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Article

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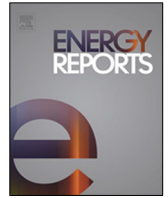
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Global solar radiation on tilted surfaces in Tunisia: Measurement, estimation and gained energy assessments

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ABSTRACT

A very important factor in the assessment of solar potential for the installation of photovoltaic plants is the availability of global irradiation data measurements. Such data must be collected over a period of time longer than 11 years and must be accurate. In some countries, it is difficult to have databases of these measures. To overcome this problem, we propose, the use of numerical models to estimate the monthly, seasonally and annually solar energy irradiation (global diffuse and direct solar radiation), especially on tilted surface.

The results obtained from the numerical models are compared to the data collected from three regions on Tunisia: Bizerte (in the north), Nabeul (near to the north east) and Djerba (in the south).

The actual measurements taken from the meteorological stations and the measurements generated by the numerical models are very close.

After the validation of the numerical models, we tried to calculate the best tilt angle for each period of the year to position a photovoltaic panel, in a given region, to reach maximum energy recovery.

The practical validation, of the optimal tilt angle search and the adequate period, was conducted at the Research and Technology Center of Energy of Borj Cedria. The obtained results are satisfactory and prove the reliability of the constructed numerical models.

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1. Introduction

Solar energy resource data is necessary for the evaluation of the profitability of installing photovoltaic plants. However, the real energy produced cannot be predicted because the energy generation process depends on climatic conditions (Tadros, 2000). The total solar radiation data is scarce in some locations, this is due to the absence of meteorological measurement stations and remote data collection networks, whose installation is expensive (Codato et al., 2008). Research and development efforts are required to ameliorate estimation processes to reach accurate predictions (Deshmukh, 2008; Ashraful Islam et al., 2016; Derouich et al., 2014).

Total measured solar radiation data are the best source of information for estimating average incident radiation necessary to calculate the productivity of an installed solar energy systems. In order to evaluate the production of a photovoltaic solar power plant, in a given region, measurements must be made over a period of at least 11 years. Generally, these measures are only available in

developed countries (Li et al., 2008; Sebaili et al., 2010; ElMghouchi et al., 2014).

To trap the maximum amount of solar radiation, it is possible to use photovoltaic panels powered and driven by a sun system tracking. These panels are often expensive and require excessive maintenance. However, a more cost-efficient method would be the implementation of a periodically-changing (either monthly or seasonally) optimum tilt angle. This period can be monthly or seasonally. The value of the tilt angle and position-shifting periods have always been determined by the measurements collected over tens of years. In the absence of these data, it is possible to use numerical models of prediction.

The measurement of solar radiation falling on tilt surface is important to estimate solar radiation in locations where there are no facilities to measure any meteorological data (Loutzenhizer et al., 2007). Studies on and measures in this field are rare (Pandey and Katyar, 2009; Miguel et al., 2001; Despotovic and Nedic, 2015). In this case, various radiation models for inclined surfaces have been proposed. Some of them include isotropic models (Liu and Jordan, 1960; Duffie and Bechman, 1991; Farhan et al., 2015) anisotropic models (Perez et al., 1986; Yao et al., 2015) and models for clear sky (Robeldo and Soler, 2002; Badescu, 2002). The total radiation

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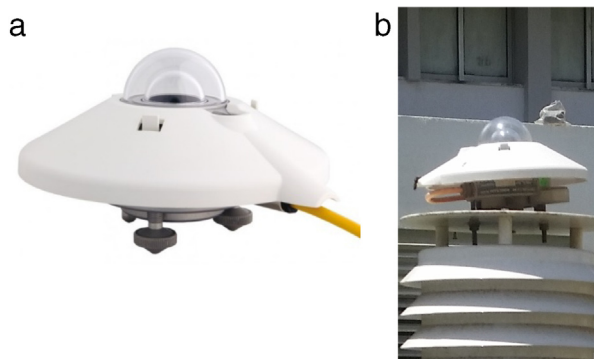


Fig. 1. CMP 3 Pyranometers for global irradiance measurements. Source: (a) (kipp_Zonen_booklet_Pyranometers) (b) (National Institute of Meteorology of Tunisia.)

Table 1
CMP3 pyranometer specifications.

Spectral range (50% points)	300 to 2800 nm
Sensitivity	5 to 20_V/W/m ²
Impedance	20 to 200_
Maximum operational irradiance	2000 W/m ²
Response time (63%)	<6 s
Response time (95%)	<18 s

on tilt surface consists of three components: beam, reflected radiation from the ground and diffuse radiation (Noorian et al., 2008; Notton et al., 2006; Maleki et al., 2017). Each one of these models predicts beam and diffuse components and global solar radiation. Hence, the possibility to estimate the incident radiation on tilted surface (Hameed et al., 2017).

