Solar Energy in M'Sila (Algerian Province)

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Abstract— **An accurate knowledge of solar radiation data for a given location is required for any project aimed at exploiting solar energy. The present paper evaluates the solar energy potential of M'Sila, (internal region of Algeria). This assessment is made based on data collected at the M'Sila weather station for 365 days by 5-minute intervals. The study site is located at a latitude of 35° 42`07``, longitude of 4° 32`43`` and an altitude of 441 m above the sea level. The maximum radiation received in M'Sila during the day does not occur at a fixed time during the year. It fluctuates around an average value of 11:40. This maximum radiation was recorded between 9:14 and 13:59. The representative days of the radiation reaching the ground of M'Sila are different from those relating to extra-terrestrial radiation. They vary from year to year. The month of July is the sunniest month in M'Sila with a total insolation of 790.14 MJ/m^2. The month of December is the least sunny month with a total insolation of 242.52 MJ/m^2. M'Sila receives a total solar energy of 6316.42 MJ/m^2 per year. That means an average insolation of 526.37MJ/m^2 per month and 17.31 MJ/m^2 per day. M'Sila has an important solar energy potential that deserves to be exploited.**

Keywords-component; Solar energy potential; Global solar radiation; M'Sila; Daily solar radiation.

I. INTRODUCTION

The 1973 oil crisis changed the world's view towards renewable energies, which have become an alternative to conventional ones. [1] Climate change felt in recent decades supports also the return to renewable energies that reduce greenhouse emissions and protect the life on earth. [1,2,3,4,5]. The depletion of fossil fuels due to increased energy demand is another factor that has encouraged the exploitation of renewable energies.[4]

Renewable energies are natural endless energies coming from renewable sources like the Sun, the waterfalls, the wind, the tides…, etc. Unlike conventional energies, every country in the world has at least one inexhaustible energy source. Therefore, renewable energies are widely and easily available around the world. As the sources of conventional energies are in a depletion phase due to their use, all the countries of the globe have adopted policies to exploit their natural energy potential.

Solar energy is the most important renewable energy source [1,5,6,7]. It is the energy created by nuclear fusion between hydrogen atoms that takes place in the sun. This abundant clean and free energy is at the origin of fossil, wind and tide energies. [1] Moreover, Solar energy is accessible to all countries, but in different amounts. For example, Northern Africa receives a large amount of solar radiation than Northern Europe. Australia is the continent that receives the highest solar energy in the world. [7]

Plants convert solar energy into chemical energy through the process of photosynthesis. The human man, in contrast, has developed many technologies to use solar energy in the form of heat [8,9] and electricity [10,11] through concentrated solar power (CSP) systems and photovoltaic cells. CSP is an active solar technology that concentrates solar energy via mirrors to power steam turbines or engines that generate heat and electricity. The existing devices on the market used to capture and convert solar energy are in perpetual innovation to overcome their current limitations.

Algeria's potential in renewable energies is strongly dominated by solar energy (i.e; 169,000 TWh/year for solar thermal, 13.9 TWh/year for solar photovoltaic and 35 TWh/year for wind energy. [12]). Due to its geographical location, Algeria has one of the largest solar deposits in the world and in particular in the Maghreb region. The average number of sunshine hours over the entire national territory exceeds 2000 hours annually and reaches the 3000 hours in the highlands and the 3500 in the Sahara. [13] The daily-received energy on a horizontal surface is of the order of 5 kWh/m^2 over most of the national territory, and of nearly 1700 kWh/m^2/year in the North and 2263 kWh/m^2/year in the south. [14]. Algeria has adopted in 2011 a strategy aiming to produce by 2030, 40% of electricity from renewable resources. [13]

An accurate knowledge of solar radiation data for a given location is required for any project aimed at exploiting solar energy. [6,15,16] However, these data are not disposable for a large number of locations, especially in developing countries where solar setups may be installed.

Fortunately, since October 2015, the M'Sila's weather station has been equipped with an automatic station that measures incident solar radiation on a horizontal surface, in addition to other meteorological parameters such as

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temperature, speed and direction of the wind... etc. The present study aims to evaluate the solar energy potential of M'Sila, (internal region of Algeria). This assessment is made based on data collected at the M'Sila weather station for 365 days by 5-minute intervals.

