occurring in the system.

2.4.2. The performance ratio

The performance ratio (PR) is the measure of the quality of the PV plant, which is independent of its location **[36].** It is expressed as a percentage and describes the relationship between the actual energy produced and the theoretical energy of a photovoltaic system. The more PR is close to 100%, the more efficient the photovoltaic system. Considering that losses are inevitable, a high-performance photovoltaic installation can have a performance ratio of up to 80%. PR is estimated from equation 1:

$$PR = E_g / E_{nominal} \quad (1)$$

Where E_g is the actual energy generated per year and $E_{nominal}$ is the theoretical energy of the plant. $E_{nominal}$ can be calculated from equation 2. Effective radiation ($G_{effective}$) is the amount of radiation that can generate energy from the panels.

$$E_{nominal} = \eta_{module} \times G_{effective} \quad (2)$$

2.4.3. Annual energy density

The annual energy density (AED) is an indicator taken into account for the choice of solar photovoltaic technologies. The AED is defined as the annual energy generated by a solar photovoltaic system in one year per unit area of modules **[10].** It is used to measure how a solar PV installation optimizes the space available for power generation. The AED of solar PV plants is estimated from equation 3.

$$AED = E_g / A_m \quad (3)$$

where A_m represents the total area of the module plane.

2.4.4. The efficiency of the system

The efficiency of the photovoltaic plant (η_{system}) is the ratio of the energy produced by the plant to the total radiation (G_{total}) available on the panel level and is estimated from equation 4.

$$\eta_{system} = E_g / G_{total} \quad (4)$$

3. Results and Discussion

Figure 1 shows the appearance of the horizontal monthly irradiations extracted from PVGis online photovoltaic simulations software. It can be noted that the average monthly irradiation of Moroccan cities is bell-shaped and within an interval of]2, 8[while those of the cities of Burkina Faso are more evenly distributed over an interval of]5, 7]. According to these results, Burkina Faso enjoys more sunshine than Morocco throughout the year. The maximum irradiation in Morocco is reached in the period from April to September and in Burkina Faso in the period from February to June corresponding to the hottest periods of the year.

3.1. Energy production

Generally, the main concern of investors and operators in the field of energy is to know how much electricity a solar PV plant would produce.

By observing Figures 2, 3, 4 and 5 it can be seen that with regard to the production of energy in kWh and whatever the technology of the modules (mc-Si, pc-Si and a-Si), in Mohammedia and Er-Rachidia, the most unfavorable months are the months of November, December and January with respectively the value of : November (249.6, 250.2 and 242.6 kWh), December (240, 240.5 and 228.4 kWh) and January (247, 247.5 and 237.6 kWh) in Mohammedia and November (284.7, 285.4 and 279.4 kWh), December (274.4, 274.9 and 265.5 kWh) and January (290, 290.7 and 285.2 kWh) in Er-Rachidia. As for Ouagadougou and Bobo-Dioulasso the most unfavorable months are July and August with respectively the value of: July (260.3, 261.2 and 265.2 kWh), August (256.6, 257.5 and 261.1 kWh) in Ouagadougou and July (247.9, 248.6 and 252.6 kWh), August (237.8, 238.5 and 243.1 kWh) in Bobo-Dioulasso. For all these cities, these periods correspond to the rainy season with low temperatures (17.6°C, 14.9°C and 16.1°C) at Mohammedia, (14°C, 9.6°C and 12°C) at Er-Rachidia (28°C and 27.2°C) at Ouagadougou and (26.4 °C and 26.5°C) in Bobo-Dioulasso, favorable to PV conversion systems. The low yields can then be explained by the cloud cover that darkens the sky.

The most favorable months are July (351.5, 352.7 and 358.6kWh), August (351.1, 352.4 and 358.8 kWh) at Mohammedia, March (369.2, 370.3 and 373.8 kWh) at Er-Rachidia, March (338.9, 340.5 and 360.4kWh) at Ouagadougou and Mars (333.1, 334.7 and 352.4 kWh) in Bobo-Dioulasso. These results can be explained by the fact that during these months the sky is clearer and the insolation is important.