All meteorological stations, of the National Institute of Meteorology of Tunisia, measure global solar radiation intensities only on horizontal surface (Evseev and Kudish, 2009). The recorded data are only the monthly averages. To overcome the problem of data scarcity, we propose in this paper, a numerical model to calculate the optimal tilt angles and to calculate the duration of holding of each angle in function of the losses to be gained in the energy production.

This paper is divided into two parts:

In the first part, we discuss in detail the construction of the numerical model. Then we evaluate the validity of the generated results in comparison with the meteorological data received from, three remote stations in different Tunisian cities, Bizerte in the north, Nabeul in the north east and Djerba in the south.

The second part is devoted to the evaluation of profit losses, engendered by the installation with fixed inclination of photovoltaic panels.

2. Model synthesis

2.1. Measurement instruments

Measurements are made by pyranometers (global solar radiation) (see Fig. 1). They are radiometers designed to measure the global irradiance on a plane surface resulting from radiant fluxes in the wavelength ranging from 300 to 2800 nm. The received radiation is converted into heat by the blackened surface. The temperature variation between the blackened surface and the body of the instrument is proportionate to the irradiance of the global solar radiation, as is measured by several thermocouples (see Table 1).

We used the data obtained from the three stations Bizerte, Nabeul and Djerba. Fig. 2 is a photo that shows the meteorological



Fig. 2. Meteorological station energy systems of the National Institute of Meteorology of Tunisia.

station energy systems of the National Institute of Meteorology in the Tunis DC. The data of global solar radiation measured (in KWh/m²) in the three meteorological stations was collected over the period between January and December of the year 2015.

2.2. Assumptions

In this work, we present the basic solar equations in detail and the empirical relations that can be, consequently be utilized to compute global irradiance as a result. We recall the main equations which are detailed in Duffies and Bechman (2006) and Stone (1993).

The Solar radiation which reaches the ground is formed by a direct radiation (I^*) and a diffuse radiation (D^*) which together form the global radiation. The sum of these components equates to the total irradiance (G^*). All these are calculated in W/m².

2.2.1. Solar energy

The earth receives daily a large flow of solar energy. The power of this radiation depends on several criteria, meteorological conditions, atmospheric diffusion (phenomena of dispersion, reflection and absorption). The average amount of solar radiation received at any earth's surface, is about 1367 W/m² (Wong and Chow, 2001). This total radiation energy is called solar constant.

The energy received depends on the day of the year and can be calculated using the following formula:

$$E_{sol} = 1367 \times (1 + 0.00334 \times \cos(360 \times (j - 2.7206) / 365.25)) \quad (1)$$

j : the order number of the day in the year ranging from 1 on January to 365 on 31 December.

for example, 1 January = 1, 20 February = 51, and so on.

A. Latitude and longitude

Latitude (Lat) is the angle formed by the equatorial plane and the vector “center of the earth → local point”. Longitude (Lon) is the angle formed by the meridian of reference (Greenwich meridian) and the meridian of the local point. The angle is negative to the west and positive to the east. As the earth takes 24 h to spin around its axis (360°) each hour represents 15 degrees of longitude deviation and therefore each degree of longitude represents 4 min.

B. Declination

Declination (Dec) is the angle formed by the vector “center of the earth → sun” and the equatorial plane of the earth. Moreover, the declination is the angular distance from the sun north or south

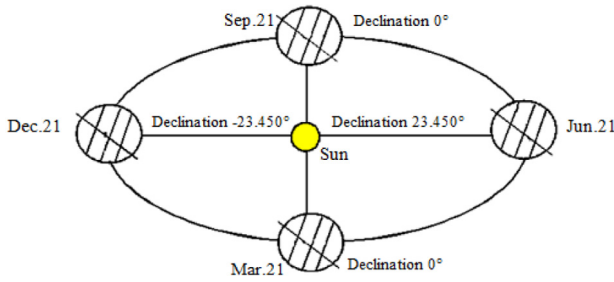


Fig. 3. Maximum and minimum value of declination angle (Maleki et al., 2017).

of the earth equator. Maximum and minimum declination angle values are illustrated in Fig. 3

According to Cooper (1969), the declination is obtained from the following equation:

$$Dec = \sin^{-1} (0.398 \times \sin (0.985 \times j - 80)) \quad (2)$$

C. Hour angle

Hour angle (Ah) measures the movement of the sun with respect to noon, which is the moment when the sun passes to the meridian plane of the place (zenith). This time angle is negative if the solar time is inferior to 12 pm. The concept is used for describing the rotation of the earth around its polar axis which is equivalent to $+15^\circ$ per hour during the morning and -15° in the afternoon (Nia et al., 2013).

The hour angle is evaluated as follows

$$Ah = 180 \times (Tsv/12 - 1) \quad (3)$$

Where Tsv is the local solar time.