II. METHODOLOGY

A. *Site Location*

M'Sila is a province of northern Algeria. It has an area of 18.718 km^2. Its capital also called M'Sila. M'Sila was a semi-arid region becoming an arid region, these last years, as found in our non-published investigation. The study site is located at a latitude of 35° 42`07``, longitude of 4° 32`43`` and an altitude of 441 m above the sea level. Fig. 1 shows the location of M'Sila in Algeria, in addition to its borders.

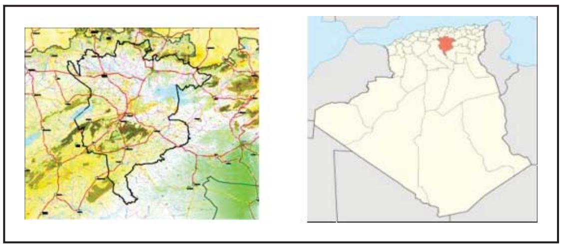

Figure 1. Location of M'Sila. [17,18]

B. *Data*

Solar radiation is the incident energy received per unit area of a surface for a particular time duration, expressed in kWh/m^2 or in J/m^2.

The data analysed in the present study were recorded by the M'Sila weather station. Solar radiation received on a horizontal surface for 365 days from November 1st, 2016 to October 31st, 2017 by 5min intervals were the data treated in the current work. Microsoft Excel software 2016 was used for this investigation.

III. RESULTS AND DISCUSSION

This work aims to examine in detail the actual solar radiation data collected by the M'Sila automatic weather station during one year of study and not to predict M'Sila solar radiation.

A. *Daily Evolution of M'Sila Solar Radiation*

The curves giving the evolution of the solar radiation during the day in M'Sila region have the same gait (the shape of a bell). They start at sunrise, go through a maximum and end at sunset. Before sunrise and after sunset, solar radiation is equal to zero. Fig.2 shows the daily evolution of the energy received on a horizontal surface of 1m^2 in M'Sila region during, the summer and winter solstices and the spring and autumn equinoxes.

In fact, during the 365 days of study, no day was free of cloud, this is confirmed by the fluctuations observed on the curves showing the evolution of the solar radiation during the day in M'Sila (see the dashed black circles in Fig. 2 as an example). In other words, if the sky is clear in the morning, it will not be in the middle or at the end of the day (even with very light cloud cover).

The times of the beginning and the end of the curve giving the evolution of daily solar radiation in M'Sila correspond to the time of sunrise and sunset respectively.

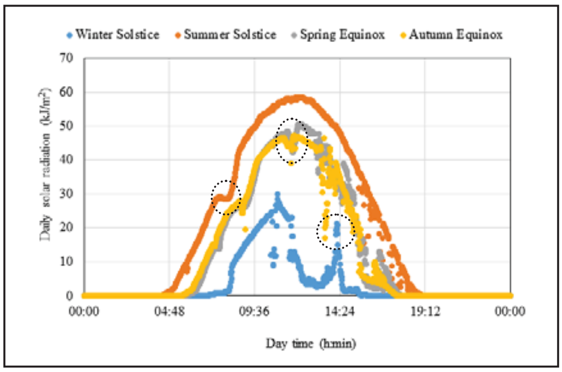

Figure 2. Daily Solar radiation evolution of M'Sila at the beginning of the four seasons.

Fig. 3 illustrates the time of sunrise and sunset over the year of study.

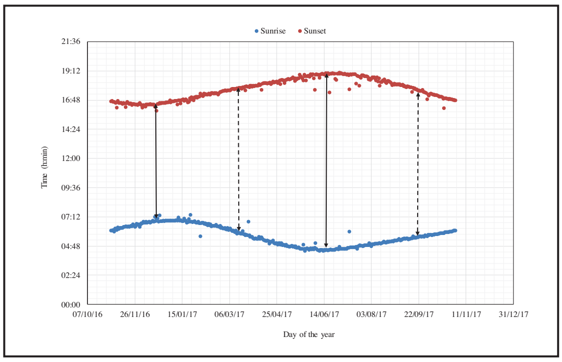

Figure 3. M'Sila's time of sunrise and sunset over the year of study.

