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Correlation between diffuse solar irradiation and Linke turbidity factor in Rabat, (Morocco)

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Abstract:
Decision making for the excellence of the performance of a given solar technology operating under nominal conditions in given locations is of crucial importance. In the present work, an approach capable of making reliable predictions of the diffuse rate of solar radiation based on the Linke turbidity factor T_L; the latter follows the model of Ineichen. However, the conversion process is technically and economically harmful. It is due to the loss of solar radiation caused by its absorption and diffusion in the atmosphere.

Meteorological, atmospheric, and radiation data for the period from February 2004 to May 2020 are used. They are authorized for this work by resources derived from satellite data of NASA, for the benefit of the "Rabat" case study and other representative regions of Morocco for a final comparison, Which is usually characterized by two major climate groups, namely low altitude sites near the Mediterranean Sea and the Atlantic Ocean, and high altitude desert climates.The successful results demonstrate that the approach allows the development of a conversion function from one parameter to another and vice versa. The regression is developed with excellent correlation rates (98%) and very low RMSE (0.014). Observation of the comparison with other sites with different geographical and climatic characteristics gave a slight dispersion, with a maximum deviation of 5% on the conversion function's parameters. Applyingapproachin the case study, the northern regions have a behavior of the hybrid system, but the southern areas only have the concentrating technology. In perspective, an atlas is conceivable.

***Key Word**:Linke turbidity factor, Diffuse radiation ratio, Clearness index, Aerosol optical depth, atmospheric, solar radiation, Moroccan climate..*

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I. Introduction

The United Nations Millennium Development Goals highlight the importance of the availability of energy alongside the eradication of poverty and precariousness [1]. Solar energy production is intermittent in nature. The prediction of both quantitative and qualitative of available solar potential relating to all regions on the solar belt can contribute to the decision on the adequate technologies to meet the sustainability objectives in a given location. The stake is of great magnitude in the various climatic zones of the world. The determination of the predominant solar radiation component is necessary to decide which system can be adopted among the solar technologies available in the market, such as solar concentration technology, photovoltaic technology, or hybrid system.

A useful coefficient to assess the solar irradiance depends on climatic conditions and atmospheric transmission, called a Linke turbidity factor T_L, which describes the optical thickness of the atmosphere. It is quite an appropriate atmospheric coefficient relative to the absorption and scattering of solar radiation in a clear and dry sky. This concept was introduced by various researchers [2]–[5].

So, the sizing and optimal management of energy systems require knowledge of the meteorological conditions to which these systems are subjected. The optimization of solar energy conversion systems for the photovoltaic sector and the concentration technology sector is based on the instantaneous values of meteorological variables, which implies a more or less precise prediction of atmospheric attenuations.

Extensive studies are being carried out in several regions of the world to assess and model the solar potential. We can cite the Markovian approaches, which have contributed to the modeling of random fluctuations in solar radiation [6]. They allowed the development of solar radiation models. More recent studies are concerned with modeling the randomness of solar radiation using neural networks and fractal analysis [6]–[9]. Some works have used insolation [10], [11], and others have used the daily average relative humidity, maximum and minimum temperature [12], [13]. Other work is also being done to assess solar potential. It is worth mentioning the first work carried out by Liu and Jordan [14], which gave a relationship linking diffuse daily solar irradiation and global one on a horizontal surface. We can also cite Orgilland and Holands approach in 1977 [15] as well as the work of Erbs et al. in 1982 [16], which correlated the diffuse fraction of solar radiation with the clearness index.

In their previous work, Ineichen and Prez [17] developed a simple empirical expression between some meteorological parameters to validate the model of solar radiation in clear skies and based on their previous developments. The atmospheric turbidity factor is a real concern of studies analyzing solar radiation patterns.

In 1989 Berk et al., initiated it from spectral simulations, which is integrated on the radiative transfer model Modtran [18]. In 1998 Molineaux et al. obtained empirical expressions for the broadband optical depth of a clear and dry atmosphere relating to Rayleigh scattering and absorption by atmospheric gases with a low influence of the stratospheric ozone content [19], whereas, Kasten has delivered his pyrheliometric formula. This expression bore his name in 1996. Linke's turbidity factor at air mass AM2 developed around three parameters, where the main unknown one is the broadband aerosol optical depth.

