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Learning Lessons from Murzuq-Libya Meteorological Station: Evaluation criteria and improvement recommendations

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ABSTRACT

In this study, an examination was conducted on weather data gathered from the Murzuq weather station over a period of nine months, specifically focusing on 15-minute time series solar radiation data. The data was sourced from the Center for Solar Energy Research and Studies in Tajoura-Tripoli, through a collaborative agreement between the Faculty of Engineering at Wadi Alshatti University and the research center. The information collected encompassed various solar radiation components, such as global horizontal solar radiation, direct normal radiation, sky-diffuse solar radiation, and ground reflected solar radiation. The aim of this study is to verify calculated values of these components using mathematical models by comparing them with their measured values. The investigation revealed that the Earth's reflectance value for the region was estimated and determined to be around 0.4. It is important to note that this figure was different from the typically advised value of 0.2 that was given in previous literature.

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الدروس المستفادة من محطة الأرصاد الجوية في مرزق ـ ليبيا: معايير التقييم وتوصيات التحسين

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ملخص: تم في هذه الدراسة تحليل بيانات الطقس المسجلة في محطة الأرصاد الجوية في مدينة مرزق، البيانات مسجلة لكل 15 دقيقة لمدة تسعة أشهر تم أشراف المركز الليبي لأبحاث ودراسات الطاقة الشمسية بتاجوراء – طرابلس، ضمن اتفاقية تعاون بين كلية الهندسة – جامعة وادي الشاطي ومركز الأبحاث. تضمنت القيم المقاسة كلا من: الإشعاع الشمسي الأفقي الكلي ، والإشعاع العمودي المباشر، والإشعاع الشمسي المنتشر من السماء، والإشعاع الشمسي المنعكس من الأرض. كما اشتمل التحليل على عدة مقارنات بين القيم المقاسة والمحسوبة لمكونات الإشعاع الشمسي باستخدام بعض النماذج الرياضية. تم حساب قيمة انعكاسية الارض (الالبيدو) للمنطقة ووجد أنها تقارب 0.37 ، والتي تختلف عن القيمة الموصى بها في المراجع والتي تقدر بحوالي 0.2. كما قدم البحث تقييما للمحطة وتصورا لمحطة نموجية استنادا على أهمية البيانات المقاسة وحاجة الباحثين لها.

1. INTRODUCTION

Solar energy is widely recognized as one of the most crucial renewable energy sources, offering a viable alternative to fossil fuels. Among all activities, electricity generation is the most polluting sector, making solar energy the optimal solution to address environmental issues [1]. Utilizing the abundant solar energy potential in electricity generation and various thermal applications can help mitigate the impact of pollutants [2-7]. This, in turn, contributes to reducing pollution caused by burning fossil fuels and carbon emissions, which are the primary culprits of global warming and climate change.In line with this, during COP 27 (The UN Climate Change Conference) held in Sharm El-Sheikh, Egypt, from 6th to 18th November 2022, the Libyan government unveiled its strategic plan for the next three decades. The plan aims to generate electric power using renewable energy sources available in the country. The goal is to have renewable energies account for 25% of the electric energy production mix by 2025, 30% by 2030, and 60% by 2050. The key sources of renewable energy for this endeavor will primarily be concentrated solar energy, PV solar, and wind energy [8]. To successfully implement this strategy, accurate climatic data, such as solar radiation components, wind speed, and air temperature, are vital for the development and feasibility of the solar energy industry. In light of this, the Libyan government has established numerous meteorological stations, including those affiliated with the National Meteorological Center (https://www.lnmc.org.ly/demo/). Additionally, various other meteorological stations are associated with research centers, universities, and airports (Fig. 1). These stations play a critical role in providing essential data for the advancement of solar energy initiatives in the country. Despite the extensive presence of meteorological stations throughout the country, there is a significant drawback in their ability to furnish essential information for scientific research and the advancement of the renewable energy industry within the nation. Regrettably, a considerable proportion of these stations are non-operational, and the remaining ones exhibit varying levels of accuracy. Most of them solely record a limited set of weather parameters, such as temperature, pressure, humidity, wind speed, and rainfall. However, more crucial measurements, such as solar radiation, might be lacking altogether. This inadequacy hinders the alignment of these stations with the aspirations of transitioning towards renewable energies in the near future. Regrettably, many developing countries face challenges in obtaining readily available solar radiation measurements primarily due to the high cost associated with measurement equipment and techniques. As a result, researchers in these regions have had to rely on mathematical models to estimate solar radiation, supplemented by climate data provided by satellite-based platforms such as Solargis [9,10], SODA [11,12], Solcast [13], Meteoblue [14,15]. However, the lack of measured and accurate data poses a significant obstacle when it comes to validating the effectiveness of these mathematical models and the reliability of satellite data [16]. Obtaining real measured data is crucial to conduct comprehensive examinations and ensure the accuracy of solar radiation predictions and assessments.

