EVALUATION OF SOLAR ENERGY RESOURCES IN MAHAJANGA : SOLAR IRRADIATION ON A HORIZONTAL SURFACE

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ABSTRACT

The long-term evaluation of the performance of solar energy conversion systems is established through the knowledge of solar irradiation at the installation site. This study is in the context of the characterization of solar energy resources in Mahajanga for application to solar energy conversion. For this, it is important to have effective methods for estimating the solar surface energy on the ground called also global terrestrial horizontal radiation. Three models for predicting the solar reservoir are adopted : Semi-empirical models (Lacis & Hansen, Davies & Hay), Meteorological models (Garg and Hussein) and Spectral models (Leckner and Richard Bird and Riordan). These models make it possible to calculate the three components of solar irradiation: direct, diffuse and global. The analysis of the results obtained shows a good correlation between the results calculated by the different models. It is also clear that the Mahajanga region has good sunshine which is favourable to the use of energy systems.

Keyword: - *Global solar irradiation, Insolation, Solar energy, solar reservoir, solar irradiation components, Semi-empirical models, Meteorological models, Spectral models .*

1. INTRODUCTION

Solar radiation is an important climatic variable that makes life on Earth possible by bringing heat and light. Abundant, renewable and available on the ground, it consists of light rays carrying energy from the sun in all wavelengths.Aware of the abundance of solar radiation in different regions of Madagascar, the country has embarked on energy transition programmes. Energy strategies using renewable energies (hydro, wind, solar, wave, biomass, geothermal, tidal) are being implemented to increase the production of electrical energy. Among the regions concerned, the Mahajanga region offers interesting potential for investing in many projects and programmes that contribute to the development of renewable energies, principally solar energy. It has a climate very favourable to the exploitation of solar energy, an exceptional amount of sunshine: its geographical location (15°40' South latitude, 46°21' East longitude and 22m altitude), with a very high sunshine rate (on average 75%) and the annual average global daily radiation measured on a horizontal plane exceeds 6000 Wh.m^{-2}. The establishment of a database is therefore of major interest and it is important to have effective methods to estimate them.

This work is part of this perspective, by adopting some theoretical models to estimate the global solar irradiation received on the ground, which take into account the diffusion and absorption effects that solar irradiation undergoes during its passage through the atmosphere. These models are based on the determination of the transmission coefficients of the different atmospheric constituents. These coefficients require the availability of current meteorological parameters (relative humidity, ambient temperature, atmospheric pressure, etc.) and geographical site parameters (latitude, longitude and altitude).

2. MATHEMATICAL MODELLING

2.1 Estimation of global solar irradiation received on the ground on a horizontal surface by spectral models

To calculate the direct, diffuse and global spectral radiation at the earth's surface, two spectral models are adopted: the Leckner [1] and Richard Bird [2] models. These models are based on knowledge of the characteristics of certain atmospheric constituents such as aerosols and clouds to determine the spectral distribution of solar radiation on the earth's surface. Leckner's spectral model provides a description of the physical behaviour of the atmosphere such as the absorption and diffusion of its constituents. The attenuation properties of the atmosphere are presented in the form of transmission coefficients to calculate the spectral components of direct, diffuse and global radiation on a horizontal surface under clear sky conditions. While Richard Bird's spectral model has the advantage of obtaining spectra for horizontal and inclined surfaces.
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- Leckner Spectral Model

The formula proposed by Bo-Leckner to calculate the spectrum of the global irradiation received on the ground in a horizontal plane is given as following [1.3]:

$$G_h(\lambda) = d(\lambda) + D(\lambda) \quad (1)$$

$d(\lambda)$: direct spectral radiation on a horizontal surface

$$d(\lambda) = I_n(\lambda) \times \cos(\theta_z) \quad (2)$$

$D(\lambda)$: Spectrum of diffuse irradiation on the ground in a horizontal plane

$$D(\lambda) = a(\lambda) \times \left[I_0(\lambda) \times \tau_0(\lambda) \times \tau_g(\lambda) \times \tau_w(\lambda) - I_n(\lambda) \right] \times \cos\theta_z \quad (3)$$

Where :

$I_o(\lambda)$: Spectral irradiation outside the atmosphere at the mean distance Earth-sun

$I_n(\lambda)$: Spectrum of normal direct irradiation to the ground on a horizontal surface

$$I_n(\lambda) = C_{t,s} \times I_0(\lambda) \times T(\lambda)$$

$$T(\lambda) = \tau_R(\lambda) \times \tau_a(\lambda) \times \tau_w(\lambda) \times \tau_0(\lambda) \times \tau_g(\lambda)$$

Distance correction factor for the Sun-Earth distance

$$C_{t,s} = 1.00011 + 0.034221\cos(\Gamma) + 0.0128\sin(\Gamma) + 0.000719\cos(2\Gamma) + 0.000077\sin(2\Gamma)$$

Angle of the day : $\Gamma = 2\pi(nj - 1/365)$ *; Day number of the year : nj = 1 (January 1st), n = 32 (February 1st)… and nj = 365 (31 December) ;*