The analysis (Fig. 6) on the total annual energy yield of the PV plant (2kWc), taking into account the total losses of conversion by technology (Fig. 7) shows that generally, for a year of operation (1st year) the amorphous silicon mini-power plant (a-Si) in Er-Rachidia delivered the largest amount of power to the network with (3795kWh), while the mc-Si installation in Bobo-Dioulasso delivered the smallest amount of energy (3439kWh). The facilities at Pc-Si in Mohammedia, Er-Rachidia, Ouagadougou and Bobo-Dioulasso yielded respectively 3677kWh, 3738kWh, 3529kWh and 3453kWh. Similarly, the mc-Si facilities in Mohammedia, Er-Rachidia and Ouagadougou yielded 3666kWh, 3726kWh and 3514kWh respectively. As for the facilities at a-Si in Mohammedia, Ouagadougou and Bobo-Dioulasso, they give respectively for one year of operation, 3656 kWh, 3643 kWh and 3560 kWh. Taking the facilities by country, we note that for Burkina Faso, whatever the technology of the modules used, the facilities in Ouagadougou produce more than those in Bobo-Dioulasso.

This high amount of energy production in Ouagadougou can be attributed to the large amount of solar radiation falling in the city (on average 2211.5kWh / m^2 / year against 2153.7 kWh / m^2 / year for Bobo-Dioulasso). In Morocco, for each technology studied here, it can be seen that the facilities in Er-Rachidia produce more. This is also explained by the amount of solar radiation received in these cities (2071kWh / m^2 / year against 1977.8kWh / m^2 / year for Mohammedia). Paradoxically, the amount of sunshine that Burkina Faso enjoys annually compared to Morocco (Fig. 1), PV installations in Burkina Faso produce less than facilities in Morocco.

This can be explained by the phenomenon of aerosol due in particular to dust, high temperatures Burkina –Faso.

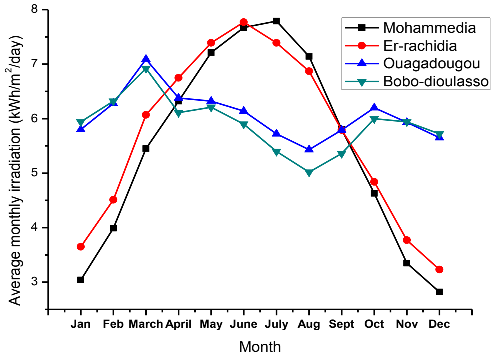

Figure 1. Monthly average irradiation of cities in (kWh / m ^{2} / day).

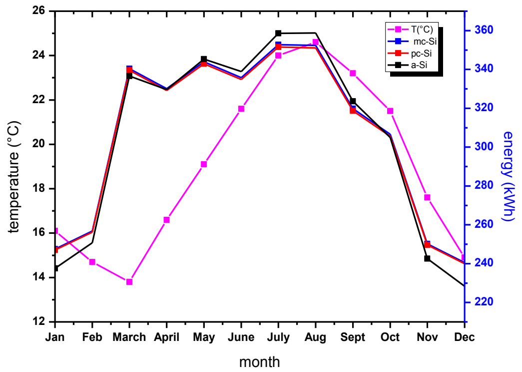

Figure 2. Monthly energy production and average monthly temperature in the city of Mohammedia.

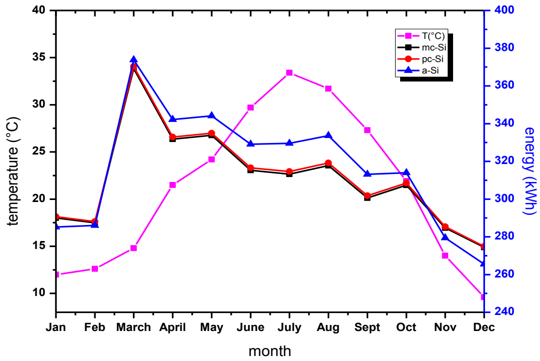

Figure 3. Monthly energy production and average monthly temperature in the city of Errachidia.