Position of the sun:

The position of the sun is defined by two angles that are:

The height of the sun (H) and the azimuth (A). (H) is known, also, as altitude, and it is the angle formed by the horizontal plane of the place considered and the vector “local point \rightarrow sun”. The expression is:

$$H = \sin^{-1} (\sin (Lat) \times \sin (Dec) + \cos (Dec) \times \cos (Ah)) \quad (4)$$

The solar azimuth (A) is the horizontal angle formed by the meridian plane (north–south axis) and the vertical plane of the vector. It is defined as the angular displacement from the south of the beam radiation projection on the horizontal plane. The sign of the azimuth is the same as that of the hour angle.

Here the azimuth angle A is represented by

$$A = \sin^{-1} (\cos (Dec) \times \sin (Ah)) / \cos (H) \quad (5)$$

Knowing about latitude and declination makes predicting the exact sunrise and sunset times possible (see Fig. 4).

$$T_{sunrise} = 12 - (\cos^{-1} (-\tan (Lat) \times \tan (Dec))) / 15 \quad (6)$$

$$T_{sunset} = 12 + (\cos^{-1} (-\tan (Lat) \times \tan (Dec))) / 15 \quad (7)$$

The duration of sunshine represents the maximum duration of the day:

$$Di = 2/15 \times \cos^{-1} (-\tan (Lat) \times \tan (Dec)) \quad (8)$$

D. Coefficient of incidence

Coefficient of incidence (CI) is the angle formed by the solar radiation with the perpendicular of a surface. This coefficient defined on the one hand by the height of the sun and its azimuth and

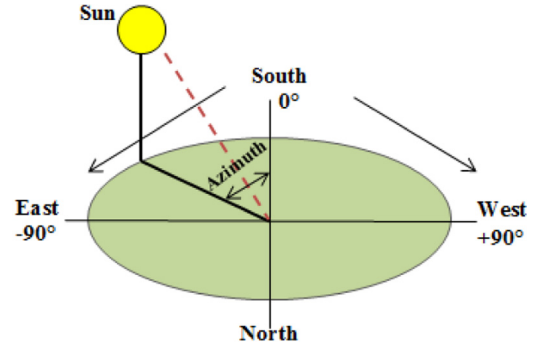


Fig. 4. Definition of the sun's Azimuth angle (Maleki et al., 2017).

on the other hand by the orientation (O) and the inclination (I) of the receiving plane. Thus, each receiving plane can be defined by a pair of values, (O, I). The orientation is negative towards the east and positive towards the west. It can be indicated by a geographical direction, like for example north-northeast. As for the inclination, it is equal to 0° for a horizontal plane and 90° for a vertical plane (Duffie and Beckman, 2006).

The coefficient of incidence, CI , is calculated by the formula (9):

$$CI = \sin (I) \times \cos (H) \times \cos (O - a) + \cos (I) \times \sin (H) \quad (9)$$

2.2.2. Direct solar flux

Direct solar radiation reaches the atmosphere but its intensity undergoes an attenuation. To evaluate this loss of radiation, the approach is as follows:

- 1- Define the altitude of the local point to know the atmospheric pressure ($Patm$):

$$Patm = 101325 \times (1 - 2.26 \times 10^{-5} \times z)^{5.25} \quad (10)$$

Where z is the altitude in meters

- 2- Define saturated vapor pressure (Pvs), average relative humidity (RH) and partial pressure of water vapor (Pv):

$$Pvs = 2.165 \times (1.098 + T/100)^{8.02} \quad (11)$$

$$Hr = 50\% \quad (12)$$

$$Pv = Pvs \times Hr \quad (13)$$

Where T is the air temperature in Celsius

- 3- Define the relative optical mass (M) from which results the optical thickness of Rayleigh (ER), which determines the attenuation due to diffusion:

$$M = Patm / (101325 \times \sin (H) + 15198.75 \times (3.885 + h)^{-1.253}) \quad (14)$$

$$ER = 1 / (0.9 \times M + 9.4) \quad (15)$$

- 4- Define Linke's disorder factor:

$$Tl = 2.4 + 14.6 \times B + 0.4 \times (1 + 2 \times B) \times \ln (Pv) \quad (16)$$

Where B is the atmospheric disturbance coefficient, which takes a value:

- $B = 0.02$ for a mountain location
- $= 0.05$ for a rural location
- $= 0.10$ for an urban location
- $= 0.20$ for an industrial site (polluted atmosphere)

Table 2
Geographical coordinates of the study locations.

City	Latitude	Longitude	Altitude
Bizerte	37° 16' 27"	09° 52' 26"	05 m
Nabeul	36° 27' 21"	10° 44' 15"	14 m
Djerba	33° 49' 00"	11° 0' 00"	51 m

The direct solar radiation (W/m^2) on a receiving plane normal to this radiation is therefore:

$$I^* = E_{sol} \times EXP(-ER \times M \times TI) \quad (17)$$

Direct solar flux on inclined and oriented surface is calculated by the formula:

$$S^* = I^* \times CI \quad (18)$$

S^* is the value of the direct solar radiation on a receiving plane (O, I).