$\tau_i(\lambda)$: Monochromatic transmission factors due to the Rayleigh effect, to diffusion by aerosols, high and low absorption by water vapour and absorption by other atmospheric gases (O_2, CO_2,...) and ozone.

$$\tau_R(\lambda) = \exp\left(-0.008735 \times \lambda^{-4.08} \times m_a\right); \tau_w(\lambda) = \exp\left(-0.3k_w(\lambda).X_w.m_r / \left(1 + 25.25k_w(\lambda).X_w.m_r\right)^{0.45}\right)$$

$$\tau_g(\lambda) = \exp\left(-1.41k_g(\lambda).m_r / \left(1 + 118.3k_g(\lambda).m_r\right)^{0.45}\right); \tau_a(\lambda) = \exp\left(-\beta\lambda^{-\alpha} m_r\right); \tau_0(\lambda) = \exp\left(-k_0(\lambda) \times \ell \times m_0\right)$$

Corrected air mass : $m_a = \frac{p}{p_0} m_r$ ***;***

Atmospheric pressure : $p = p_0 \times exp\left(-0.0001184 \times z\right)$

Relative optical air mass : $m_r = \left[\cos(\theta_z) + 0.15(93.885 - \theta_z)^{-1.253}\right]^{-\ell}$

Reduced ozone layer thickness: $\ell = \left[235 + \left(150 + 40\sin\left(0.9856(nj - 30)\right) + 20\sin(3L)\right) \times \left(\sin^2(1.28\varphi)\right)\right] / 1000$

Ozone air mass : $m_0 = 35 / \left(1224\cos^2(\theta_z) + 1\right)^{0.5}$

Condensable water thickness corrected by optical path of irradiation at through this layer: $X_w = 0.795 \times U_w$

Condensable water thickness obtained from temperature T (in K) and relative humidity RH (in %):

$$U_w = \frac{0.493}{T} \frac{HR}{100} . \exp\left(26.23 - \frac{5416}{T}\right)$$

Zenith angle $\theta_z = 90° - h$ *; Sun's height:* $\sin(h) = \cos(\varphi) \times \cos(\delta) \times \cos(\omega) + \sin(\varphi) \times \sin(\delta)$ *;*

Solar declination (varies between -23.45° (on December 21) and +23.45° (on June 21))

: $\delta = 23.45 \times \sin\left[(360/365) \times (nj + 284)\right]$ ***;***

Hour angle: $\omega = \frac{360}{24}(12 - TSV)$ *; Real solar time* : $TVS = TL - \left(TU - \frac{L}{15}\right) + \frac{\Delta t}{60}$;

Correction of time equation

$$: \Delta t = 9{,}87\sin 2\left(\frac{2\pi}{365}(nj - 81)\right) - 7{,}53\cos\left(\frac{2\pi}{365}(nj - 81)\right) - 1{,}5\sin\left(\frac{2\pi}{365}(nj - 81)\right)$$

TU: Universal time (time difference with respect to the Greenwich meridian);
TL: Legal Time (given by a watch).

- Richard Bird and Riordan Spectral Model

The global radiation is the sum of the two direct and diffuse components, it is given by the formula [2,3] :

$$G_h(\lambda) = d(\lambda) + D(\lambda) \quad (4)$$

The direct spectral radiation on a horizontal surface is expressed as following :

$$d(\lambda) = I_n(\lambda) \times \cos(\theta_z) \quad (5)$$

The normal direct radiation to the ground on a surface normal to the direction of the sun for a wavelength λ, is given by:

$$I_n(\lambda) = I_0(\lambda) \times C_{t-s} \times \tau_R(\lambda) \times \tau_a(\lambda) \times \tau_w(\lambda) \times \tau_0(\lambda) \times \tau_g(\lambda)$$

The terms $\tau_R(\lambda)$, $\tau_a(\lambda)$, $\tau_w(\lambda)$, $\tau_o(\lambda)$, $\tau_g(\lambda)$, are the transmission functions of the atmosphere at wavelength relatively and respectively to molecular diffusion, attenuation by aerosols, water vapour absorption, ozone absorption and absorption by uniform gas mixtures.

$$\tau_R(\lambda)=\exp\left(-\frac{m_a}{\lambda^4\left(115.6406-(1.335)\lambda^{-2}\right)}\right);\tau_a(\lambda)=\exp\left(-\beta\lambda^{-\alpha}m_r\right);\tau_0(\lambda)=\exp\left(-k_0(\lambda)\times\ell\times m_0\right)$$

$$\tau_w(\lambda)=\exp\left(-\frac{0.2385k_w(\lambda).w.m_r}{\left(1+20.07k_w(\lambda).w.m_r\right)^{0.45}}\right);\tau_g(\lambda)=\exp\left(-\frac{1.41k_g(\lambda).m_a}{\left(1+118.93k_g(\lambda).m_a\right)^{0.45}}\right)$$