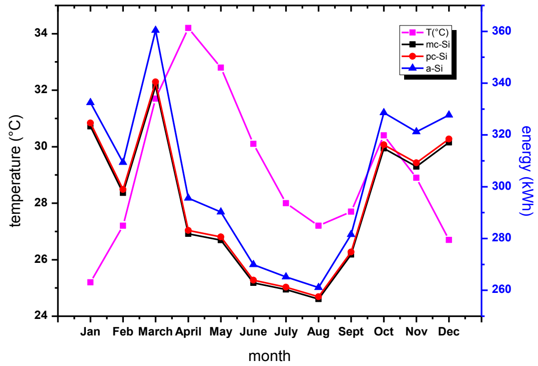

Figure 4. Monthly energy production and average monthly temperature in the city of Ouagadougou.

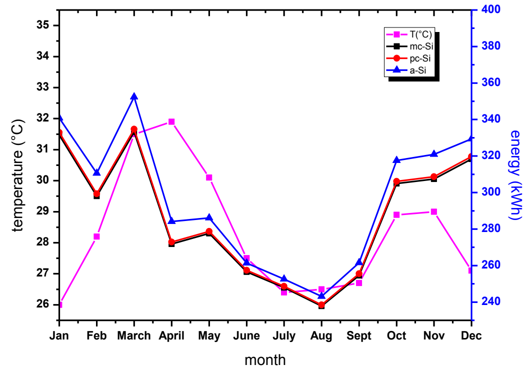

Figure 5. Monthly energy production and average monthly temperature in the city of Bobo-Dioulasso.

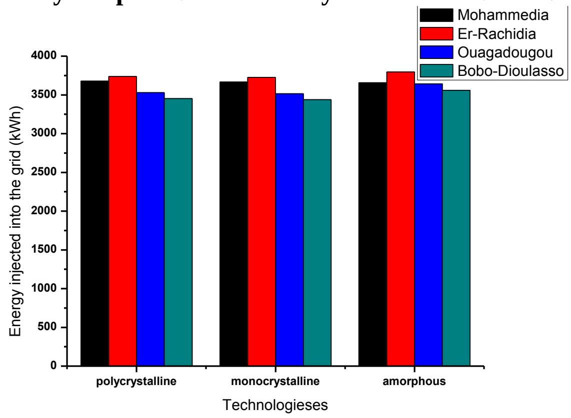

Figure 6. Total energy injected into the network by module technology.

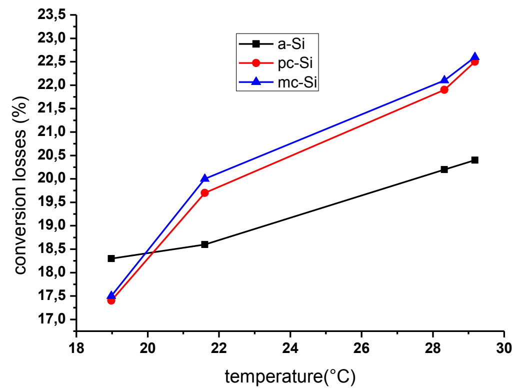

Figure 7. Losses according to the average annual temperature of the cities.

3.2. Choice of module technology

Figure 7 shows the total losses of energy conversion in the system as a function of the ambient temperature of the implantation site and by technology. As it can be seen from the graph and the literature **[15] [37-38],** the ambient temperature has a negative effect on the efficiency of the conversion system. This effect depends on the type of panels used. The higher the temperature, the greater the losses are, and this regardless of the technology of the modules.