The sun rises very early and sets very late at the summer solstice. In contrast, at the winter solstice, it rises very late and sets very early (see Fig.2 and Fig.3 (solid lines)). Moreover, the longest day (summer solstice) lasts 14:19:48, however the shortest day (winter solstice) lasts 8:30:36. In the spring and autumn equinoxes, the duration of the day is equal to that of the night (see Fig.2 and Fig.3 (dashed lines)).

The maximum radiation received in M'Sila during the day does not occur at a fixed time throughout the year. It fluctuates around an average value of 11:40. This maximum radiation was recorded between 9:14 and 13:59 (see Fig.4). It should be noted that 80% of the maximum solar radiation in M'Sila is received, on average, between 9:57 and 13:38.

The maximum amount of solar energy reaching the ground of M'Sila during the day does not happen at the same time as the air temperature peak. An example is given in Fig. 5. Indeed, the air heats up due to the radiation coming from the sun; it reaches its maximum temperature after reception of the maximum solar energy. The difference between the times when solar radiation is at its maximum value and when the temperature is at its peak is explained by the thermal inertia of the air (air heat capacity).

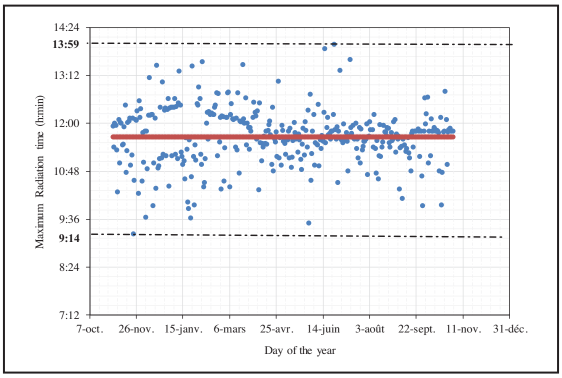

Figure 4. Maximum radiation time recorded in M'Sila region.

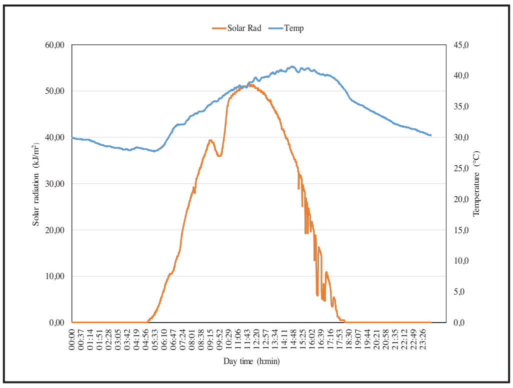

Figure 5. Daily evolution of solar radiation and temperature in M'Sila on August 19th.

This phase shift is estimated, on average, to 2 hours and 36 minutes during the year of study, it varies according to the day of the year and the nature of the sky.

B. Monthly Evolution of M'Sila Solar Radiation

The monthly solar radiation evolution in M'Sila is not uniform as seen above concerning the daily solar radiation evolution (See Fig.6). In general, the monthly solar energy tends to rise in January, February, March, April, and May and to fall during the remaining months. Sometimes the trend of monthly solar radiation does not follow the trend mentioned above. This result was found during the month of December of the year 2016, and the months of January, February, May, and June of the year 2017.

For extra-terrestrial solar radiation, the typical day of the month is the day where daily global radiation approximates the monthly averaged daily global radiation of the same month.

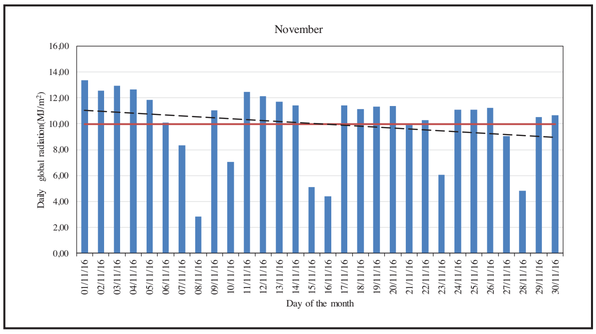

Figure 6. Monthly solar radiation evolution of the month of November in M'Sila (a decrease trends).