Ozone air mass : $m_0=\dfrac{1+\frac{h_0}{6370}}{\left(\left(\cos(\theta_z)^2\right)+2\frac{h_0}{6370}\right)^{0.5}}$

h_0, is the altitude of the maximum ozone concentration which is approximately equal to 22 km.
Diffuse radiation is composed of three elementary components: the Rayleigh diffusion component: DR(λ) ; the aerosol diffusion component: Da(λ) and the component that takes into account the multiple reflections of radiation between the ground and the atmosphere: Dm(λ) :

$$D(\lambda)=D_R(\lambda)+D_a(\lambda)+D_m(\lambda) \qquad (6)$$

$$D_R(\lambda)=I_0(\lambda)\times C_{t-s}\cos(\theta_z)\times\tau_g(\lambda)\times\tau_0(\lambda)\times\tau_w(\lambda)\times\tau_a(\lambda)\times\left(1-\tau_R(\lambda)\right)\times 0.5$$

$$D_a(\lambda)=I_0(\lambda)\times C_{t-s}\cos(\theta_z)\times\tau_g(\lambda)\times\tau_0(\lambda)\times\tau_w(\lambda)\times\tau_R(\lambda)\times\left(1-\tau_a(\lambda)\right)\times F_a(\lambda)\times\omega_0(\lambda)$$

$$D_m(\lambda)=\frac{\left(I_n(\lambda)\times\cos(\theta_z)+D_R(\lambda)+D_a(\lambda)\right)\times r_s(\lambda)\times r_g(\lambda)}{\left(1-r_s(\lambda)\times r_g(\lambda)\right)}$$

$F_a(\lambda)$ is the part of diffuse energy directed forward and ω_0 is the first diffusion albedo of aerosols. The value of ω_0 depends on the type of aerosols present in the atmosphere, as it is often assumed that ω_0 is equal to 1. in this model, Bird uses $F_a(\lambda)=0.9054$ and $\omega_0(\lambda)=0.82$ regardless λ .
$r_g(\lambda)$ is the albedo of the ground and $r_s(\lambda)$ is the albedo of the air defined by the fraction of the energy reflected by the sky to the considered surface:

$$r_s(\lambda)=\tau'_0(\lambda)\times\tau'_w(\lambda)\times\tau'_g(\lambda)\times\left[0.5\tau'_a(\lambda)\left(1-\tau'_R(\lambda)\right)+\left(1-\tau'_a(\lambda)\right)\times 0.22\omega_0(\lambda)\right]$$

The Transmittance $\tau'_i(\lambda)$ are the same coefficients detailed above (the $\tau_i(\lambda)$) but with an optical air mass m_a equal to 1.9, which corresponds to a zenith angle equal to 60º.

2.2 Estimation of the global solar irradiation received on the ground on a horizontal surface by semi-empirical models

Semi-empirical models take into account the diffusion and absorption effects of solar radiation during its passage through the atmosphere. They are based on the determination of the transmission coefficients of the different atmospheric constituents. These coefficients require the availability of current meteorological parameters (relative humidity, ambient temperature, atmospheric pressure, etc.) and geographical site parameters (latitude, longitude and altitude).

- Semi-empirical model of Davies and Hay

The relationship proposed by Davies & Hay [4], for the calculation of global radiation on a horizontal plane, which is the sum of the two direct and diffuse components, is given by :

$$G=I+D=\frac{I+D_R+D_a}{1-\rho\rho'_a} \qquad (7)$$

The direct irradiation on a horizontal plane is given by equation (8):

$$I = I_{sc} \times \left(\tau_R \times \tau_0 - \alpha_w \right) \times \tau_a \times \cos\left(\theta_z\right) \qquad (8)$$

Horizontal diffuse irradiation is the sum of the three diffuse components due to the various types of diffusion of solar irradiation by the atmospheric pellicle: the diffusion from Rayleigh diffusion Dr, the diffusion after diffusion by aerosols Da and the diffusion due to the multiple reflection phenomenon (several times) of solar irradiation between the ground and the sky Dm.

$$D = D_R + D_a + D_m \qquad (9)$$

τ_i : Transmission coefficients of direct irradiation after molecular or Rayleigh diffusion, absorption by ozone, diffusion by aerosols, absorption of direct irradiation by water vapour

$$\tau_R = 0,972 - 0,08262 m_a + 0,00933 m_a^2 - 0,00095 m_a^3 + 0,000437 m_a^4$$

$$\tau_0 = 1 - \alpha_0 ; \tau_w = 1 - \alpha_w$$

$$\tau_a = \left(0,12445\alpha - 0,0162\right) + \left(1,003 - 0,125\alpha\right) \times \exp\left[-\beta m_a \left(1,089\alpha + 0,5123\right)\right]$$