The observation of Table 1 shows that Mohammedia has the lowest average annual temperature 18.98°C and the highest is recorded by the city of Ouagadougou 29.18°C. The total conversion losses are estimated at 17.4% for the city of Mohammedia, 19.7% for the city of Er-Rachidia, 20.2% for the city of Bobo-Dioulasso and 20.4% for the city of Ouagadougou. The high rate of field module losses in the city of Ouagadougou is explained by the fact that it is the hottest of the year. With regard to the monthly irradiations average of the different cities (Fig. 1), we can see that Ouagadougou has the most important energy potential. However the values of the energy injected into the network (Fig.6) show the opposite in terms of energy produced. What can once again be explained by the losses during the conversion.

Figure 8 compares the actual energy produced by an installation at the Faculty of Science and Technology of Mohammedia (FSTM) composed of three mini-power plants of 2kWc each pc-Si, mc-Si and a-Si and the productivity of a PV installation of the same type estimated by PVsyst software. It can be seen through these curves that for the city of Mohammedia, the most suitable technology is the polycrystalline. The estimated annual production of the polycrystalline silicon plant is 3677 kWh and the actual annual production of the installation at the FSTM of 3463.58 kWh represents a difference of 5.80% compared to the estimated production **[9].** This difference can be explained by the fact that in commercial sizing software of solar thermal or photovoltaic systems, the inclination of the sensors is required and the software 'tilts' horizontal global solar irradiations contained in the database with generally a low accuracy. In addition, the measurements are made with satellites that are kilometers from the ground, making the accuracy still low. Nevertheless, these softwares allow us to have an idea about the energy production expected in a given site. For Er-Rachidia, Ouagadougou and Bobo-Dioulasso, amorphous silicon plants produce more, which will certainly be confirmed with the analysis of performance factors.

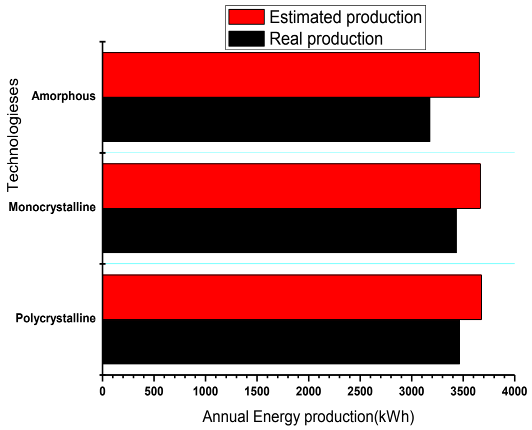

Figure 8. Comparative curve of the production of the city of Mohammedia.

3.3. Performance ratio

The performance ratio (PR) that illustrates the impact of the losses (collection losses at the PV field + system losses (inverter)) on the power output of the PV installations is shown here in Fig. 9. The observation of this Figure shows that the performance ratio of different technologies varies across countries and cities. In the first year of operation, PR of mini-power stations in pc-Si ranged from 77.1% (Ouagadougou) to 81.9% (Mohammedia); those with mc-Si 76.8% (Ouagadougou) - 81.6% (Mohammedia); and those with a-Si 79.6% (Ouagadougou) - 81.4 (Mohammedia). The low PR values correspond for the most part to mc-Si and a-Si technologies and are recorded in the city of Ouagadougou in Burkina Faso, the highest values are recorded in the city of Mohammedia in Morocco.

With regard to the average temperatures in the different cities (Table 1), we note that the higher the temperature, the lower the PR and those regardless of the type of module technology.

It can be seen that temperatures in cities of Burkina Faso (Table 1) are well above 25°C normal temperature test modules.

3.4. Annual energy density and system efficiency

Depending on the technology of PV modules, for the same power rating, the number of modules and therefore the area occupied is not the same depending on whether polycrystalline silicon, monocrystalline silicon or amorphous silicon technology is used. Nowadays, lack of space is a major problem that limits the deployment of large scale renewable energy technologies especially in urban areas where land availability is a concern. The annual energy density in the study of solar systems makes it possible to favor one technology to the detriment of another. Large PV fields occupy large areas often leading to rivalries with farming systems.