2.2.3. Diffuse solar flux

The diffuse solar radiation arrives at the receiving plane after being reflected by clouds, dust, aerosols and soil. It is assumed that the diffuse solar radiation does not have a predominant (therefore isotropic) direction, so the orientation of the receiving plane does not matter. Only its inclination is decisive.

Thus, the diffuse flux for inclined receiver D^* in W/m^2 is calculated by the formula:

$$D^* = 125 \times \sin(H)^{0.4} \times ((1 + \cos(I))/2) + 211.86 \times \sin(H)^{1.22} \times ((1 - \cos(I))/2) \quad (19)$$

The albedo is called the fraction of the solar radiation reflected by a surface (here the ground), this albedo coefficient has been integrated into the formula (19) with an average value of 0.22. This coefficient depends on the nature of the soil, its temperature and its ability to reflect solar radiation.

2.2.4. Global solar flux

The total solar energy received on an inclined surface is the sum of beam and diffuse radiations directly incident on a surface and it is expressed as follows:

$$G^* = S^* + D^* \quad (20)$$

The global radiation is the maximum radiation that it is possible to have on a given receiving plane (O, I), such as a solar thermal collector. The conversion of this energy into usable energy relies on the characteristics of the receiving plane. The collected energy is, also, attenuated by the efficiency of the solar cells, i.e. its ability to make use of this energy. For most part of the work, the model includes numerical definitions with numerous coefficients whose values are regularly valid for many areas in the world.

In this study, measured data of global solar radiation and isotropic model has been used to estimate total solar radiation on inclined flat surfaces.

1-Solar radiation in horizontal surface

The measures were carried out in the year 2015 in the three cited locations. Geographical coordinates are detailed in Table 2.

Results generated by numerical model in horizontal surface are close to those provided by the meteorology station as detailed in Tables 3–5.

In Fig. 3, we present the global solar irradiation measured for the year 2015 and estimated measures for Nabeul station.

A good match was found between the experimental measures and those generated in the case of horizontal surface (see Tables 3–5).

Table 3
Values of measured global solar radiation and estimated by the model in horizontal surface, Bizerte Station, 2015.

Month	Global solar radiation (kWh/m^2)		Number of measured Days
	Model	Meteorology	
Jan.	69	68	31
Feb.	76	74	28
Mar.	126	119	29
Apr.	182	179	28
May.	220	215	31
Jun.	248	240	30
Jul.	239	239	30
Aug.	214	208	31
Sep.	126	137	27
Oct.	98	88	26
Nov.	79	77	30
Dec.	69	71	31

Table 4
Values of measured global solar radiation and those estimated by the model in horizontal surface, Nabeul station, 2015.

Months	Global solar radiation (kWh/m^2)		Number of measured days
	Model	Meteorology	
Jan.	80	79	28
Feb.	96	82	27
Mar.	158	130	29
Apr.	182	193	30
May.	220	211	30
Jun.	229	193	30
Jul.	232	121	16
Aug.	221	39	6
Sep.	160	155	29
Oct.	130	101	28
Nov.	89	82	28
Dec.	75	31	13

The monthly irradiation calculated from the meteorology considering the number of days in a month and daily measured irradiation (see Fig. 5).

In addition, we cannot have a good approximation on cloudy days. This is shown in the Fig. 5, where we observe a coincidence between estimated and measured data except for the three points when it was cloudy. Therefore, measures should be taken over a period longer than 11 years, to ensure that climatic conditions are favorable.

Fig. 5 represents the global solar radiation from January 1 to December 31. We notice that the model gives a good approximation for the whole year. In Nabeul station for July, August, October, November and December the measurement from the meteorology station are taken respectively only in 16, 6, 28, 28, 13 days. This explains the importance of numerical simulation for estimating solar radiation to compensate for the lack of data.

3. Solar radiation on tilted surface

We will discuss the effect of tilting photovoltaic panels to maximize the capture of solar rays. The experimental validation of the calculations will be carried out in comparison with the data collected in the Research and Technology Center of Energy of Borj

Table 5
Values of measured global solar radiation and estimated by the model in horizontal surface, Djerba station, 2015.