Coefficient corresponding to the absorption of direct solar irradiation by the ozone layer :

$$\alpha_0 = \frac{0.02118 U_0}{1 + 0.042 U_0 + 3.23.10^{-4} U_0^2} + \frac{1.082 U_0}{\left(1 + 138.6 U_0\right)^{0.805}} + \frac{0.0658 U_0}{1 + \left(103.6 U_0\right)^3}$$

where, U_0, the thickness of the ozone layer corrected by the optical path of solar radiation through this layer in cm NTP (Normal Temperature and Surface Pressure) and defined by :

$$U_0 = \ell \times m_r$$

α_w, represents the absorption coefficient of direct radiation by water vapour, is given by the equation :

$$\alpha_w = \frac{2.9 X_w}{\left(1 + 141.5 X_w\right)^{0.635} + 5.925 X_w}$$

X_w : Condensable water thickness corrected by optical path of irradiation

$$X_w = m_a \times U_w$$

U_w : Thickness of water condensable at the vertical of the place (cm) obtained from the temperature T (in K) and the relative humidity RH (in %)

$$U_w = \frac{0.493}{T} \frac{HR}{100} . \exp\left(26.23 - \frac{5416}{T}\right)$$

α and β which are respectively the parameter characterizing the visibility of the sky and the Angström haze coefficient. In this work, α = 1.3. The coefficient β is 0.02 for a very pure sky (deep blue) and 0.2 for a polluted sky (milky blue).

$$D_R = I_{sc} \times \tau_0 \times \tau_a \left(1 - \tau_R\right) \times 0.5 \cos\left(\theta_z\right)$$

$$D_a = I_{sc} . \cos\theta_z . \left(\tau_0 . \tau_r - \alpha_w\right) . \left(F_c \omega_0 \left(1 - \tau_a\right)\right)$$

$$D_m = \frac{\left(I + D_a + D_R\right) \times \rho \times \rho'_a}{1 - \rho \times \rho'_a}$$

With ρ is the albedo of the ground. The dispersion albedo ω_0 of the atmosphere, for urban/industrial regions,, and for rural/agricultural regions, $\omega_0 = 0.9$ [1]. Clear sky albedo of the considered site is given by the relationship :

$$\rho'_a = 0.0685 + \left(1 - F_c\right)\left(1 - \tau'_a\right)$$

The values of the direct dispersion coefficient of atmosphere Fc are given as a function of the zenith distance according to Robinson.

Table-1 : Values of the factor Fc in function of the zenith distance according to Robinson [8]

θz(°)	0	10	20	30	40	50	60	70	80	85
Fc	0.92	0.92	0.90	090	0.90	0.85	0.78	0.68	0.60	0.50

The constraint on τ_a indicates that the transmission coefficient of solar irradiation after aerosol diffusion should be calculated for an air mass value equal to :

$$m_a = 1.66\,\frac{p}{p_0}$$

- Semi-empirical model of Lacis & Hansen

The semi-empirical model of Lacis and Hansen [5] expresses the general form of the global solar radiation on a horizontal plane according to equation (10):

$$G = I_{sc} \times \cos(\theta_z)\left[\frac{(0.647 - \rho'_s - \alpha_0)}{(1 - 0.0685\rho)} + 0.353 - \alpha_w\right] \quad (10)$$

The coefficient corresponding to the absorption of direct solar radiation by the ozone layer is calculated in the Davies and Hay model.
The absorption coefficient of direct radiation by water vapour α_w is in the Davies and Hay model. In this model, the corrected air mass is expressed by :

$$m_a = m_r\left(\frac{p}{p_0}\right)^{0.75} \times \left(\frac{273}{T}\right)^{0.5}$$

2.3 Estimation of the global solar irradiation received on the ground on a horizontal surface by meteorological models

Meteorological models use linear relationships to transform measured ground data (sunstroke, temperature, humidity, etc.) into a global solar irradiation flux. These models have the advantage of being applicable to any state of the sky (any sky).

- Garg Model

The Garg model makes it possible to estimate the monthly mean of the global irradiation on a horizontal plane from the meteorological parameters of the site linking the extraterrestrial solar irradiation calculated on a horizontal plane, the monthly means of the insolation fraction, the absolute humidity Ha, the relative humidity HR and the ambient temperature T[6].

$$G = G_0(0{,}14 - 0{,}4\sigma - 0{,}0055Ha) \quad (11)$$

$$Ha = HR\left(4{,}7923 + 0{,}3647T_a + 0{,}0055T_a^{\,2} + 0{,}0003T_a^{\,3}\right)$$

The insolation fraction or insolation rate corresponds to the ratio between the actual daily insolation time S and the theoretical daily insolation time outside atmosphere S_0.

$$\sigma = \left(\frac{S}{S_0}\right)$$

The ratio of the daily global irradiation G terrestrial to the measured daily global extraterrestrial irradiation Go is called the clarity index :

$$K_t = \left(\frac{G}{G_0}\right)$$

Monthly mean per day of global irradiation outside the atmosphere:

$$G_0 = \frac{24}{\pi} I_{SC} \left[\cos(\varphi)\cos(\delta)\sin(\omega_s) + \omega_s \sin(\varphi)\sin(\delta)\right]$$