Consequently, in 1998 Molineaux et al. found it weakly influenced by an air mass at a wavelength of 700 nm [19]. While in 1980, Bird and Huldstrom approached it based on the attenuation at two wavelengths 380 nm and 500 nm [20].A new formulation of dependence between three parameters, which are the aerosols optical depth at the wavelength 550 nm, the content of water vapor in the atmospheric column, and the altitude of the place, has been unveiled and highly validated.The new transparent sky model of Ineichen and Prez developed in 2008[17] was based on the model of Mächler et al. established in 2004 [21], the last is a link of continuation of the chain, based on Mayer's LibRadtran radiative transfer model revealed in 1997[22].

The formulation of Ineichen et al. has been adapted and is in full agreement with this work within specified limits. Namely, aerosol optical depth is valued at 550 nm between 0 and 0.6, the water vapor contents in atmospheric column values between 0.2 and 10 cm, and altitudes limited between 0 until 7 km.

Ineichen et al. stated that the conversion function between the different parameters is then a better multivariate fit on the radiative transfer calculation results. In other words, the clearness transparency of the atmosphere is indicated by the fraction of the radiation arriving at the top of the atmosphere and passing through it towards the Earth's surface as global radiation. It is a measure of the degree of sky clarity[23].

The clearness index reflects the troposphere's meteorological variations depending on the location of the study, associated with astronomical and meteorological calculations. Its evaluation requires calculations taking into account the season of the year and geographical considerations as well as measurements of the global variations in solar irradiation at the Earth's surface.The clearness index is widely used in terms of sky conditions classification, on which it depends on the global solar irradiance [24].A low clearness index means low overall radiation, usually due to a turbid sky with a large portion of diffuse radiation component. On the other hand, the high clearness index means high global radiation, dominated by the direct solar irradiation component [25].

The clearness index (KT) is defined as a ratio of the monthly average daily global solar radiation on a horizontal surface (H) to the monthly average daily horizontal radiation at the top of atmosphere (H_0).

In this work, it seemed useful to us, as a first step, to study the modeling of the theoretical attenuation of solar radiation, represented by the Linke turbidity factor, then to carry out its comparison with the diffuse ratio, on the location of Higher Normal School of Rabat: ENS (French abbreviation: Ecole Normal Supérieure). In a second step, to establish a relationship that allows the conversion between the clearness index and the Linke turbidity factor. As a result, the study will quickly lead to the prediction of all solar radiation components in clear and dry skies. Such an approach was not carried out in previous work. Finally, a determination of the predicted solar energy available on the site will be carried out with a view of the installations' accurate and proper size.

In the state of the art of case studies concerning the Moroccan regions, specific sites have been identified, whose the atmospheric turbidity are studied: (i) the Angad area of Morocco [26] (ii) Estimation the radiative forcing of the atmospheric aerosol from the passive remote sensing in Oujda [27] (iii), and more recently, on a global scale, the turbidity factor estimate is made available by SoDa-pro web services almost everywhere in the world[28]. On the other hand, numerous methods have been developed to estimate T_L values, which depend on the theoretical value of a cloudless atmosphere's total optical thickness. The optical thickness of water and aerosol in the bright and dry atmosphere leads to the Linke turbidity coefficient T_L, representing the observed extinction. However, it has a disadvantage of having a relationship with the air mass. [19].

To apply the conversion function between the Linke turbidity and the atmospheric water vapor and aerosol contents. It is required to measure the atmospheric water vapor contents and the aerosol optical depth at its wavelength at 550 nm, where the ozone has a low-level consumption of solar radiation [19].

Although the water vapor content can be evaluated from the available climatological data, it is almost impossible for the aerosol optical depth.

II. Material And Methods

Case study areas in the Köppen-Geiger climate scale: In the northwest of Africa found the Moroccan area, which has various characterizations climatic and geographic. Rabat region is its political capital, located in the "Csa" in KGC scale, having a Mediterranean warm-summer Climate, and oceanic influence. The methodology developed around the data of the ENS locality. The northern zone of the country is marked by two influences of climate currents, where the Mediterranean climate and the currents of the Atlantic Ocean merge.

Case study Location: ENS locality positioned in the latitude 33°58'44.3994", the longitude - 6°49'40.8", and the altitude of 101 m agl.