Months	Global solar radiation (Kwh/m ²)		Number of measured days
	Model	Meteorology	
Jan.	103	108	31
Feb.	120	115	28
Mar.	170	172	31
Apr.	201	203	30
May.	229	234	31
Jun.	230	233	30
Jul.	229	229	30
Aug.	203	203	30
Sep.	170	171	30
Oct.	134	134	31
Nov.	97	97	30
Dec.	89	89	31

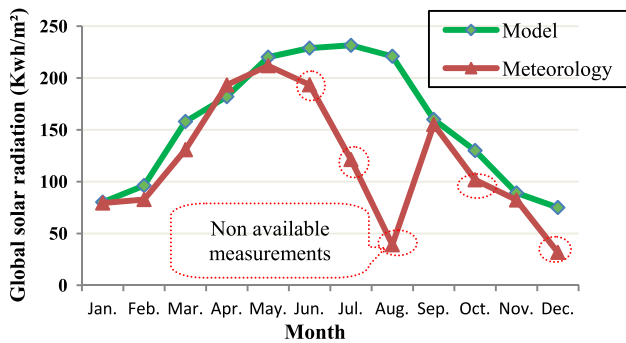


Fig. 5. Comparison of measured global solar radiation and estimated by the model in horizontal surface, Nabeul Station, 2015.

Cedria. We will put emphasis on the importance of the inclination of the solar panel to maximize the efficiency of the energy generation process. We note that the proposed model provides a good approximation of the solar flux received on a horizontal plane throughout each day of the year. Our study aims, also, to examine the performance of solar radiation model for estimating the daily global solar radiation on tilt surface at the three different stations.

The global irradiance received by a tilted surface (with an angle in respect to the horizontal plane) in the sum of both beam flux and diffuse flux densities. With a numerical simulation, we can evaluate the maximal energy that could be received by choosing an optimal angle of inclination.

Many simulations are carried out to investigate the effect of the tilt angle. Results from simulation for Bizerte city are shown in Fig. 6. The daily value of total solar radiation was maximum during the 26th day of July with a peak value equal to 950 W/m².

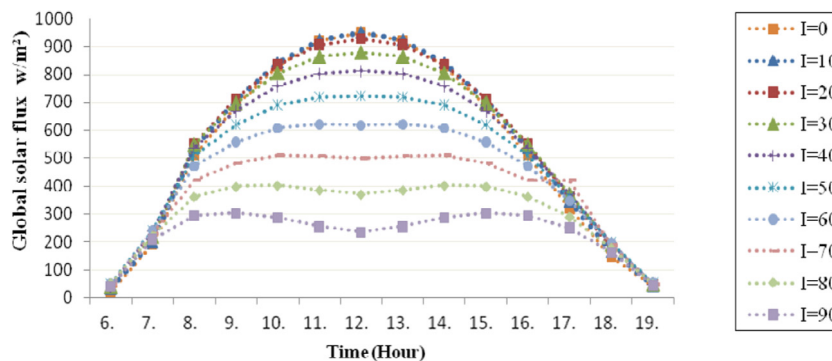


Fig. 6. Global solar flux (W/m²) of the July 26th days for different inclination angle in Bizerte station.

Table 6
Seasons and optimal tilts angle, case of Bizerte city.

Season	Optimal tilt angle
Winter	67°
Spring	40°
Summer	7°
Autumn	37°

Table 7
Values of annual global solar radiation of Bizerte city with different tilt angle.

Angles	Annual global irradiation (kWh/m ²)
0°	1719
10°	2020
20°	2110
30°	2150
40°	2140
50°	2070
60°	1950
70°	1780
80°	1570
90°	1320

Table 8
Optimal tilt angles and latitude.

City	Annual optimal tilt angle	Latitude
Bizerte	37°	37°16'27"
Nabeul	36,6°	36°27'21"
Djerba	33,3°	33°49'00"

To find the optimal angle of inclination, we have used a numerical calculation program which varies the inclination angle from 0° to 90° in steps of 10° for each hour and throughout the whole year. The calculated daily powers are used to calculate the monthly and annual powers for each angle of the interval under consideration (see Figs. 6–8 and Tables 7, 10)

The values of monthly, seasonal and annual optimum tilt angle obtained for Bizerte city are presented in Tables 6 and 11. These are also plotted against the day of the year in Fig. 9.

The optimum angle for a given season is calculated by averaging the values of the optimum tilt angle for each month within that specific season (see Table 6). The optimum angle for maximum solar energy radiation capture varies according to the months of the year (see Fig. 8). The optimum tilts angle increase in winter months and decreases to minimum value in summer and autumn months (Jamil et al., 2016).

Annual optimum tilt angle was calculated by averaging the value of optimum tilt angles for all months of the year and was found equal to 37° in Bizerte. This value of optimal tilt angle is adequately close to the latitude of the studied location (see Table 8).

Table 9
Values of Global solar radiation of Nabeul city with different tilt angles.