At the limit of the atmosphere, the daily insolation is identical to the theoretical insolation So which corresponds to the duration of the day. It depends only on the latitude of the site and the declination.

$$S_0 = \frac{2}{15}\cos^{-1}(-\tan(\varphi)\times\tan(\delta))$$

- Hussain model

Hussain's model [7] is based on the model of Garg et al. It allows us to estimate the global irradiation as a function of the monthly means of absolute humidity, the duration of insolation and the extraterrestrial irradiation calculated on a horizontal plane. This expression is given as following:

$$G = G_0 \left(0,394 - 0,364\left(\frac{S}{S_0}\right) - 0.0035Ha\right) \qquad (12)$$

3. RESULTS AND DISCUSSIONS

3.1 Characteristics of Mahajanga site

The specifications of the Mahajanga site located in the northwestern region of Madagascar are given by the meteorological quantities according to Table 1.

Table-2 : Geographical coordinates of Mahajanga site

Latitude (°)	Longitude (°)	Altitude (m)	Méridien de référence(°)	Albédo du sol	DEL
15°40' South	46°21' East	22m	40°	0 ,35	0 ,9h

Based on the measured data available from the Mahajanga site, the curves described below provide a preliminary idea of the distribution of the solar field in the Mahajanga region. The following curves represent respectively the annual changes in the monthly means of daily insolations, insolation fractions, global irradiation outside the atmosphere and temperatures from 01 January 2010 to 31 December 2018.

The analysis of the results represented above makes it possible to evoke the following remarks: The annual mean insolation measured at the Mahajanga site takes high values between 100 h and 340 h almost all year round. Sunny days from 200 h to 300 h are the most common. The curves of the insolation and the measured insolation time evolve in the same way. The insolation fraction takes low values in summer (0.3 to 0.6) and high values in winter (0.9). In Mahajanga the sky is normally clear during the long dry season, whereas during the rainy season, the hours of sunshine decrease slightly.

The curves in Chart 2 illustrate respectively the monthly mean temperature during the years 2010 to 2018 for the city of Mahajanga. Mahajanga is hot all year round, but temperatures decrease slightly from June to September, especially at night. Here are the average temperatures. The ambient temperature in Mahajanga varies between 19.43 ^{o}C and 34 °C throughout the year. The maximum value is in October and the minimum value is in July.

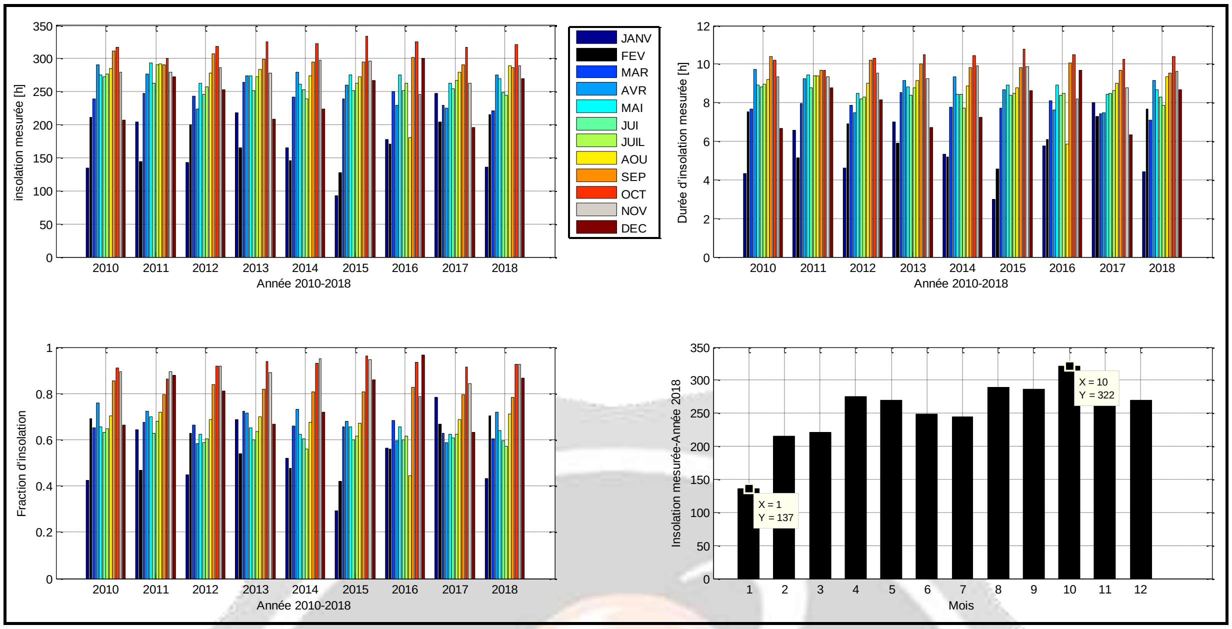

Chart -1: Monthly mean insolation - Mahajanga (2010-2018)