The solar radiation and meteorological Data: In order to achieve the objective of the present work, the hourly averaged time series of all the radiation components and the hourly meteorological data were collected and analyzed from Feb 1, 2004, to May 30, 2020, provided from National Aeronautics and Space Administration (NASA) / Goddard Space Flight Center. All data are gathered in the soda-pro web service [28].

Meteorological, atmospheric, and radiation data are measured, made available, and authorized for this work respectively by meteorological variables from MERRA2 (NASA) resource, The CAMS-AOD (Copernicus Atmosphere Monitoring Service Aerosols service) and CAMS-RAD Copernicus Atmosphere Monitoring Service v3.2 all-sky irradiation (derived from satellite data of NASA). All data is extracted in hourly steps except that AODs are available in three-hour stages, then they have been controlled and verified, in order really to ensure that the data meet a defined set of quality criteria. So, the data has been subjected to a quality control procedure [29]. (i) The real possibility (ii) The extreme limits, the tolerated rare observations and, (iii) the physical coherence.

The clearness index incorporates a single number of the properties of the atmosphere (effects of aerosols optical depth, water precipitation, and altitude), giving rise to the extinction of solar beam irradiation [30]. The intermediary of this index can check the coherence between the direct, global, and diffuse irradiance.

Governing equations: The Linke turbidity factor was computed from the empirical expression for the normal beam radiation [17], where "β," is a multiplicative coefficient corrected altitude depending on the altitude of the site, "I0," the normal incidence extraterrestrial irradiance, "AM," is the air mass [31] and "I," was the measurements of hourly direct normal irradiance data on a horizontal surface.

$$\boldsymbol{I} = \boldsymbol{\beta}.\boldsymbol{I}_0.\mathbf{exp}\{-0.09.\boldsymbol{AM}.(\boldsymbol{T}_L - 1)\} \tag{1}$$

Therefore, as proposed by Ineichen, we can invert the expression and extract the Linke turbidity factor from radiations measurements [8]:

$$\boldsymbol{T}_L = 3,91.\exp\left(0,689.\frac{\boldsymbol{p}_0}{\boldsymbol{p}}\right).\boldsymbol{\delta}_{550} + 0,376.\boldsymbol{Ln}\left(\boldsymbol{Wp}\right) + (2 + 0,54.\frac{\boldsymbol{p}_0}{\boldsymbol{p}} - 0,5.\left(\frac{\boldsymbol{p}_0}{\boldsymbol{p}}\right)^2 + 0,16.(\frac{\boldsymbol{p}_0}{\boldsymbol{p}})^3 \tag{2}$$

Recalling the Leckner expression of the atmospheric water vapor expression, as following [32]:

$$\boldsymbol{Wp} = 0,493.\frac{RH}{\boldsymbol{T}}.\mathbf{exp}\left(26,23 - \frac{5416}{\boldsymbol{T}}\right) \tag{3}$$

where Wp, RH, p_0, p , T & $\delta550$ are respectively the water precipitation (cm), the relative humidity (in fractions of 1), sea level pressure at the site's altitude, the temperature (K) and the aerosols optical depth at the considered wavelength (550 nm).

The clearness index K_T [33], where the hourly clearness index can be defined as:

$$K_T = I / I_0 \tag{4}$$

The faction of diffuse radiation is defined as:

$$K_d = I_d / I \tag{5}$$

And the hourly diffuse index is defined as:

$$K_C = I_d / I_0 \tag{6}$$

The range of $0 \leq KT < 0.35$ represents completely turbidly periods, with more than 90% of the incident global solar radiation being diffused.

The range of $0.35 \leq KT < 0.70$ corresponds to partially sunny periods, while KT represents sunny periods >0.70 irradiance [34].

Note: H and I are respectively the daily and hourly global solar radiation.

III. Results and discussions

Table 1 presents a summary situation of meteorological data, aerosol optical depth (AOD), and the results of calculated parameters such as the thickness of water vapor contents in the atmospheric column (Wp), as well as the Linke turbidity T_L on the location of the study at the ENS of Rabat.

Moreover, Table 2 shows the monthly average of the main components of solar irradiation, namely the data of the diffuse component, the beam direct component of solar irradiation, and the global radiation operated on a horizontal surface, as well as the direct normal component and the monthly averages of the K_T clearness index, the K_d diffuse ratio and the K_C diffuse coefficient.