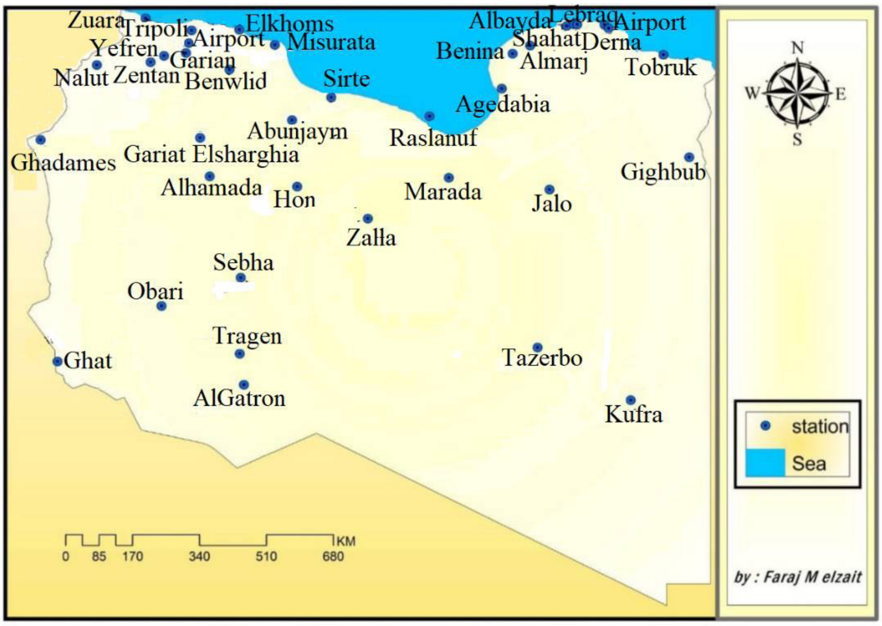

Fig. 1. Location of meteorological stations.

Transposition models, which rely on global horizontal and sky-diffuse horizontal radiation, have become widely employed in the solar energy industry to estimate the global tilted solar radiation. This tilted solar radiation consists of three components: direct, diffuse, and ground reflected radiation. The direct radiation can be computed using the geometric relationship between horizontal and tilted surfaces, while ground reflected radiation can be estimated with the help of an isotropic model and simple algorithms. However, the situation becomes more intricate when dealing with sky-diffuse irradiation. In this study, we evaluated the meteorological station of the Libyan Center for Desert Research and Development of Desert Communities in Murzuq city to assess the extent to which the recorded data has been utilized. Furthermore, we conceptualized the characteristics of an ideal meteorological station that could provide weather data with accurate outputs suitable for scientific research. Based on these findings, we provided recommendations to enhance the outcomes of the Murzuq station for scientific purposes.

Fig. 2 was constructed using information from approximately 70 published research papers in the renewable energy field. The figure presents a word cloud representation of recurrent data, emphasizing its significance in scientific publications. We emphasize the importance of satisfying the data needs of scientific research and the relevance of acquiring the necessary data to conduct comprehensive scientific investigations. Fig. 2 vividly illustrates the criticality of certain climatic parameters in the realm of renewable energy. The font size in the figure directly corresponds to the frequency with which each parameter was mentioned in the research papers, ranging from 1 to 100. Larger font sizes signify more frequent mentions, underscoring the significance of these specific parameters in the context of renewable energy studies.

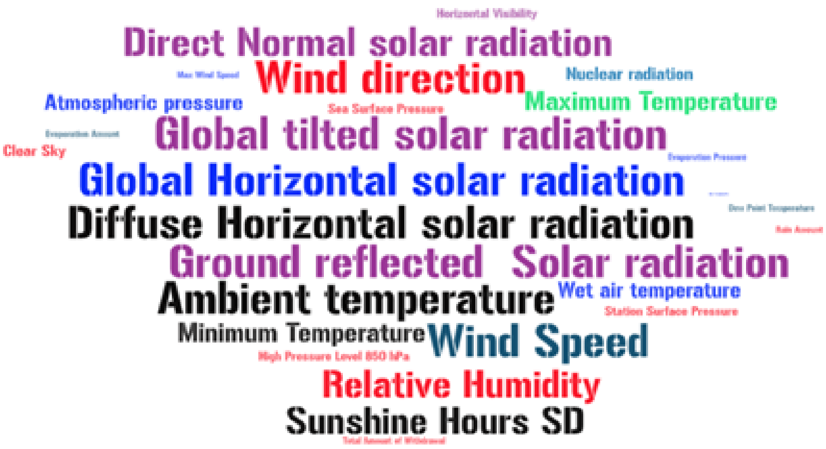

Fig. 2. Word cloud presentation of the recurring parameters in renewable energy researches.

Numerous studies have emphasized the importance of measuring global tilted solar radiation at various inclination and azimuth angles [17]. Nassar et al. discovered that the validity of transformation models varies with changes in tilt and azimuth surface angles [18,19]. Ahwide presented a mathematical framework for predicting and assessing hourly solar radiation based on daily solar radiation data for three different locations in Libya [20]. Pashiardis and Kalogirou evaluated the quality of hourly measurements of global solar irradiance obtained from a pyranometer and direct normal irradiance obtained from a sunshine duration sensor for several locations in Cyprus [21]. Mubarak et al. conducted measurements of global tilted radiation at different inclination and orientation angles using 14 crystalline silicon PV devices. Seven of these devices were south-facing and tilted at 10°, 20°, 30°, 40°, 50°, 60°, and 70° angles. Six sensors were vertically tilted, facing N, S, E, W, SE, and SW, while a single sensor was installed horizontally [17]. Mediavilla et al. measured global vertical solar radiation incident on facades facing North, East, South, and West to validate four transposition models (Isotropic, Circumsolar, Klucher, and Hay). The results indicated that the Klucher model was the most suitable for all orientations, while the Isotropic model was only valid for the north orientation, and the Circumsolar model for the east and west-facing surfaces [22]. The subsequent sections of the paper are organized as follows: Section 2 provides information about the study area. Section 3 gives a summary of the methods used for theoretically calculating solar radiation intensity and the practical mechanisms for measuring it. The third section graphically presents the obtained results, which are further discussed and analyzed. The study concludes with the final section, which includes some relevant recommendations related to the research.