In this study, we sought to find the existence of a typical day for the solar radiation reaching the horizontal ground surface of M'Sila during the year of study. Table I illustrates the results found. According to Table I, it is noticed the existence of a representative day for each month of the year of study, since the relative difference between the monthly averaged global daily radiation and the daily global radiation does not exceed 2%.

TABLE I. MONTHLY AVERAGED DAILY GLOBAL RADIATION AND TYPICAL DAYS

Month	M.A.D.G.R (MJ/m^2)	Day of the Month	D.G.R (MJ/m^2)	Relative Error (%)
January	9.30	14(17)	9.32	0.15
February	12.71	02(15)	12.63	0.59
March	17.18	14(16)	17.05	0.75
April	20.08	03(15)	19.95	0.68
May	23.74	18(15)	24.15	1.71
June	25.91	28(10)	25.89	0.08
July	25.49	26(18)	25.44	0.20
August	21.33	27(17)	21.31	0.10
September	18.87	24(16)	18.77	0.57
October	14.97	22(16)	14.85	0.77
November	10.00	21(15)	9.89	1.04
December	7.82	10(11)	7.84	0.16

M.A.D.G.R.:Monthly Averaged Daily Global Radiation, D.G.R. : Daily Global Radiation, The number between brackets is the representative day of the extra-terrestrial radiation.

The representative days of the radiation reaching the ground of M'Sila are different from those relating to extra-terrestrial radiation. Indeed, these latter are independent of the year of study, but those relating to radiation collected by the meteorological station are not constant, they vary from year to year. This is confirmed by the analysis made on the data recorded by the M'Sila Weather Station from October 2015 to October 2017. Moreover, the evolution manner of the typical days requires more data.

C. Annually Evolution of M'Sila Solar Radiation

The curve describing the daily annual evolution of solar radiation in M'Sila admits two extremums; a peak-taking place in June and a minimum taking place in December or January. In this investigation, the minimum was recorded in January. The daily annual evolution of solar radiation in M'Sila during the year of study is presented in Fig.7. In fact, the daily annual radiation does not follow a random evolution as seen with the monthly one (see Fig.6 and Fig.7).

The annual evolution of the averaged daily temperature follows the same gait as the annual daily solar radiation, but with a shift to the right due to the heat capacity of the air.

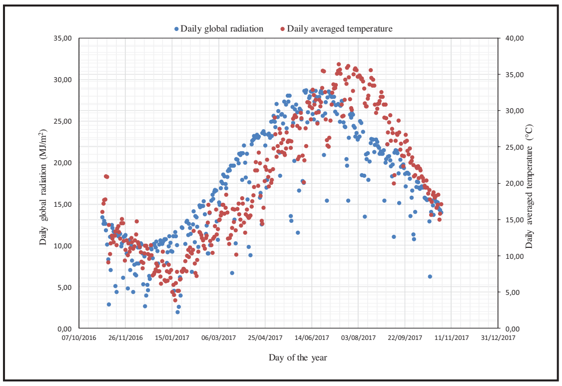

Figure 7. Daily annual evolution of solar radiation and temperature in M’Sila region.

Moreover, the temperature of the air is only a consequence of the thermal energy received from the sun. More than 30 days separate the peak of solar radiation from the peak of temperature. Furthermore, the coldest day is not the one that receives the lowest solar radiation, and the hottest day is not the one that receives the maximum solar energy (see again Fig.7).

Although the annual evolution of the day length admits two extremums, it does not have the same appearance as the annual solar radiation evolution (Fig.8). When comparing the daily solar radiation to the day length over the year of study, it can be seen that the summer solstice is not the day that receives the maximum energy, likewise, the winter solstice is not the day that receives the minimum solar energy.

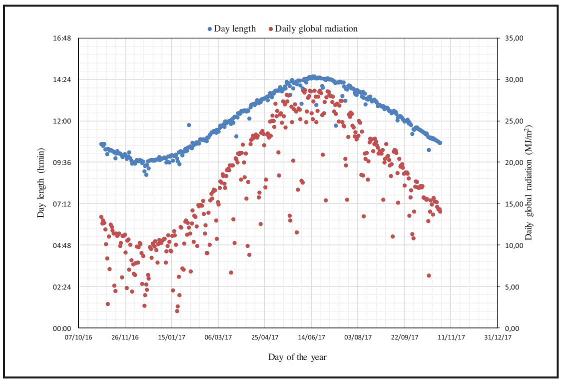

Figure 8. Daily length and daily global radiation in M’Sila region during one year.