All these coefficients and parameters presented without dimension vary only with climatic and meteorological fluctuations, and flows the seasons of the year. In conformity withmany research studies have been carried out to estimate Linke's turbidity factor, clearness index, and associated parameters such as diffuse ratio and diffuse coefficient for the similar Mediterranean location.

The literature presents numerous studies in different places of Morocco. On the one hand, the studies relating to the Linke turbidity factor do not cover the country [35]–[37]. On the other hand, and other researches have studied, those relating to the clearness index were less important [38]–[41].

Table no 1: summarization of meteorological, and atmospheric measurements data (HR: relative humidity, Temperature, pressure, and AOD: Aerosol optical depth), the calculated data (Wp: Water precipitation thickness, and T_L: turbidity Linke factor) over the studied location.

Mois	RH	Temperature	Pressure	AOD	WP	T_L
	[%]	[K]	[hPa]	-	[cm]	-
Jan.	60.12	289.11	1,008.74	0.13	1.84	3.46
Feb.	57.66	289.96	1,005.89	0.17	1.86	3.77
Mar.	55.33	291.80	1,003.78	0.21	1.98	4.07
Apr.	54.75	293.63	1,001.03	0.22	2.19	4.20
May.	52.75	296.42	1,001.12	0.25	2.47	4.48
Jun.	51.05	299.15	1,001.47	0.26	2.80	4.64
Jul.	49.93	300.98	1,001.22	0.30	3.05	4.99
Aug.	47.85	302.17	1,000.46	0.32	3.12	5.11
Sept.	51.03	299.99	1,001.99	0.23	2.94	4.44
Oct.	52.22	297.74	1,002.09	0.20	2.64	4.12
Nov.	56.84	292.90	1,003.82	0.14	2.18	3.57
Dec.	58.74	290.40	1,008.21	0.12	1.95	3.38
Year	54.02	295.34	1,003.31	0.21	2.42	4.19

Influence of meteorology on Linke's turbidity factor: The warm summer climate, the predominance of relative humidity, and the cold winter characterize the state of the atmosphere of Rabat location and all littoral regions as the (Csa) KGC scale. Besides, the proximity to the region (Bwh) KGC scale characterized the high altitude desert of Morocco where the dust/sand are major elements carried by the wind. So, the T_L factor developed around an average of 4.19, (the highest of 5.11 in august and the lowest of 3.38 in December).

The Linke turbidity factor makes the high value in the hot season, which period registering a high amount of aerosols optical depth AOD and temperature.

Influence of solar irradiation on clearness index and diffuse ratio: Liu et al. [14] have shown in the literature that the climatic conditions of a particular location can be characterized by the clearness index K_T. This is the ratio of the daily global radiation H, on a horizontal surface to the amount of radiation collected daily at the top of the atmosphere "TOA."

The maximums of the K_T index correspond to clear days and the minimums to strongly turbid days. During the winter season, the shortening of sunshine day length characterizes the index, besides the cloudiness effect. So, they constitute the accumulation of low value plots.

The percentage of turbid or very turbid moments shows 0.23%, whose K_T clearness index is less than 0.35, and the partially sunny moments represents the percentage of 29.53%, with a clearness index is between 0.35 and 0.7, then the sunny periods show a rate of 70.24% with a clearness index corresponds to the range 0.7-1.

In general, the clearness index fluctuates between 0.70 and 0.74, so the location has a partially sunny or sunny situation. K_d represents the part of the diffuse fraction of the global radiation on a horizontal surface. For a turbidly day, H_d tends towards H, and K_d tends towards 1. For a sky and clear weather, H_d reaches its minimum value and H its maximum.

It should be noted that K_d and K_T are complementary. K_d evolves inversely with K_T when one increases the other decreases. The maximum values are around 40.5%, and the minimums are around 20%, that is, the values of the class [0.10-0.20] represent 70.42%, and the class 0.30-0.50 represents 27.64%. At the same time, the monthly average variation is irregular and shows an average of 25%. The average value of K_d over 16 years and four months is less than 40%, which shows a considerable amount of solar radiation is absorbed or scattered.