2. INFORMATION ABOUT THE STUDY AREA

The city of Murzuk is situated in the southern part of Libya, precisely at latitude 25.9044° N and longitude 13.8972° E. It is located at an elevation of 449 meters above sea level. Fig. 3 presents an aerial image of the Libyan Center for Desert Research and Desert Community Development, the site where the meteorological measurement devices are positioned.

Fig. 3. Aerial view of the Libyan Center for Desert Research and Desert Community Development.

3. METHODOLOGY

This section reviews the available devices used in the meteorological station to measure solar radiation.

3.1. Solar radiation measurement devices

3.1.1. Pyranometer

The pyranometer serves as a valuable instrument for measuring solar radiation. When placed in a horizontal position, it measures the global horizontal solar radiation. However, its capabilities extend further, as it can also measure the global tilted solar radiation when positioned at a specific angle of inclination [23]. The main components of the pyranometer are elaborated in [24]. Additionally, the pyranometer can be used to measure ground reflected solar radiation when it is inverted and facing the Earth. In Fig. 4, there is a device that contains two pyranometers connected to each other—one facing upwards to measure the solar radiation from the sky, and the other facing downwards to measure the ground-reflected solar radiation. This setup enhances the instrument's versatility and utility in solar radiation measurements.

3.1.2. Shadow ring pyranometer

The shadow ring is a useful tool when combined with a pyranometer to create a "diffusometer," as depicted in Fig. 5. Its purpose is to block direct radiation from reaching the pyranometer throughout the day, allowing the shaded pyranometer to exclusively measure diffuse radiation [25]. However, to obtain accurate measurements, corrections are necessary. Firstly, the measurements need to be corrected to account for the portion of the sky obscured by the shadow ring. Additionally, the part of the solar radiation reflected from the Earth onto the inner part of the ring must be subtracted from the readings [26].

Fig. 4. Two channel pyranometer device.

The correction process was conducted at the Libyan Center for Research and Studies of Solar Energy in Tripoli to ensure the accuracy of the measurements obtained with this device. These corrections are vital to achieve precise and reliable measurements of diffuse radiation, providing valuable data for solar energy studies and applications.

Fig. 5. A shadow-ring pyranometer device.

3.1.3. Pyrheliometer

The pyrheliometer is a specialized device utilized to measure the Direct Normal Irradiation (DNI) consistently [27]. This instrument is paired with a tracking mechanism that continuously follows the movement of the sun, as shown in Fig. 6. The significance of DNI measurement lies in its crucial role in estimating the performance of concentrated solar power systems, including Concentrated Photovoltaic (CPV), trough parabolic, heliostat field, linear Fresnel, and dish parabolic concentrated solar power plants. Accurate DNI measurements are essential for assessing the feasibility and efficiency of these concentrated solar power systems, allowing for optimal design and operation. By providing precise information about the solar radiation that directly hits the solar collectors, DNI measurements play a pivotal role in the successful implementation and integration of concentrated solar power technologies, thus promoting sustainable and clean energy solutions.

Fig. 6. A pyrheliometer device.

3.2. Estimation of solar radiation components

The calculation of solar radiation involves several governing equations that are essential for determining the weather parameters required to estimate global solar radiation and its components [28], [29]. One of the fundamental equations is for the global horizontal solar radiation (G_h) [30]:

$$G_h = H_b + H_d \quad [W/m^2] \qquad ....(1)$$

The direct beam solar radiation, denoted as H_b, is measured in watts per square meter (W/m^2), while the sky-diffuse solar radiation, represented as H_d, is also measured in watts per square meter (W/m^2). Both G_h and H_d are obtained through measurements using a pyranometer and a shadow-ring pyranometer, respectively. In recent developments, a small black ball has been introduced to shade the pyranometer instead of using the traditional shadow-ring. The tracker ensures that the ball is continuously moved so that the pyranometer's eye remains shaded. This modern shading system eliminates the need for measurement corrections, as the ball's area is negligible compared to that of the shadow-ring [31]. As a result, more accurate solar radiation measurements can be obtained using this innovative technique. Moreover, this tracking system presents an opportunity to create a comprehensive measurement platform. By utilizing the tracking device, a pyrheliometer device can also be installed alongside the pyranometer, as illustrated in Fig. 7 [32]. This integration allows for simultaneous measurements of both direct normal irradiation (DNI) and global horizontal solar radiation, providing valuable data for various solar energy applications and research.

Fig. 7. Meteorological station platform with pyranometer, shadow-ball pyranometer and pyrheliometer [33].

According to eq. 1, the direct beam solar radiation H_b is unmeasured parameter and it can be estimated from eq. 1 as [30]:

$$H_b = G_h - H_d \quad [W/m^2] \qquad \text{...............} (2)$$

The DNI can be derived from H_b through a division by the cosine of the solar zenith angle θ_z [30]:

$$DNI = \frac{H_b}{\cos\theta_z} \quad [W/m^2] \qquad \text{................} (3)$$

$$\cos\theta_z = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega \qquad \text{........} (4)$$