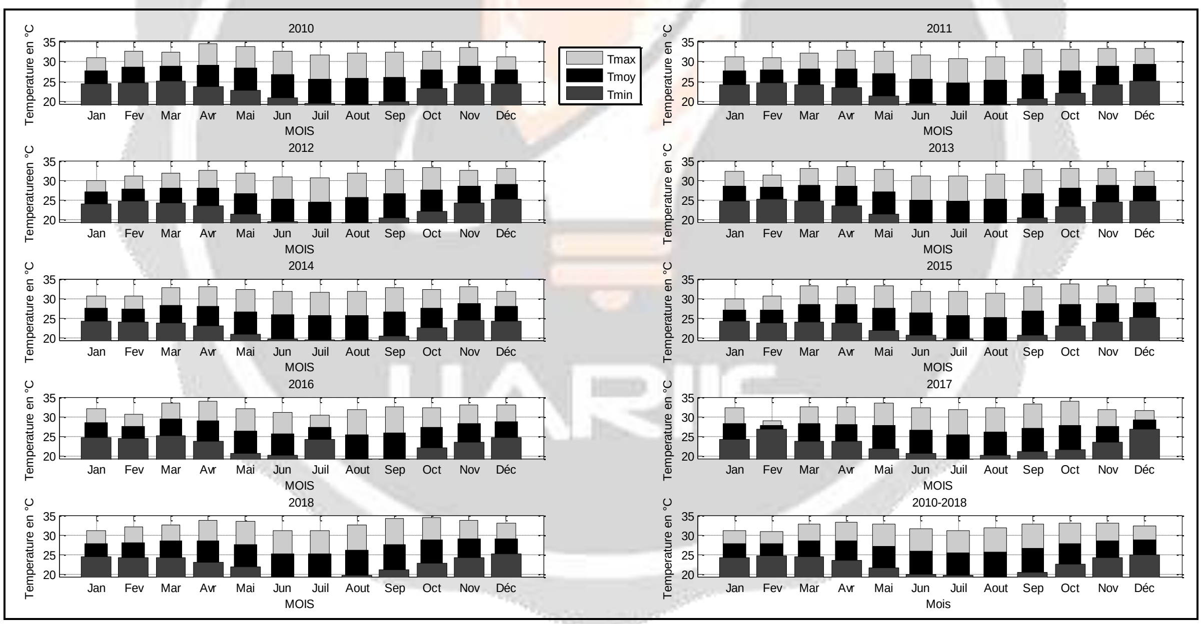

Chart -2 : Monthly mean temperature - Mahajanga (2010-2018)

3.2 Results of spectral models

In the energy sector, electrical energy production can be achieved by converting solar illumination using photovoltaic cells. These cells convert only part of the radiation corresponding to their spectral selectivity, which depends on the type of material used. The efficiency of photovoltaic cells is related to their spectral selectivity and therefore to the spectral distribution of solar radiation.

The curves in Chart 3 represent the spectral distributions of extraterrestrial solar irradiation and the components of solar irradiation at ground level on a horizontal plane as a function of wavelength calculated according to the Leckner and Bird & Riordan models, respectively. The spectra of solar radiation calculated by the Leckner model and the Bird & Riordan model in the curves in Chart 3 look almost the same. The spectral distribution of extraterrestrial solar irradiation approximately follows the distribution of a black body at a temperature of 5760 K [7]. The values of the spectra of solar irradiation (direct, diffuse and global) on a horizontal surface are always lower than the values of extraterrestrial solar irradiation, due to the influence of the Earth's atmosphere. The spectra range from shorter to longer wavelengths. Above 2.5 µm, extraterrestrial irradiation is low, and solar irradiation reaching the Earth is very low due to the high absorption of carbon dioxide. For wavelengths shorter than 0.3 µm, solar irradiation reaching the Earth's surface is negligible in terms of energy, due to high absorption by ozone, and thus cannot play any role in terrestrial applications such as the use of solar energy.