So, this situation significantly increases the diffuse component in Rabat because this region of Morocco is the direct subject of the effect of Mediterranean, oceanic currents, and the indirect impact from the desert zone in arrears the Atlas mountain range.

Table no 2: Monthly average daily of principle components solar irradiation, clearness index K_T, the diffuse ratio K_d, and the diffuse coefficient K_C over ENS Rabat location.

Month	H_0 (TOA)	H (Global)	H_b (Beam)	H_d (Diffuse)	Hb,n (Direct Normal Irradiation) [kWh/m²/day]	K_d	K_T	K_H
	Top of atmosphere [kWh/m²/day]	**Irradiation on horizontal surface [kWh/m²/day]**				$= H_d/H$	$=H/H0$	$= H_d/H_0$
Jan.	5.28	3.73	2.78	0.95	6.38	0.26	0.71	0.18
Feb.	6.67	4.79	3.57	1.23	6.93	0.26	0.72	0.18
Mar.	8.45	6.17	4.64	1.54	7.67	0.25	0.73	0.18
Apr.	10.06	7.42	5.65	1.78	8.37	0.24	0.74	0.18
May.	11.10	8.13	6.11	2.02	8.58	0.25	0.73	0.18
Jun.	11.48	8.33	6.24	2.09	8.62	0.26	0.73	0.18
Jul.	11.24	8.00	5.70	2.30	7.82	0.29	0.71	0.20
Aug.	10.36	7.27	5.07	2.20	7.18	0.31	0.70	0.21
Sept.	8.94	6.35	4.64	1.71	7.25	0.27	0.71	0.19
Oct.	7.20	5.05	3.66	1.38	6.63	0.28	0.70	0.19
Nov.	5.62	3.94	2.92	1.02	6.34	0.26	0.70	0.18
Dec.	4.85	3.39	2.52	0.87	6.12	0.26	0.70	0.18
Year	8.46	6.06	4.47	1.59	7.34	0.26	0.72	0.19

Relationship conversion between the Linke turbidity and the diffuse ratio parameter: Figures 1- 5 highlight the correlation between the diffuse ratio and the Linke turbidity factor, gathered by winter, spring summer and autumn seasons.

The correlation of the diffuse ratio is linear with the natural logarithm of Linke's turbidity factor as shown in the following equation:

$$K_d = a.\ln\left(T_L\right) + b \qquad (7)$$

The results are summarized in the table 3, where the correlation of the normal logarithm of the Linke turbidity factor, with diffuse ratio K_d makes a good fitting. “a” and “b” are empirical location-dependent constants, the parameter “a” is the slope and “b” is the intercept.

The diffuse ratio data and the normal logarithm of the Linke factor have an excellent linear fit in the spring and summer from March to September, having a coefficient of determination R2 greater than 95%, and the lowest root mean squared error RMSE less than 0.023.

The autumn and winter season are characterized by a reduction in the number of hours of sunshine. Dropping temperature and an increase in relative humidity, So the situation implies a high variability of water vapor contents in the column atmosphere (high variability of HR, pressure and temperatures) and constitutes the accumulation of low value plots.

It can also be seen in those figures 1-5 the excellent correlation for the natural logarithm of Linke's turbidity factor on a segment [1 to 2], with the diffuse irradiation ratio, conforming to the range of T_L [0 to 8]. The few values exceeding this range are atypical.

As a reminder, the T_L factor is defined as the number of clear and dry atmospheres producing the same attenuation as the atmospheric conditions considered.

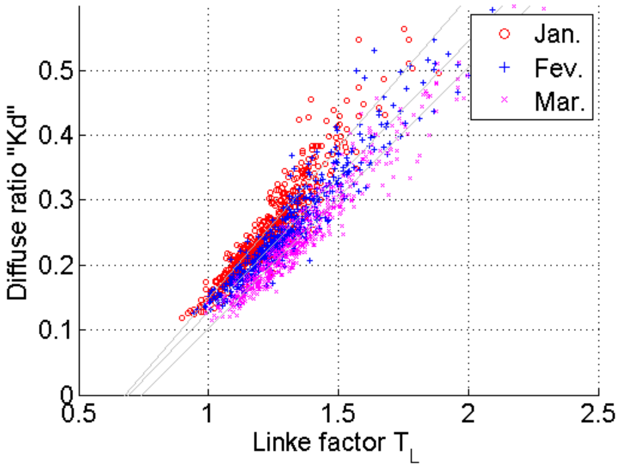

Figure 1- Logarithmic correlation of the Link TL cloud factor vs. the diffuse solar irradiance on a horizontal surface in the first quarter of the year (winter)