Where: ϕ states for latitude angle, δ is the solar declination angle, and ω is the hour angle [30]:

$$\delta = 23.45 \sin\left[\frac{360}{365}(n+284)\right] \qquad \text{..........} (5)$$

$$\omega = 15 \times (12 - h) \qquad \text{..................} (6)$$

Where: n presents the Julian day and h is the time in 24-hour mode.
Since DNI is a value measured at the considered meteorological station, it is a good opportunity to verify the validity of this equation.
The Ground reflectivity -Albedo (ρ_g) is also can be obtained from a measured quantity by divided the measured ground-reflected solar radiation (H_g) over the measured global horizontal solar radiation (G_h) [30]:

$$\rho_h = \frac{H_g}{G_h} \qquad \text{.............................} (7)$$

3.3. Comparison methods

Three different measures are used to examine the accuracy of the derived correlations. root mean square error (RMSE), mean bias error (MBE), and the coefficient of determination (R2) [34]:

$$RMSE = [\frac{1}{n}\sum_{i=1}^{n}(I_{i,c} - I_{i,m})^2]^{1/2} \qquad \text{...........}(8)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(I_{i,c} - I_{i,m}) \qquad \text{...............}(9)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(I_{i,m} - I_{i,c})^2}{\sum_{i=1}^{n}(I_{i,m} - I_{i,c})^2}, \quad \bar{I} = \frac{1}{n}\sum_{i=1}^{n} I_{i,m} \qquad \text{.......}(10)$$

The smaller values of RMSE and MBE and the best value is zero. For the Coefficient of Determination (R^2), the best possible scenario is when R^2 equals 1. This means that the model's predicted values perfectly match the observed values. In other words, the model explains all the variance in the measured data, and there is no unexplained variation. R^2 ranges from 0 to 1, where 0 indicates that the model explains none of the variance, and 1 indicates a perfect fit between the model and the data.

4. RESULTS AND DISCUSSIONS

4.1. Presentation of the measured parameters

The meteorological station conducts measurements and records data in time series, with readings taken every 15 minutes, starting from 0:00 on 1st February to 11:00 on 20th September 2018. The station captures data for several weather parameters, including: Wind speed (m/s) and direction.; Atmospheric pressure (mpar); Air temperature (°C); Relative humidity (%) and Solar radiation components (W/m²): a. Global horizontal solar radiation; b. Ground reflected solar radiation; c. Direct normal solar radiation; d. Sky-diffuse solar radiation.

Additionally, the station provides corrected values for the sky-diffuse solar radiation, ensuring the accuracy and reliability of the measured data. Figs. 8-14 display the weather data obtained from the meteorological station in Murzuq at hourly time intervals. Fig. 8 specifically represents the wind speed data recorded on an hourly basis. The measured wind speed data serves as a crucial input for validating the wind energy potential in the region [35, 36].

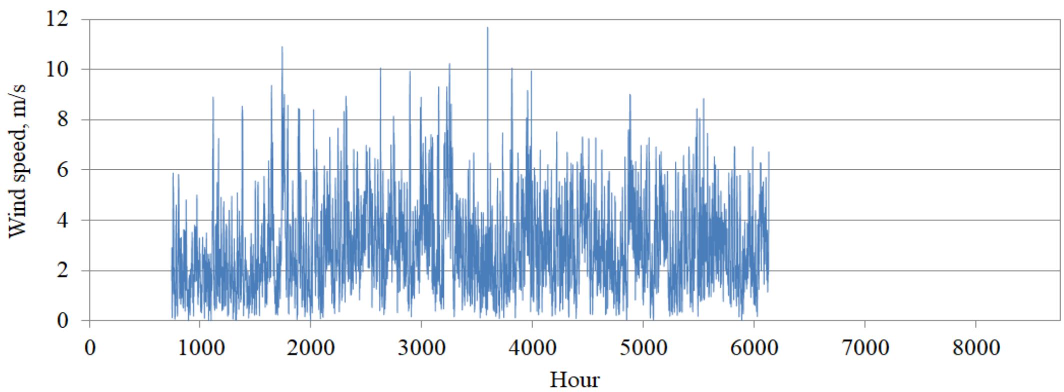

Fig. 8. Hourly wind speed.

Accurate wind speed measurements are essential for assessing the feasibility and performance of wind energy projects, helping to identify suitable locations and optimize the design and operation of wind turbines. The hourly wind speed data provides valuable insights into the wind patterns and variability, enabling better planning and utilization of wind resources for sustainable energy generation.

Fig. 9 represents the air temperature data recorded at hourly intervals. Air temperature is a critical weather parameter that holds significant importance in energy calculations. It plays a vital role in various applications, such as: Calculating cooling and heating loads in buildings [37, 38]; Determining water heating requirements [39]; Assessing the effectiveness and efficiency of solar systems [40]; and estimating solar radiation [41]. The accurate measurement of air temperature is essential for making informed decisions in energy-related fields. It aids in optimizing building designs for energy efficiency, evaluating the performance of renewable energy systems, and predicting energy demand. As a fundamental weather parameter, air temperature serves as a key component in numerous energy-related calculations and assessments. Hourly based relative humidity is displayed in Fig 10. The relative humidity is used to determine the comfort zone in the indoor environment of buildings and is therefore used in cooling load calculations and energy audit. In Fig. 11, the global horizontal solar radiation is displayed. This component of solar radiation is considered the primary source for calculating all other solar radiation components. It serves as a crucial indicator for assessing the feasibility of solar energy systems. Additionally, global horizontal solar radiation is essential for estimating solar heat gain in buildings. Fig. 12 showcases the hourly-based measured Direct Normal Irradiation (DNI) data. DNI is an essential parameter, particularly in the context of concentrating solar technologies, such as Concentrating Solar Power (CSP) systems, trough parabolic, dish parabolic, heliostat field, and linear Fresnel collectors [42]. Fig. 13 displays the hourly sky diffuse solar radiation data. Sky diffuse solar radiation is of significant importance in evaluating photovoltaic solar fields, especially in scenarios where shadows occur. In regions affected by shadows, direct solar radiation is absent, leaving only sky diffuse and ground reflected solar radiation [43]. Fig. 14 exhibits the ground reflected solar radiation data at hourly intervals. Ground reflected solar radiation plays a crucial role in studying the optimal design of solar fields and assessing the feasibility of solar radiation augmentation through reflectors [44].