Figure 10 shows the DEA of the various mini-plants studied. The DEA of the a-Si installation varies from 113.74kWh / m^2 (Bobo-Dioulasso) to 121.25kWh / m^2 (Er-Rachidia) in the first year of operation. For pc-Si and mc-Si installations, the DEA varies respectively from 265.62kWh / m^2 (Bobo-Dioulasso) to 287.54kWh / m^2 (Er-Rachidia) and from 264.54kWh / m^2 (Bobo-Dioulasso) to 286.62kWh / m^2 (Er-Rachidia). A higher AED indicates better use of the land. Technologically speaking, it is noted that for all cities, pc-Si installations have the best AED, followed by those at mc-Si and those at a-Si. The lowest AED of A-Si installations can be explained by the low general level of efficiency of the a-Si modules.

When space becomes an important criterion for selecting PV technologies in these cities, it is recommended that investors opt for pc-Si technology. The overall efficiency of the system (η) is also another important parameter studied in this article. Fig. 11 shows that pc-Si PV installations in all cities have maximum efficiency (η), followed by mc-Si and then a-Si installations. The high value of the efficiency of the pc-Si installations can be explained by the efficiency of the PV modules used. The highest efficiency for pc-Si systems is recorded in Mohammedia (12.58%) and the lowest in Ouagadougou (11.85%). The mc-Si and a-Si systems give a maximum value of 12.55% to Mohammedia, a minimum value of 11.80% in Ouagadougou and 5.20% (Mohammedia) and 5.09% (Ouagadougou). In Burkina Faso the best efficiency is worth 11.93% corresponding to the installation in pc-Si while instead the low value (5.09%) in Ouagadougou corresponds to the facilities at a-Si In Morocco, the highest value of 12.58% (Mohammedia) is recorded by the pc-Si installation and the lowest value of 5.18% (a-Si) is recorded in Er-Rachidia.

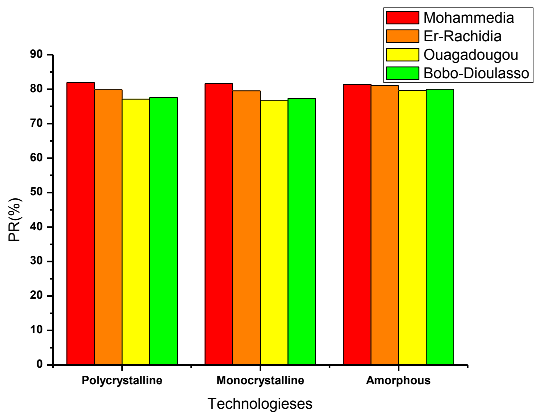

Figure 9. Technology Conversion System Performance Ratio.

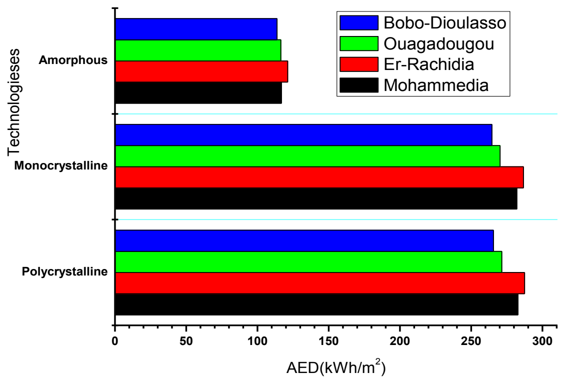

Figure 10. Annual Energy Density by Module Technology.