Fig.9 shows the evolution of the monthly global radiation during the study year in M’Sila. It can be seen that the two curves giving the daily annual radiation evolution and the one giving the monthly annual radiation evolution have the same appearance except that the last one is finer (more refined), presenting no fluctuation (see Fig. 8 and Fig. 9).

It should be noted that the month of July is the sunniest month in M’Sila with a total insolation of 790.14 MJ/m^2 and an average insolation of 25.49 MJ/m^2/day. In addition, the average monthly radiation in M'Sila peaks in June (Fig.9 and Table I) with a value of 25.91 MJ/m^2/day. Indeed, there is no significant difference between the solar radiation of the months of June and July ($p>0.05$) (see again Fig.9). The month of December is the least sunny month with a total insolation of 242.52 MJ/m^2 and an average insolation of 7.82 MJ/m^2/day.

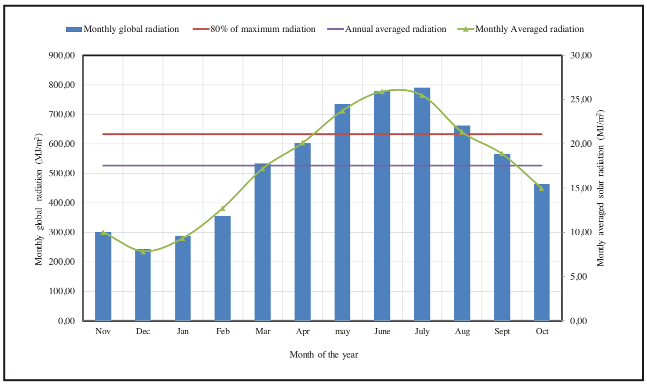

Figure 9. Evolution of the monthly global radiation during the study year in M’Sila.

M'Sila receives a total solar energy of 6316.42 MJ/m^2 per year. That means an average insolation of 526.37MJ/m^2 per month and 17.31 MJ/m^2 per day. Assuming a conversion efficiency of 8%, solar energy reaching the ground of M'Sila can provide 140 kWh/m^2/year of useful energy. Global solar radiation of the months of March, April, May, June, July, August, and September exceeds the average annual radiation. So, in M'Sila region, seven months of the year receive a monthly radiation above the annual average (see again Fig.9). More than 80% of the maximum solar energy is received in the months of May, June, July, and August. Based on this analysis, it is recommended to include the month of May in the thermal gains calculations of the M'Sila buildings. Which is not taken into consideration in current thermal regulations.

Fig. 10 illustrates the relation between monthly averaged daily length and monthly averaged daily global radiation.

As seen from Fig. 10, there is a very strong positive correlation between the averaged daily length and the monthly averaged daily global radiation (Pearson coefficient= 0.98).

Moreover, there is a very strong positive correlation between the averaged daily temperature and the monthly averaged daily global radiation (Pearson coefficient= 0.90) (see Fig. 11).

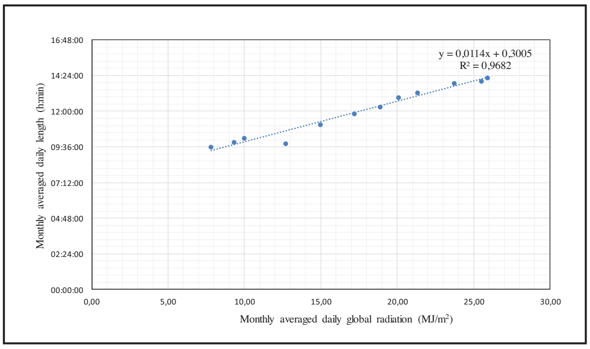

Figure 10. Relation between monthly averaged daily length and monthly averaged daily global radiation.