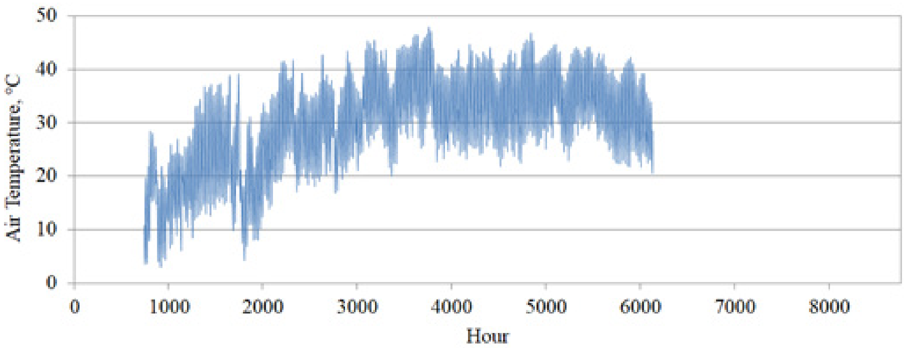

Fig. 9. Hourly air temperature.

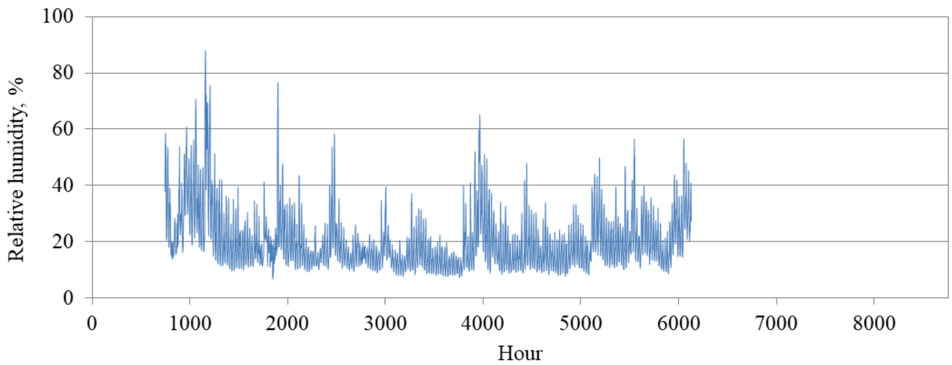

Fig. 10. Hourly relative humidity.

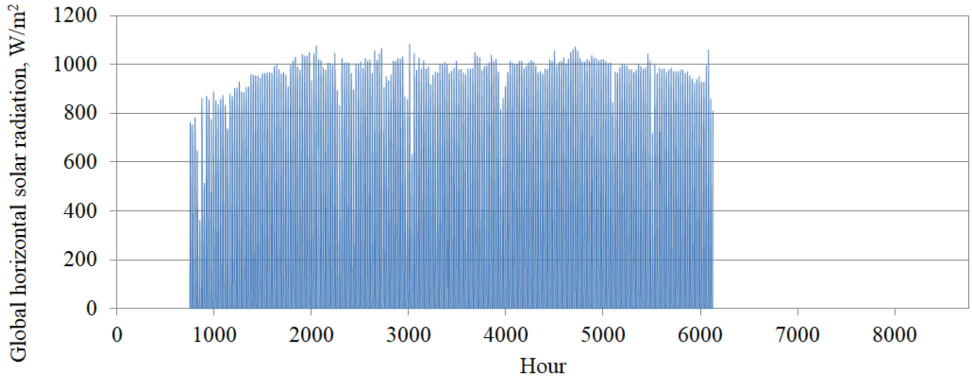

Fig. 11. Hourly global horizontal solar radiation.

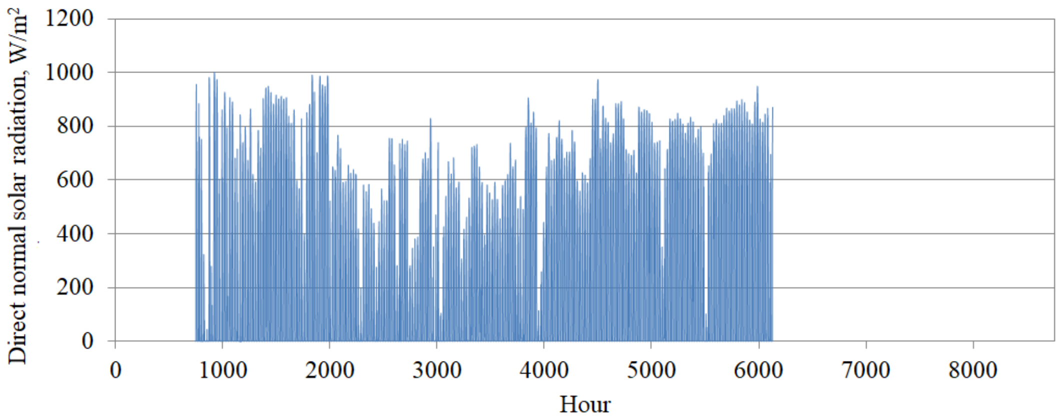

Fig. 12. Hourly direct normal solar radiation.