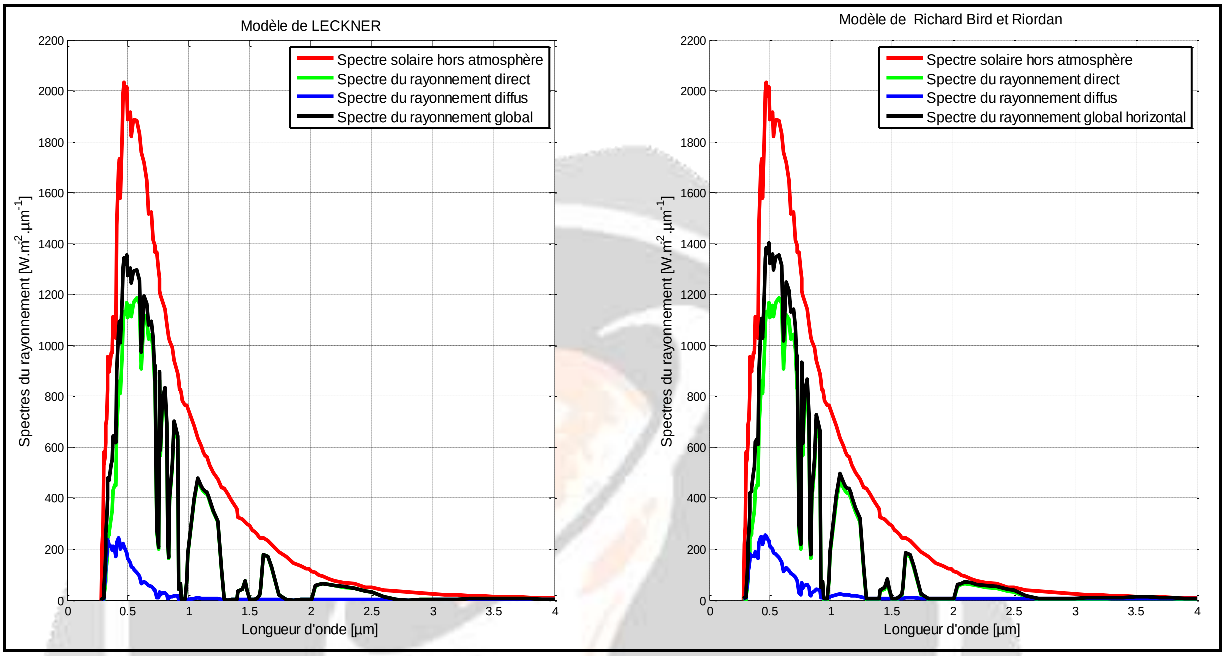

Chart -3 : Spectral distribution of extraterrestrial and ground level irradiation calculated by Leckner - Bird & Riordan models. Site: Mahajanga

In conclusion, to consider applications using solar energy, only the wavelengths of solar irradiation ranging from 0.3 to 2.5 µm can be considered interesting. The importance of direct irradiation depends on the attenuation by the atmosphere due to dispersion and absorption. On a clear day, about 80% of the radiation reaching the Earth is direct radiation. These distinctions are important for solar energy applications, as some solar collectors such as concentrated collectors use only direct solar irradiation, while plane thermal solar collectors value all solar irradiation.All photovoltaic modules do not have the same spectral response. It depends on technology. Crystalline silicon and CIGS have an absorption band that ranges from 300 to 1120 nm while amorphous silicon and CdTe only cover the range of 350 to 800 nm. In addition, the solar spectrum, due to the continuous change in the position of the sun (and therefore of the AM) and the composition of the atmosphere, changes all the time. This continuous variation of the solar spectrum results in a variation, different according to the path, of the photogenerated current and therefore of the power supplied by the module.

3.3 Semi-empirical model results

he curves in Chart 5 represent the results of the estimation of the components of direct, diffuse and global solar irradiation on a horizontal plane calculated by the semi-empirical models of Davies & Hay and Lacis & Hansen under clear sky conditions in the city of Mahajanga, respectively.

According to these charts, the evolution of the daily global irradiation on a horizontal plane is evaluated from sunrise to sunset. Solar irradiation varies during the day. The representative curves of the model are close and follow the same pace throughout the day. They are weak near sunrise and sunset and reach their maximum at real solar midday, in the middle of the day, if the sky remains the same for a day. However, if the sky changes from one state to another, significant fluctuations occur on the radiance. These fluctuations are mainly due to the presence of clouds.