Angles	Annual global irradiation (kWh/m ²)
0°	1872
10°	2050
20°	2140
30°	2180
40°	2170
50°	2100
60°	1980
70°	1800
80°	1590
90°	1330

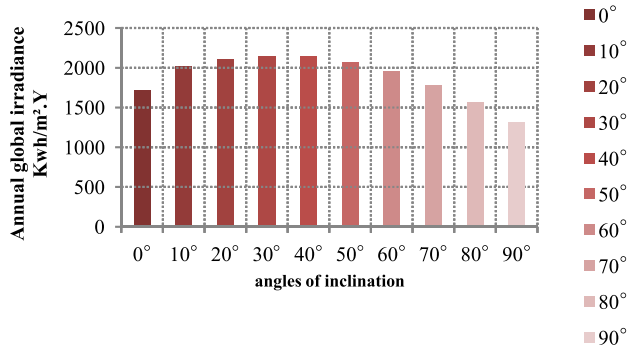


Fig. 7. Annual global irradiation of 2015 for Bizerte station.

Table 10
Values of Global solar radiation of Djerba city with different tilt angles.

Angles	Annual global irradiation (kWh/m ²)
0°	1976
10°	2240
20°	2340
30°	2380
40°	2360
50°	2280
60°	2150
70°	1950
80°	1710
90°	1430

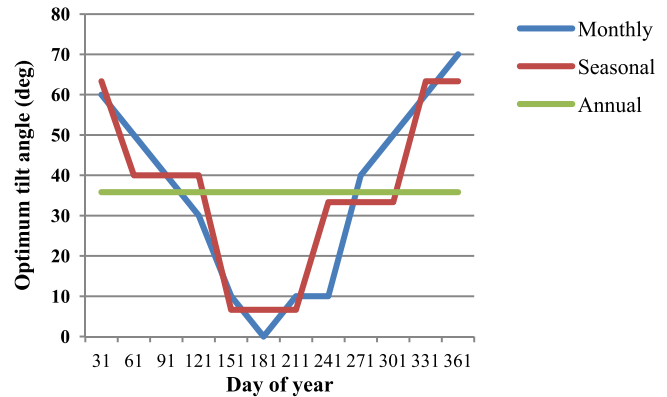


Fig. 9. Variation of monthly, seasonal and annual optimum tilt angle in Tunisia.

It should be noted that the information about the maximum received solar radiation and the tilt angle are useful for sun tracking collectors that are manually or automatically adjusted.

The same calculations led to similar results in the cities of Nabeul and Djerba (see Tables 8–10 and 12).

The gains calculated for each city are detailed in Table 13. In the case of Bizerte and Nabeul, the expected gains from a monthly change in the angle of inclination of the panels are almost equal to the expected gains of a seasonal variation. They are significantly higher than the expected gains, if the panels have a fixed inclination throughout the year.

As the monthly variation of the inclination requires much more effort, it is advisable, in the case of the cities of Bizerte and Nabeul, to change the angle of inclination of the panels each season. The shortfall is not too great.

However, in the case of the town of Djerba, the monthly gain is much higher than the seasonal and annual gain. The variation of the inclination, of the panels, must be monthly. If not, the shortfall will be significant and the losses will be considerable (see Table 14).

The gain P_G (in percentage) in the availability of solar radiation on an inclined surface and it is defined as:

$$P_G (\%) = (G_{lopti}^* / G_{I=0}^* - 1) \times 100 \tag{21}$$

Where i = month, season or annual.

$$P_L (\%) = (1 - G_{loptj}^* / G_{imonthly}^*) \times 100 \tag{22}$$

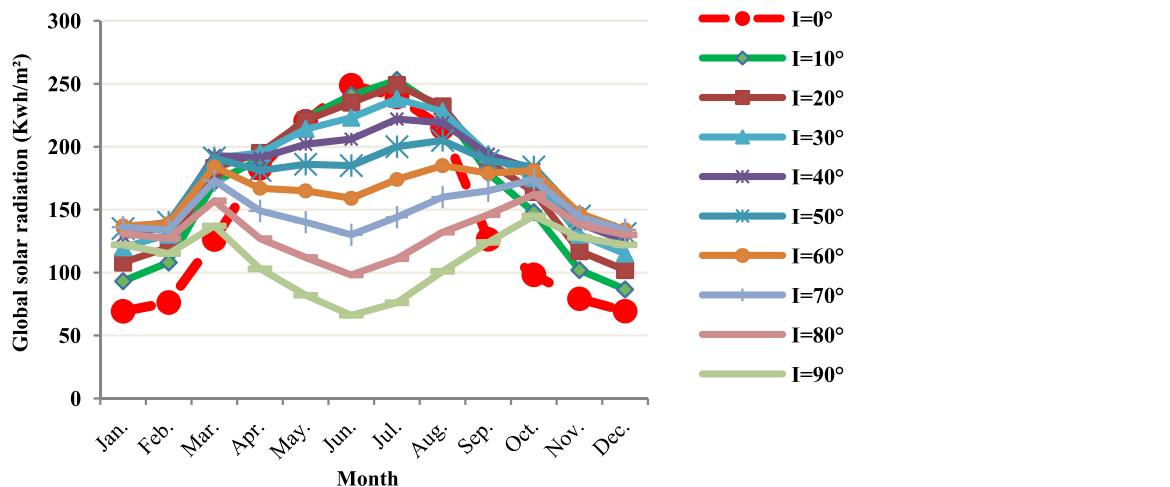


Fig. 8. Global solar radiation for Bizerte station in the year 2015 for different inclination angle.