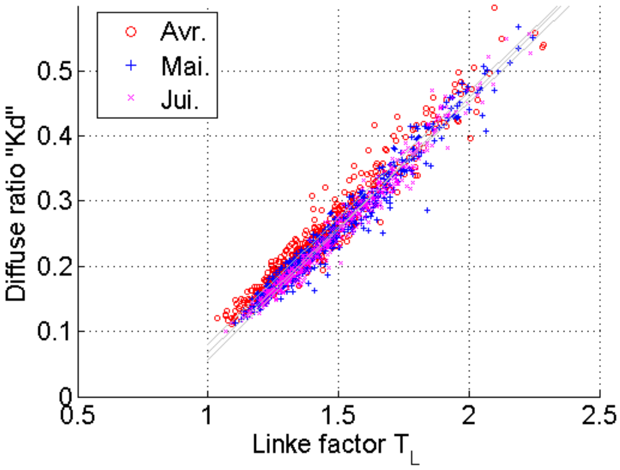

Figure 2- Logarithmic correlation of the Link T_L cloud factor vs. the diffuse solar irradiance on a horizontal surface in the second quarter of the year (spring)

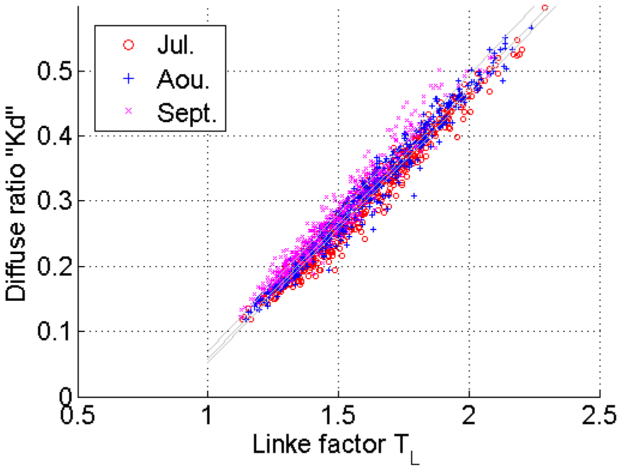

Figure 3- Logarithmic correlation of the Link T_L cloud factor vs. the diffuse solar irradiance on a horizontal surface in the third quarter of the year (summer)

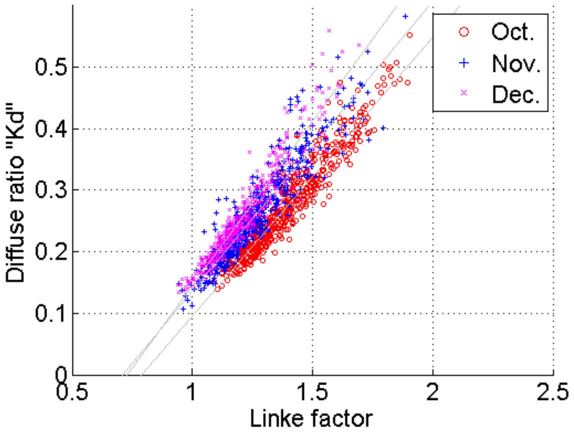

Figure 4- Logarithmic correlation of the Link T_L cloud factor vs. the diffuse solar irradiance on a horizontal surface in the last quarter of the year (autumn)

The figure 5 shows, the global correlation between the clearness index and the normal logarithm of T_L.

The model is applied to (Bwh) KGC scale which is hot desert climates, in particular, Ouarzazate (Latitude: 31°2'34.7994", Longitude: -6°51'54" and Altitude: 1557m agl). The designed region is located in the south of Morocco under a desert climate, at high altitude, and under the shadow of the Atlas mountain range.

The conditions of this locality do not cause a dry atmosphere, including a rural aerosol type. The comparison with the regression proposed over the entire range of input parameters, a slight dispersion is observed, with a maximum deviation of 5% on the parameters (a and b) of the preview relationship estimated between of the $\ln(T_L)$ and K_d.