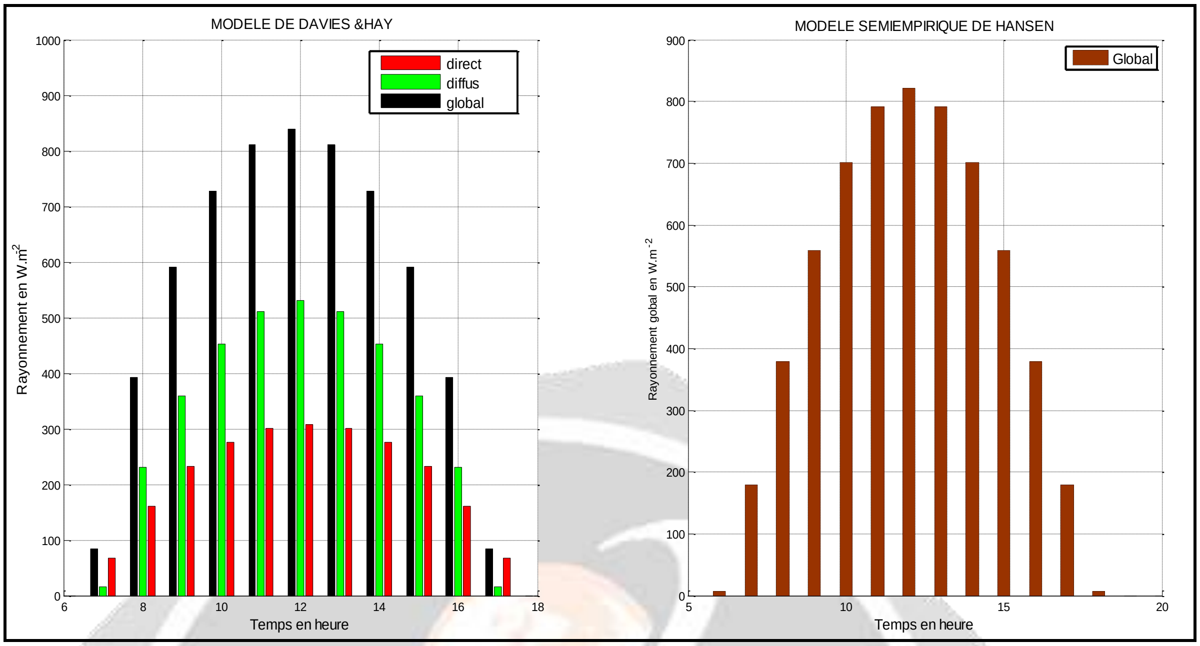

Chart -4 : Solar irradiation on a horizontal plane calculated by the Semi empirical models of Davies & Hay and Lacis & Hansen - Site: Mahajanga

3.4 Results of meteorological models

The meteorological models proposed by Garg and Hussain take into account three meteorological parameters (relative humidity, ambient temperature and sunstroke duration) and some astronomical parameters (solar constant, distance from earth to sun, monthly mean of extraterrestrial irradiation, theoretical duration of the day). According to the results obtained, the Hussain and Garg models lead to very good results, particularly that of M. Hussain.

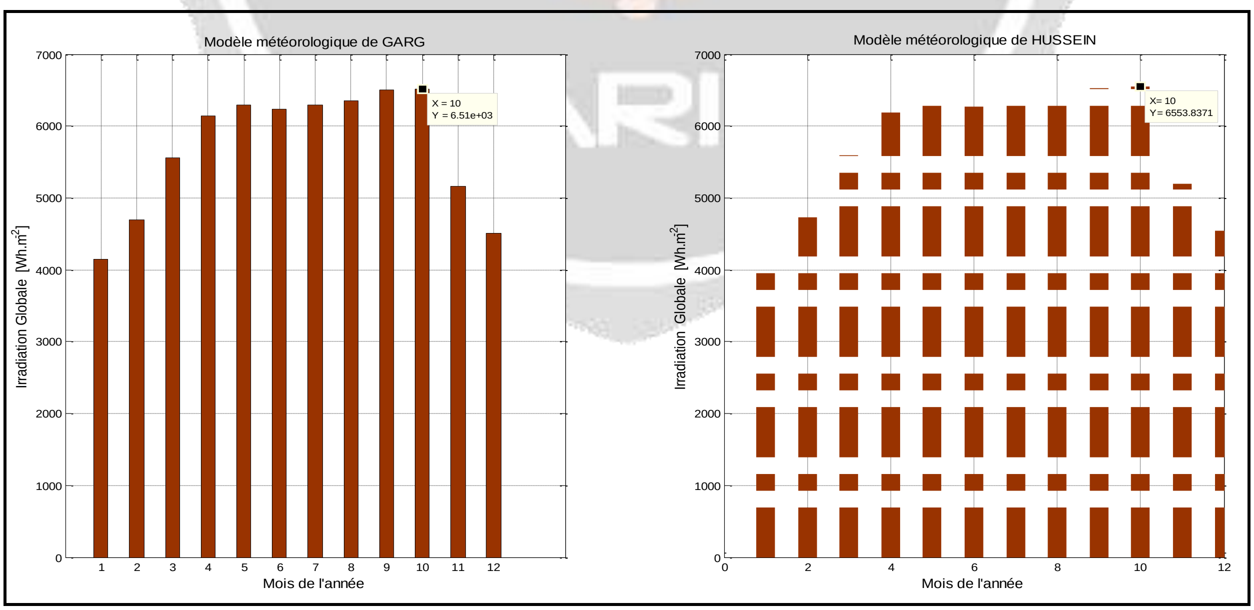

Chart -5 : Monthly mean per day of global solar radiation from 2010 to 2018 received on a horizontal plane calculated by the Garg and Hussain models - Mahajanga Site

4. CONCLUSIONS

Knowing the characteristics of certain components of the atmosphere (aerosols and clouds) at the site, spectral models can accurately predict the spectral components of solar irradiation on the ground. The availability of current meteorological parameters (relative humidity, ambient temperature, atmospheric pressure, etc.) and geographical site parameters (latitude, longitude and altitude) makes it possible to estimate the three components of direct, diffuse and global solar irradiation on the ground using semi empirical models. The limitation of these models is that they are only applicable in clear sky situations. In addition, meteorological models make it possible to calculate the global radiation using directly the data measured on the ground (sunstroke, temperature,...) collected in meteorological stations. These models have the advantage of being applied to any state of the sky (any sky). These models have been proposed in the literature by different scientists and related to several sites around the world.

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BIOGRAPHIES

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