Table 11
Monthly solar radiation for Bizerte station with different tilts angles.

Months	Global solar radiation (kWh/m ²)									
	I=0	I=10	I=20	I=30	I=40	I=50	I=60	I=70	I=80	I=90
Jan.	69.2	93.2	108	120	129	135	137	136	131	122
Feb.	76.2	108	120	130	137	140	139	134	127	115
Mar.	126.2	172	183	191	193	191	184	173	157	137
Apr.	182	190	195	195	191	181	167	149	127	103
May.	220	223	221	214	202	186	165	140	112	82
Jun.	248.9	241	235	223	206	185	159	130	98	66
Jul.	239.6	253	249	238	222	200	174	144	111	76
Aug.	214.9	229	232	228	219	205	188	160	132	101
Sep.	126.4	179	188	194	194	189	179	165	146	124
Oct.	98.2	148	164	175	182	184	181	174	162	145
Nov.	79.8	102	117	130	139	145	144	144	138	128
Dec.	69	86.6	102	115	125	131	134	134	130	122
Annual (KWh/m²/y)	1719	2020	2110	2150	2140	2070	1950	1780	1570	1320

Table 12
Monthly, seasonal and annual optimum tilt angle for south facing surfaces in Bizerte city.

Months	I _{opt} °	Seasons	I _{opt} °	Annual	I _{opt} °
Jan.	60°		66.66°	Annual	37.5°
Feb.	50°	Spring	40°		
Mar.	40°		40°		
Apr.	30°		40°		
May.	10°	Summer	6.66°		
Jun.	0°		6.66°		
Jul.	10°		6.66°		
Aug.	20°	Autumn	36.66°		
Sep.	40°		36.66°		
Oct.	50°		36.66°		
Nov.	70°	Winter	66.66°		
Dec.	70°		66.66°		

Table 14
Monthly, seasonal and annual optimum tilt angle for south facing surfaces in Djerba city.

Months	I _{opt} °	Seasons	I _{opt} °	Annual	I _{opt} °
Jan.	60°		60°	Annual	36.6°
Feb.	60°	Spring	40°		
Mar.	40°		40°		
Apr.	20°		40°		
May.	10°	Summer	10°		
Jun.	10°		10°		
Jul.	10°		10°		
Aug.	20°	Autumn	36.66°		
Sep.	40°		36.66°		
Oct.	50°		36.66°		
Nov.	60°	Winter	60°		
Dec.	60°		60°		

Table 13
Monthly, seasonal and annual optimum tilt angles for south facing surfaces in Nabeul city.

Months	I _{opt} °	Seasons	I _{opt} °	Annual	I _{opt} °
Jan.	60°		60°	Annual	36.6°
Feb.	60°	Spring	40°		
Mar.	40°		40°		
Apr.	20°		40°		
May.	10°	Summer	10°		
Jun.	10°		10°		
Jul.	10°		10°		
Aug.	20°	Autumn	36.66°		
Sep.	40°		36.66°		
Oct.	50°		36.66°		
Nov.	60°	Winter	60°		
Dec.	60°		60°		

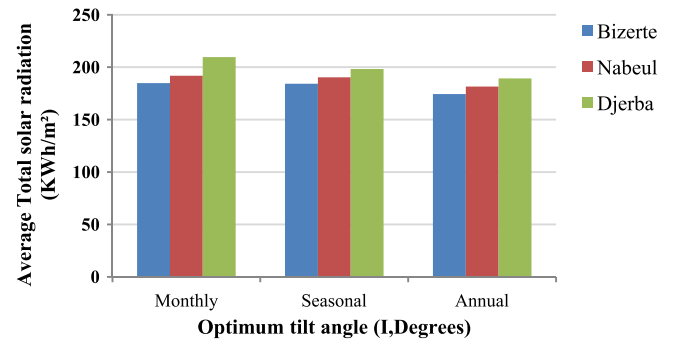


Fig. 10. Comparison of average maximum total solar radiation for Bizerte station at month, season and annual tilt angles.

Where $j =$ seasonal, annual (see Table 15).

Experimental Validation

In this part, we use the measured data obtained from the Research and Technology Center of Energy of Borj Cedria (see Fig. 10), (Lat 36°44' N, Long 10°21' N). We compare the values of the energy produced in the months of April and May, in the year 2016 with the values of energy estimated by our numerical model.

The photovoltaic panels are inclined at an angle of 30°.

Results of simulation are detailed respectively for the month of April and May in Figs. 12 and 13. The estimated energy produced by the model is close to the energy measured using the ups SB2100-TL shown in Fig. 11. This can reinforce the model and render the validity of global solar radiation in tilted surface in any given location more trustworthy.