In the aim of optimal management and sizing of the installation of energy systems using either photovoltaic technology or solar concentration technology or hybrid systems, the proposed approach is strongly requested to associate the Linke trouble factor with diffuse rate radiation by only one data study at a time.

The approach ensures the right decision to excel in the performance of a given technology in the right places and under nominal conditions.

This painful process is due to the loss of solar radiation caused by the parameters inducing its absorption and scattering in the atmosphere. They are cited in particular: AOD aerosols (Aerosols Optical Depth) defined by carbon from soot, sea salt, organic and mineral matter (sulfate, nitrate, and ammonia), and dust, besides taking into account the precipitable water vapor contents in the atmospheric column, and the altitude of the location.

Although meteorological data are available, aerosol measurements are not available, especially for southern countries. On the other hand, measurements of water vapor can be easily obtained using relative humidity and temperature. Concerning the altitude, the measurements of the geographical coordinates of the place are identified.

The prediction of the optical depth of airborne aerosols in the atmosphere characterizing a given site is statistically modeled by the Weibull distribution [42].

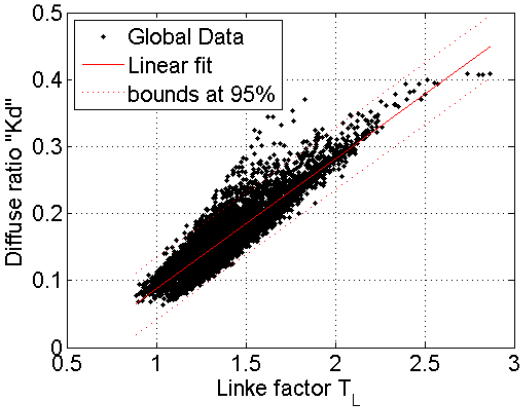

Figure 5-Logarithmic correlation of the Link T_L cloud factor vs. the diffuse solar irradiance on a horizontal surface in one year

Table no 3: Correlation of the normal logarithm of the Linke turbidity factor, with diffuse ratio K_d (16 years and four months of the measurements from Feb 2004 to May 2020 in Rabat).

Month	Slope “a”	Intercept “b”	Coefficient of determination R^2	RMSE
Jan.	0.4647	-0.3161	0.9108	0.02487
Feb.	0.4170	-0.2884	0.9132	0.02657
Mar.	0.4024	-0.2996	0.9523	0.02244
Apr.	0.3883	-0.3076	0.9460	0.02062
May.	0.3846	-0.3171	0.9657	0.01646
Jun.	0.4021	-0.3456	0.9806	0.01454
Jul.	0.4102	-0.3580	0.9748	0.01518
Aug.	0.4149	-0.3565	0.9764	0.01530
Sept.	0.4244	-0.3548	0.9505	0.01798
Oct.	0.4537	-0.3581	0.9217	0.02350
Nov.	0.4707	-0.3339	0.8717	0.02836
Dec.	0.5331	-0.3879	0.9072	0.02323
Year	0.3309	-0.1991	0.8139	0.0444

The geographic and climatic diversity of the various Moroccan localities, including the particular dominances for each region, are under oceanic, Mediterranean, continental, desert, Saharan, and mountain influence.

Thus, the most significant results of this work can be summarized as follows: The Linke turbidity factor related to attenuation from the top of the atmosphere was estimated from $T_L = 3$ corresponding to a diffuse solar rate of $K_d = 0.20$ over the winter season with a drop in direct radiation and grows directly up to $T_L = 6$ corresponding to a diffuse solar rate of $K_d = 0.45$ over the summer season despite the increase in direct radiation which favors concentration technology. So we must not neglect the diffuse component, which will be lost unnecessarily. We can also note that the regions of the south and the extreme south of Morocco (Sahara) have a low and constant attenuation coefficient and very intense beam irradiance over the whole year; this implies the orientation towards the technology of concentration since the ratio of diffuse radiation cannot exceed 20%.

Initially tested in Moroccan regions, this approach can be generalized to regions with similar climatic conditions. This approach could also find applications in renewable energies.

Therefore, northern regions like “Csa” on the KGC scale behave likely to accommodate PV technology installations for power generation and small concentration technology installations for heat generation because they have more than 50% of times a diffuse rate having more than 30% of the global radiation.