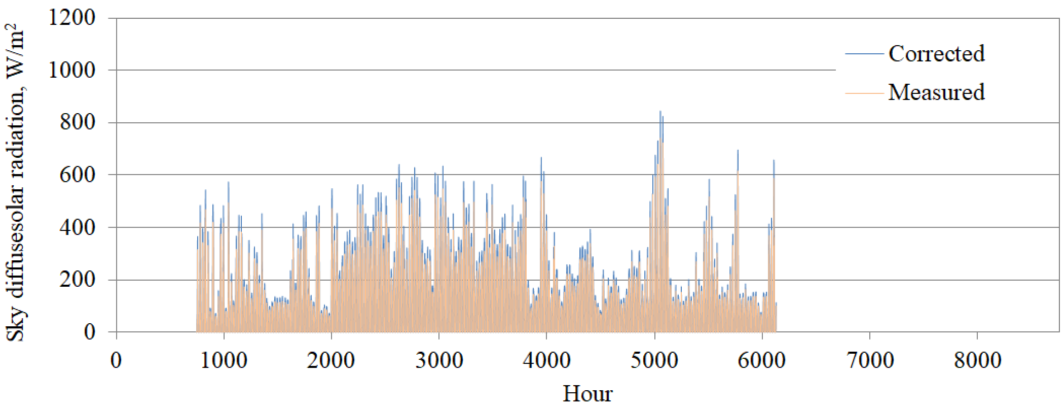

Fig. 13. Hourly horizontal sky-diffuse and corrected solar radiation.

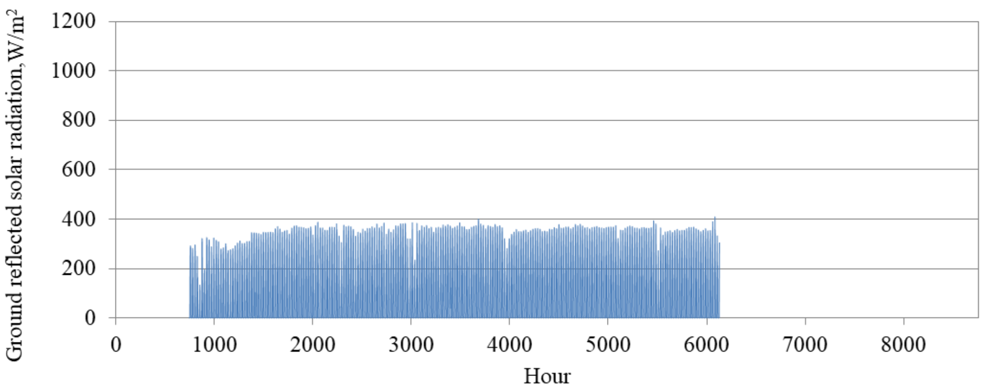

Fig. 14. Hourly ground reflected solar radiation.

4.2. Drawn information

4.2.1. Frequency wind speed and Weibull distribution function (Fig. 15).

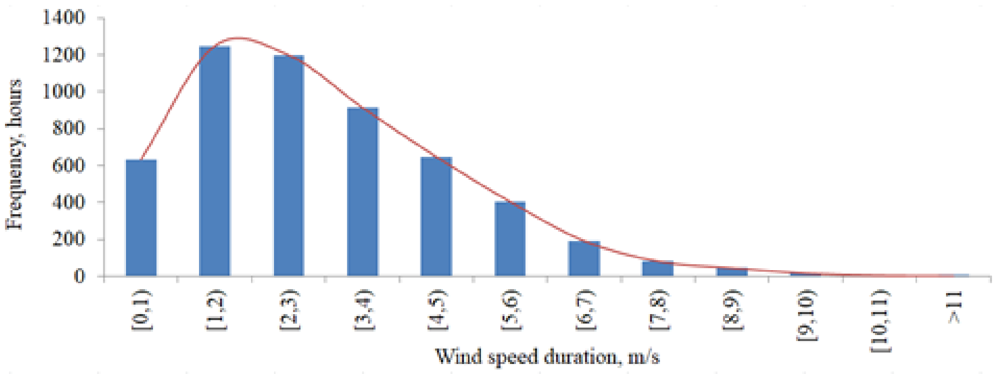

Fig. 15. Frequency wind speed and Weibull distribution function.

Wind speed for a given location can be characterized by probability distribution function $f(v)$.

$$f(v)_{80\,m} = 1\times10^{-5}v^5 - 0.0005v^4 + 0.0077v^3 - 0.052v^2 + 0.1286v + 0.0775 \quad ....(11)$$

Given $f(v)$, the mean of wind power generated $\overline{P}_{gen}$ by a specific wind turbine can be estimated as [45]:

$$\overline{P}_{gen} = \int_{cutin\ speed}^{cutout\ speed} f(v)_{80\,m} P(v)\,dv \qquad ....(12)$$

Where: $P(v)$ stated for the power curve of a specific wind turbine. The subscript 80m denotes to the wind turbine hub height. Often in metrological station the wind speed is measured at 10 m. The power law method is one of the available methods by which the wind speeds could be estimated at elevations that reach turbine hub height as:

$$\frac{v_2}{v_1} = \left(\frac{z_2}{z_1}\right)^{\alpha} \qquad ....(13)$$

Where: v_1 and v_2 are the wind speeds at z_1 and z_2 heights, and α is the wind shear coefficient which considered 1/7 in most cases [46].