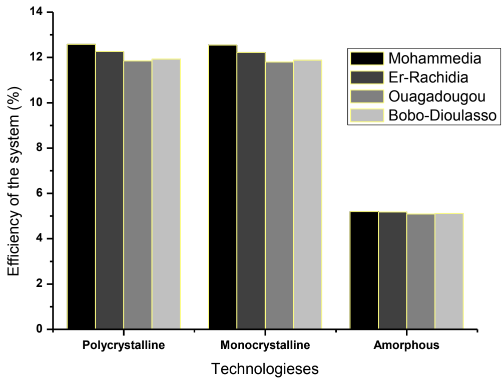

Figure 11. Overall System Efficiency by Module Technology.

4. Conclusion

In this paper, a comparative evaluation of silicon (polycrystalline, monocrystalline and amorphous) silicon technologies for a 2kWc mini-plant connected to the network under climatic conditions in Burkina Faso and Morocco is carried out. In Burkina Faso, the study focused on Ouagadougou and Bobo-Dioulasso, in Morocco it concerned Mohammedia and Er-Rachidia.

On the PR side, the a-Si technology is the most appropriate for energy production (Er-rachidia, Ouagadougou and Bobo-dioulasso) and the pc-Si technology for the city of Mohammedia. However in terms of overall system efficiency and in some circumstances where space availability might be a problem, pc-Si modules seem to be the most appropriate in both countries. In general, we can see that whatever the performance indicator used, photovoltaic installations in Morocco produce more than those in Burkina Faso. This is paradoxical in terms of the radiation that benefits both countries. Solar irradiation alone is not enough to draw conclusions about the productivity of a facility in a given city. Illumination and temperature are two extremely important parameters in the behavior of solar cells.The impact of the ambient temperature on the operation of the modules and the inverter as important as the ambient temperature of the place. The overall performance index of the installation therefore depends on the geographical location. The further you get from the ocean, the warmer and dryer the climate, and the effect of pollution, dust and temperature on the energy output of the modules is greater.

Note that in this article we performed simulations and that the performances found are certainly not the exact performance of a PV installation in reality. However, the results obtained can provide useful information to managers and investors regarding the choice of the appropriate module technology taking into account of course the conditions prevailing in the site.

Reference

[1]W. Arnold and J. Reitze,”Electric power in a carbon constrained world”, William Mary Environ. Law Policy Rev., 2010, vol. 34, no. 3, pp. 821.

[2]A. Kumar and T. C. Kandpal,”CO2 emissions mitigation potential of some renewable energy technologies in India”, Energy Sources, Part A Recover. Util. Environ. Eff., 2007, vol. 29, no. 13, pp. 1203 - 1214.

[3]A. Kumar and T. C. Kandpal,”Potential and cost of CO2 emissions mitigation by using solar photovoltaic pumps in India”, Int. J. Sustain. Energy, 2007, vol. 26, no. 3, pp. 159 - 166.

[4]S. Mishra,”Techno-Economics of Rooftop Solar Photo voltaic Systems in India”, Indian Institute of Technology Delhi, 2017.

[5]David Funk, ”l’énergie solaire : circonstances et conditions d’exploitation au québec”, Université de Sherbrooke Canada, janvier 2010, pp.i

[6]’No Title’. [Online]. https://solar.gwu.edu/what-types-solar-photovoltaic-technologies-exist-today-and-how-do-they-work [Accessed: 16-May-2018].

[7]D. C. Law et al.,”Future technology pathways of terrestrial III-V multijunction solar cells for concentrator photovoltaic systems”, Sol. Energy Mater. Sol. Cells, 2010, vol. 94, no. 8, pp. 1314 - 1318.

[8]E. Karami, M. Rafi, A. Haibaoui, A. Ridah, B. Hartiti, and P. Thevenin, ”Performance analysis and comparison of different photovoltaic modules technologies under different climatic conditions in Casablanca”, J. Fun-dam. Renew. Energy Appl., 2017, vol. 7, no. 3, pp. 3 - 8.