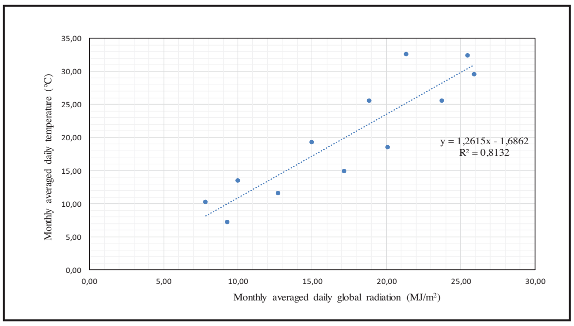

Figure 11. Averaged daily temperature vs monthly averaged daily global radiation.

IV. Conclusion

This investigation permits to retain that M'Sila has an important solar energy potential. Indeed, the solar energy incident on M'Sila has a magnitude of 17MJ/m^2/day.

In M'Sila region, seven months of the year receive a monthly radiation above the annual average.

The maximum radiation was recorded between 9:14 and 13:59. It should be noted that 80% of the maximum solar radiation in M'Sila is received, on average, between 9:57 and 13:38.

References

[1] S. A. Kalogirou, "Solar thermal collectors and applications" Progress in Energy and Combustion Science, vol. 30, pp. 231–295, 2004.

[2] J. Kim, S. Y. Park, J. Lee, "Do people really want renewable energy? Who wants renewable energy?: Discrete choice model of reference-dependent preference in South Korea", Energy Policy, in press.

[3] Y.Tian, C.Y.Zhao, "A review of solar collectors and thermal energy storage in solar thermal applications", Applied Energy, vol. 104, pp. 538-553, 2013.

[4] A. Shahsavari, M. Akbari," Potential of solar energy in developing countries for reducing energy-related emissions", Renewable and Sustainable Energy Reviews, vol. 90, pp. 275-291, 2018.

[5] K. Ka-LunLau, F. Lindberg, E.Johansson, M. I. Rasmussen, S.Thorsson, "Investigating solar energy potential in tropical urban environment: A case study of Dar es Salaam, Tanzania", Sustainable cities and Society, vol. 30, pp. 118-127, April 2017.

[6] M. Chegaar, A.Chibani, "Global solar radiation estimation in Algeria", Energy Conversion and Management, vol. 42, pp. 967-973, 2001.

[7] E. Kabir, P. Kumar, S. Kumar, A. A. Adelodun, K.H. Kim, "Solar energy: Potential and future prospects", Renewable and Sustainable Energy Reviews, vol. 82, Part 1, pp. 894-900, February 2018.

[8] S. Seddegh, X. Wang, A.D. Henderson, Z. Xing, "Solar domestic hot water systems using latent heat energy storage medium: a review", Renew Sustain Energy Rev, vol. 49, pp. 517-533, 2015.

[9] M.R. Islam, K. Sumathy, S.U. Khan,"Solar thermal systems and their market trends", Renew Sustain Energy Rev, vol.17, pp.1-25, 2013

[10] International Energy Agency (IEA). Key World Energy Trends excerpt from: World energy balances.

[11] Solar Power Technology and Economics. Available from:⟨http://www.mpoweruk. com/solar_power.htm⟩; [accessed on 07 July2018].

[12] CDER, "Les énergies renouvelables en Algérie : chiffres clefs, publication des services économiques", pp. 13, novembre 2013.

[13] Noureddine Said, "Potentiel Solaire de l'Algérie: PV et CSP, Conférence sur le PV et CSP et intégration au réseau", Algies, May 28th 2013.

[14] Bentouba Saïd, "L'énergie renouvelable en Algérie et l'impact sur l'environnement", Journal of Scientific Research N° 0, vol. 1, pp.49, 2010.

[15] M. Ouagued, A. Khellaf, L. Loukarfi, "Estimation of the temperature, heat gain and heat loss by solar parabolic trough collector under Algerian climate using different thermal oils", Energy Conversion and Management, vol.75, pp. 191-201, November 2013

[16] M.Hussain, L. Rahman, Md. M. Rahman, "Technical note: Techniques to obtain improved predictions of global radiation from sunshine duration", Renewable Energy, vol. 18, pp.263-275, October 1999.

[17] http://www.msila-dz.org/?action=formunik&type=sous_menu&idformunik=29, [accessed on 20 June 2016].

[18] https://en.wikipedia.org/wiki/M%27Sila_Province [accessed on 20 July2018].