4.2.2. DNI from beam direct solar radiation (Fig. 16).

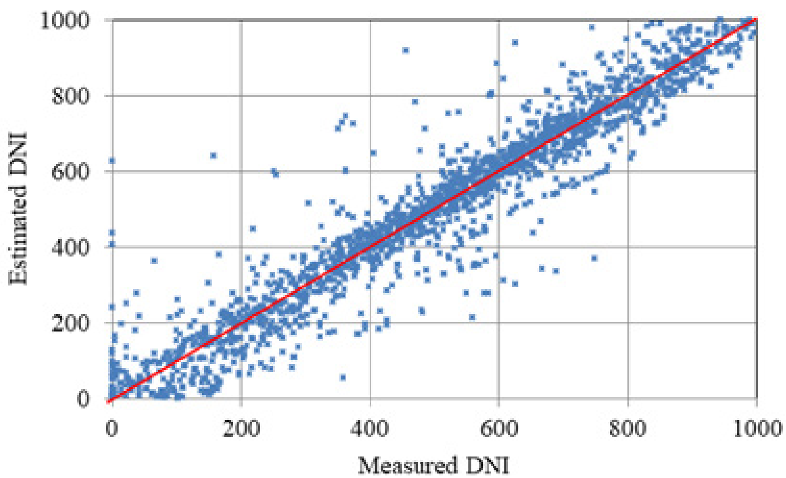

Fig. 16. Comparison between the measured value of DNI and the one calculated.

There is a debate about the possibility of obtaining vertical solar radiation from direct solar radiation [47]. This study proved that it can be used eq. 3 to estimate the DNI directly from the beam solar irradiance, as it implicitly shown in Fig. 16.

4.2.3. Ground reflectivity or Albedo (Fig. 17)

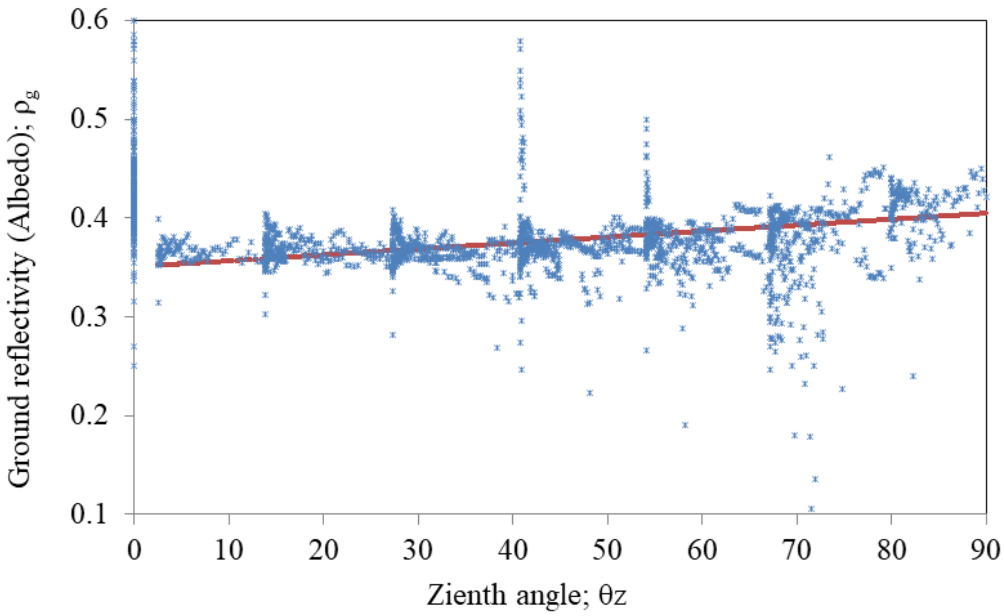

Fig. 17. Ground reflectivity or Albedo.

Fig. 17 illustrates that the measured ground albedo value deviates significantly from the recommended reference value of 0.2 [43], as well as from the equation adopted by SANDIA [48]. Additionally, an alternative equation has been proposed for calculating albedo as a function of the solar azimuth angle, expressed as follows:

$$\rho_g = 6 \times 10^{-4}\theta_z + 0.35 \quad \text{.................... (14)}$$

Where θ_z represents the solar zenith angle in degrees, the albedo can be alternatively considered as 0.4. This value, 0.4, is the average value of measurements and is often used for ease of calculation and simplicity in solar energy studies. By assuming a constant albedo of 0.4, it becomes more convenie nt for modeling and analyzing solar radiation data without the need to consider variations in ground reflectivity based on solar angles.

The eval uation was conducted on an hourly basis, covering nearly 9 months' worth of data records. Table 1 presents the statistical analysis results of the Direct Normal Irradiation (DNI) and Alb edo models.

Table 1. Values of calculated RMSE, MBE and R^2 for DNI and ρ_g.

Parameter	Correlation	RMSE	MBE	R^2
DNI	Eq. (3)	92.44	-4.90	0.65
Albedo (ρ_g)	0.4	0.569	0.262	-7.580 (reject)
	Eq. (14)	0.277	0.197	-1.034 (reject)

Table 1 provides a comprehensive evaluation of the Direct Normal Irradiation (DNI) and Albedo

models. Specifically, for DNI, the Root Mean Square Error (RMSE) index yielded an unsatisfactory value, indicating some level of discrepancy between the calculated and measured DNI values. Moreover, the Bias Meteorological Estimator (BME) index suggests that the DNI model tends to underestimate the actual DNI measurements. However, the Coefficient of Determination (R^2) proved successful in describing a reasonable correspondence between the calculated and measured DNI values, as evidenced implicitly in Fig. 16.
R^2 is a valuable indicator that quantifies the goodness-of-fit of the model, and in this case, it demonstrates a relatively strong correlation between the estimated and measured DNI values. On the other hand, concerning the ground albedo (ρ_g), the R^2 index failed to adequately describe the congruence between the calculated and measured values. In contrast, the RMSE index recorded good scores, indicating that, on average, the calculated albedo values were relatively close to the measured values. However, the Mean Bias Error (MBE) index suggests that the albedo model tends to overestimate the actual ground albedo values. These evaluation metrics are essential for assessing the accuracy and performance of the DNI and Albedo models.
They provide valuable insights into the strengths and weaknesses of the models and guide researchers in refining and improving their solar energy calculations. The use of multiple evaluation indices allows for a more comprehensive assessment of the models' capabilities and helps ensure that the results are robust and reliable.