[9]D. A. Quansah, M. S. Adaramola, G. K. Appiah, and I. A. Edwin, ”Performance analysis of different grid-connected solar photovoltaic (PV) system technologies with combined capacity of 20 kW located in humid tropical climate”, Int. J. Hydrogen Energy, 2017, vol. 42, no. 7, pp. 4626- 4635.

[10]P. Arjyadhara1, A. S. M, and J. Chitralekha, ”Analysis of Solar PV cell Performance with Changing Irradiance and Temperature”, Int. J. Eng. Comput. Sci., 2013, vol. 2, no. 1, pp. 2319 - 7242.

[11]H. Bahaidarah, S. Rehman, A. Subhan, P. Gandhidasan, and H. Baig, ”Performance Evaluation of a PV Module under Climatic Conditions of Dhahran, Saudi Arabia”,Energy Explor. Exploit., 2015, vol. 33, no. 6, pp. 909 - 929.

[12]N. M. Kumar, M. R. Kumar, P. R. Rejoice, and M. Mathew, ”Performance analysis of 100 kWp grid connected Si-poly photovoltaic system using PVsyst simulation tool”, Energy Procedia, 2017, vol. 117, pp. 180- 189.

[13]M. Mathew, Y. K. Sharma, and M. A. Magry,”Design and analysis of solar photovoltaic based coal mine reclamation in India”, International Conference on Intelligent Computing, Instrumentation and Control Technologies, IEEE, 2017, pp 1 - 4.

[14]Ibrahim NEYA.,” Etude de l’influence de la température surles paramètres photovoltaïques dans les conditions réelles de fonctionnement”, Mémoire de l’’Institut International d’Ingénierie en Eau et Environnement (2iE), Octobre 2015.

[15]M. Drif et. al., ”UNIVER project. A Grid Connected Photovoltaic System of 200 kWp at Jan University. Overview and performance analysis”, Sol. Energy Mater. Sol. Cells, 2007, vol. 91, pp. 670 - 683.

[16]Y. Ueda, K. Kurokawa, K. Kitamura, M. Yokota, K. Akanuma, and H. Sugihara,"Performance analysis of various system configurations on grid-connected residential PV systems", Sol. Energy Mater. Sol. Cells, 2009, vol. 93, pp. 945 - 949.

[17]T. Khatib, K. Sopian, and H. A. Kazem, "Actual performance and characteristic of a grid connected photovoltaic power system in the tropics: A short term evaluation", Energy Convers. Manag., 2013, vol. 71, pp. 115 - 119.

[18]M. S. Adaramola and E. E. T. Vagnes, "Preliminary assessment of a small-scale rooftop PV-grid tied in Norwegian climatic conditions", Energy Convers. Manag, 2015, vol. 90, no. 90, pp. 458 - 465.

[19]M. Diez-Mediavilla, M. I. Dieste-Velasco, M. C. Rodriguez-Amigo, T. Garcia-Calderon, and C. Alonso-Tristan, "Performance of grid-tied PV facilities based on real data in Spain: Central inverter versus string system", Energy Convers. Manag., 2014, vol. 86, pp. 1128 - 1133.

[20]L. Ayompe et al., "Measured Performance of a 1.72 kW Rooftop Grid Connected Photovoltaic System in Ireland", Energy Convers. Manag., 2011, vol. 52, no. 2, pp. 816 - 825.

[21]V. Sharma, A. Kumar, O. S. Sastry, and S. S. Chandel, "Performance assessment of different solar photovoltaic technologies under similar outdoor conditions", Energy, 2013, vol. 58, p. 511 - 518.

[22]M. Mathew and J. Hossain, "Analysis of a grid-connected solar photo- voltaic system with different PV technologies", International Conference on Circuits and Systems, IEEE, pp1 - 6.

[23]T. Ishii, K. Otani, R. Sato, and R. Morinaga, "Comparison between indoor and outdoor performance of various PV modules in Japan", 27th European Photovoltaic Solar Energy Conference and Exhibition, 2012.