4. Conclusion

Faced with the gradual disappearance of fossil energy sources, solar energy is undoubtedly becoming the energy of the future. Seeking a new solar photovoltaic or thermal energy sites of high-productivity, has become a strategic priority for many countries.

To validate any given site choice, it is necessary to collect measures of radiations over many years. These measures are not often available.

In this paper, we proposed the use of numerical models to estimate the energetic potential of a given site. The results generated by the calculation program were validated by the data measured at three sites Bizerte, Nabeul and Djerba.

Table 15
Total solar radiation (kWh/m²) for south facing surfaces at monthly, seasonal and annual optimum tilt angles.

Month	Bizerte				Nabeul				Djerba			
	$G_{i=0}^*$	G_{iopt}^* monthly	G_{iopt}^* seasonal	G_{iopt}^* annual	$G_{i=0}^*$	G_{iopt}^* monthly	G_{iopt}^* seasonal	G_{iopt}^* annual	$G_{i=0}^*$	G_{iopt}^* monthly	G_{iopt}^* seasonal	G_{iopt}^* annual
Jan.	69.2	137	137	122	80.2	147	147	135	103	182	174	158
Feb.	76.2	140	138	131	96.2	147	144	142	120	181	166	164
Mar.	126.2	193	188	186	158	197	197	197	170	220	209	209
Apr.	182	195	196	184	182	196	191	194	201	214	199	201
May.	220	223	218	200	220.2	225	225	208	229.2	229	222	206
Jun.	248.9	248.9	242	208	228.9	238	238	210	230	241	235	210
Jul.	239.6	253	253	224	231.6	251	251	226	229.6	253	248	225
Aug.	214.9	232	224	219	221	231	223	223	203.5	235	227	222
Sep.	126.4	194	191	190	160	187	188	188	170	203	192	193
Oct.	98.4	184	184	176	130	183	180	180	134	203	179	185
Nov.	79.8	145	144	133	89.1	156	156	145	97.1	181	167	154
Dec.	69	134	135	119	75	145	145	131	89	175	162	144
Average	157	184	184	174	156	191	190	181	164	209	198	189
% Gain	–	17.7	17.3	11.0		23.0	22.0	16.3		27.3	20.4	14.9



Fig. 11. Laboratory of photovoltaic, Research and Technology Center of Energy of Borj Cedria.

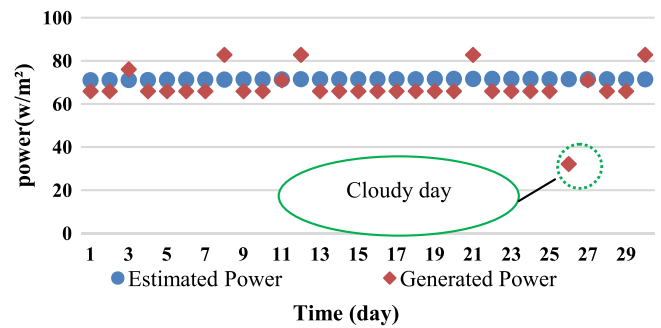


Fig. 13. Comparison of power generated and power estimated in the location of Borj Cedria, May 2016.

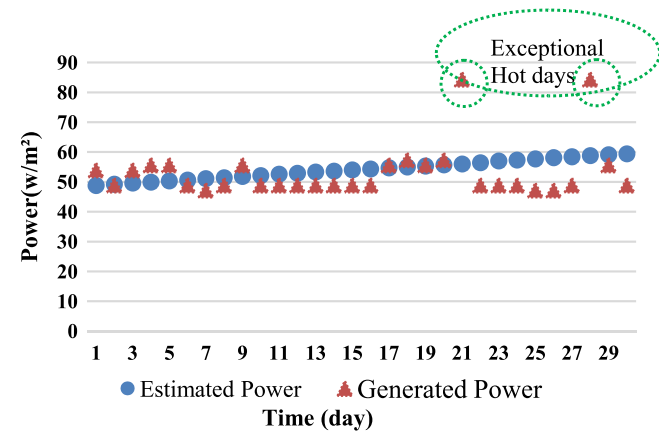


Fig. 12. Comparison of power generated and power estimated in the location of Borj Cedria, March 2016.

In the second part of this paper, we emphasized the need to choose an optimal inclination of photovoltaic panels for a predetermined period, which can be monthly, seasonal or annual. The calculation of the optimum angle of inclination and of the fixation period was validated by the data collected at the Research and Technology Center of Energy of Borj Cedria.

However, it seems interesting, too, to predict climatic variations that are increasingly intense today. These variations may affect the quality of the predictions. It is necessary to think of integrating the climatic factor in the numerical models to be designed for the determination of an energetic potential of a site.

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