The southern regions as the KGC "Bwh" scale have a behavior likely to accommodate only concentrated solar technology to produce both electricity and heat because the situation shows a predominance of the direct component, it has a frequency of 71% for a diffuse solar rate achieving less than 15% of the global radiation.

IV. Conclusion

In the present work, a generalized approach to correlate the Linke turbidity factor and the diffuse rate is proposed. This approach can make reliable predictions on the daily and monthly mean values of the Linke T_L turbidity factor.

The proposed approach has been adequately tested in different climatic regions of Morocco. Based on the proposed methodology, the optical depth of aerosols and the thickness of atmospheric water vapor calculated from meteorological data and solar radiation data for 16 years and four months, i.e., from February 2004 to May 2020.

The Linke factor was evaluated according to the Ineichen et al. model for air mass AM2, the diffuse rate is calculated based on global, diffuse, and direct solar radiation data. Authorized to use from derived from satellite data of NASA.

These results considerably increase the almost rare knowledge with this parameter of diffuse radiation rate linked to Linke's factor; it is valuable with the clearness index.

Finally, the inference from this study is that Morocco, in general, has two major climate groups, namely the low altitude sites near the Mediterranean Sea and the Atlantic Ocean, and the high altitude sites with a desert climate. An approach for converting between Linke's turbidity factor and solar radiation scatter rate and vice versa is developed. The Linke factor used follows the model of Ineichen et al. It depends on the water vapor content in the atmospheric column and the optical depth of the aerosols, also associating the altitude of the site under the conditions of validity of the model.

Linear regression was developed with the help of clear and dry sky. The results found are compared in different regions of Morocco, according to the Kôppen Geiger climate scale. The extreme case is that of the high altitude desert sites located in the south of Morocco is chosen for comparison with the study case, which is a low altitude site located in the north. Observation of the comparison gave a slight dispersion, with a maximum deviation of 5% on the conversion function parameters (a and b).

The method of correlating Linke's turbidity factor to the diffuse rate of solar irradiation was highlighted. It is therefore beneficial to assess the solar field of a given site and to decide on the appropriate technology in this place on the one hand and to be able to manage the electricity production facilities by converting solar energy on the other hand. So, by applying in the case study, the northern regions have a behavior of the hybrid system, but the southern areas only have the concentrating technology.

This approach could also find applications in several fields, namely, renewable energies, environmental sciences, agriculture, meteorology.

In perspective, a Moroccan atlas concerning the determination of the Linke's clouding factor and the parameters of correlation with the diffuse rate of solar radiation is envisaged.

Nomenclature

ENS	Higher Normal School of Rabat (French abbreviation: Ecole Normal Supérieure).
NASA	National Aeronautics and Space Administration
MACC	Monitoring Atmosphere Composition and Climate
CAMS-RAD	Copernicus Atmosphere Monitoring Service all-sky irradiation
CAMS-AOD	Copernicus Atmosphere Monitoring Service Aerosols service
AM	Air mass
T_L	Linke turbidity factor
AOD	Aerosol Optical Depth
Wp	Atmospheric water vapor [cm]
RH	Relative humidity [%]
T	Temperature [K]
P	Pressure [hPa]
P_0	Pressure at sea level [hPa]
K_T	Clearness index
Kd	Diffuse irradiation ratio
K_C	Hourly diffuse index
TOA	Top of atmosphere
H_0	Monthly Average Daily Radiation at TOA [kWh/m^2/day].
H	Daily Global Solar Radiation on a Horizontal Surface [kWh/m^2/day].
H_b	Daily Beam solar radiation on a horizontal surface [kWh/m^2/day]
$H_{b,n}$	Daily direct beam (normal) radiation [kWh/m^2/day]
H_d	Daily diffuse solar radiation on a horizontal surface [kWh/m^2/day]
I_0	Hourly radiation at the top of atmosphere [kWh/m^2]
I	Hourly beam solar radiation [kWh/m^2]
KGC	Köppen-Geiger Climate scale
Csa	Hot-summer Mediterranean climate KGC scale
Bwh	Hot desert climates KGC scale
“agl”	above ground level
RMSE	Root Mean Square Error, W/m^2
R2	Coefficient of correlation

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Conflict of interest

The authors declare that they do not have any conflict of interest

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