[24]C. Canete, J. Carretero, and M. Sidrach-de-Cardona, "Energy performance of different photovoltaic module technologies under outdoor conditions", Energy, 2014, vol. 65, p. 295 - 302.

[25]M. E. Baoglu, A. Kazdaloglu, T. Erfidan, M. Z. Bilgin, and B. Cakr, "Performance analyzes of different photovoltaic module technologies under Izmit, Kocaeli climatic conditions", Renew. Sustain. Energy Rev., 2015, vol. 52, pp. 357 - 365.

[26]S. Edalati, M. Ameri, and M. Iranmanesh, "Comparative performance investigation of mono- and poly-crystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates", Appl. Energy, 2015, vol. 160, p. 255 - 265.

[27]Adel Mellit and Alessandro Massi Pavan, 'Performance prediction of 20 kWp grid-connected photovoltaic plant at Trieste (Italy) using artificial neural network',‖Energy Convers Manage, Volume 51, Issue 12, December 2010, Pages 2431-2441.

[28]H. Colin (CEA-INES), C. Duvauchelle (EDF), G. Moine (TRANSENERGIE), Y. Tanguy (TRANSENERGIE), B. Gaiddon (HESPUL), T. Tran-Quoc (IDEA), 'Raccordement des installations photovoltaïques au réseau public de distribution électrique à basse tension',Avril 2010, http://www.photovoltaique.info/IMG/pdf/ESPRIT_Raccordement_des_centrales_PV_au_RPD_BT_en_France.pdf,[accessed : 15 April 2018].

[29]A. Guenounou, A. Malek , M. Aillerie, ' Comparative performance of PV panels of different technologies over one year of exposure: Application to a coastal Mediterranean region of Algeria', Energy Conversion and Management 114 (2016) 356–363.

[30]https://ma.ambafrance.org/Inauguration-d-une-centrale-solaire-a-Ouarzazate-4-fevrier-2016[accesed:16 March 2017].

[31]Ministère de l'Energie, des Mines de l'Eau et de l'Environnement (Maroc),'Stratégie énergétique nationale horizon 2030', 2007, http://www.orientalinvest.ma/telechargementfichiers/energies/strategie_energetique_nationale.pdf

[32]Partenariat Énergétique Maroco-Allemand PAREMA : 'Les énergies renouvelables et l'efficacité énergétique au Maroc', 2016, http://dkti-maroc.org/wp-content/uploads/sites/61/2016/12/Les-e%CC%81nergies-renouvelables-et-l%E2%80%99efficacite%CC%81-e%CC% 81nerge%CC%81tique-au-Maroc.pdf][Accessed : 02 Feb 2018].

[33]European External Action Service (EEAS)., "Inauguration de la centrale solaire photovoltaïque de Zagtouli,",20 Fevrier 2018. http://eueuropaeeas.fpfis.slb.ec.europa.eu:8084/delegations/burkina-faso/40088/inauguration-de-la-centrale-solaire-photovolta%C3%AFque-de-zagtouli_fr [Accessed: 23 Avril 2018].

[34] http://photovoltaic-software.com/pvgis.php

[35]A. Bruno and M. Wittmer, "PVsyst User's Manual, 2014",[Online].Available:http://www.pvsyst.com/images/pdf/PVsyst Tutorials.pdf. [Ac-cessed: 17-Aug-2017]

[36]SMA Solar Technology AG, "Performance ratio - Quality factor for the PV plant",[Online].Available: http://files.sma.de/dl/7680/Perfratio-TI-en-11.pdf. [Accessed: 29-Dec-2017].

[37]S. BENSALEM, ' Effets de la température sur les paramètres caractéristiques des cellules solaires', Mémoire de magister de l'Université Ferhat Abbas-Setif (Algerie), 2011.

[38]M. Shravanth Vasisht, J. Srinivasan, and S. K. Ramasesha, "Performance of solar photovoltaic installations: Effect of seasonal variations", Sol. Energy, 2016, vol. 131, pp. 39 - 46.