4.2.4. Cloudiness index

The cloudiness index is the ratio of the diffuse solar radiation to the global horizontal solar radiation.
Fig. 18 presents the cloudiness index Kd as function of hourly cloudiness index.
There are several mathematical models that estimate total, diffuse and direct solar radiation from cloudiness index [49].

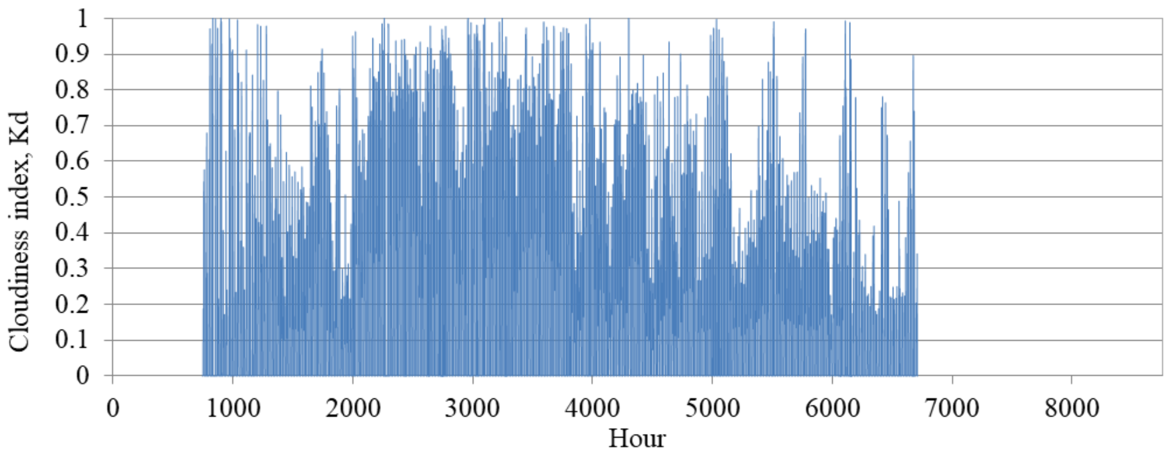

Fig. 18. Hourly cloudiness index.

4.3. Evaluation of meteorological stations

According to the word cloud presentation in Fig. 2, the present work designed this evaluation criterion for quality control of the stations and to ensure the scientific effectiveness of the stations as it presented in Table 2.

Table 2. Meteorological station evaluation criterion.

No	Weather Parameter	Weight	Essential measurements
1	Ambient temperature	10	✓
2	Global Horizontal solar radiation	10	✓
3	Diffuse Horizontal solar radiation	10	✓
4	Global tilted solar radiation	10	✓
5	Ground reflected Solar radiation	10	
6	Direct Normal solar radiation	10	
7	Wind Speed	10	✓
8	Wind direction	10	
9	Relative Humidity	9	✓
10	Sunshine Hours SD	9	
11	Minimum Temperature	9	✓
12	Maximum Temperature	9	✓
13	Atmospheric pressure	7	✓
14	Wet air temperature	6	
15	Nuclear radiation	5	
16	Clear Sky	5	
17	Rain Amount	4	
18	Soil temperature	2	
19	Sea Surface Pressure	2	
20	Station Surface Pressure	2	
21	Horizontal Visibility	2	
22	Max Wind Speed	1	✓
23	Evaporation Pressure	1	
24	Dew Point Temperature	1	
25	Evaporation Amount	1	
	Total points	155	

5. CONCLUSIONS

From the study, the following conclusions can be drawn:

1. The study includes essential indicators that highlight the availability and feasibility of renewable energies and provides methods for calculating them. These indicators play a crucial role in assessing the potential for harnessing renewable energy sources and guide in making informed decisions for sustainable energy planning and development.
2. The study successfully demonstrates the ability to estimate the direct normal solar irradiation (DNI) using the measured beam direct solar radiation. This finding is valuable as it allows for the estimation of DNI, which is crucial for the design and optimization of various concentrating solar power systems.
3. The study obtains a new value for the albedo coefficient, which differs from the recommended value. This new albedo value is based on the measured ground reflected solar radiation data, providing a more accurate representation of the ground reflectivity for the specific location or conditions under study.
4. The study introduces criteria designed to evaluate meteorological stations. These criteria likely assess the accuracy, reliability, and completeness of the data obtained from these stations, which is vital for ensuring the quality and usefulness of meteorological data in various

applications, including renewable energy studies.

In summary, the study enhances the understanding of renewable energy potential, provides methods for estimating solar irradiation, offers a new albedo coefficient, and introduces evaluation criteria for meteorological stations. These findings contribute to advancing solar energy research and promoting the sustainable utilization of renewable energy resources.

6. RECOMMENDATIONS:

At the conclusion of the study, the following recommendations are made to maximize the benefits from weather stations and further advance solar energy research:

5. It is crucial to establish and maintain a network of meteorological stations to continuously monitor and record weather data at various locations across Libya. This comprehensive data collection will provide a better understanding of regional climate patterns and support various renewable energy projects and applications.
6. To improve solar energy assessments, it is recommended to measure global tilted solar radiation for multiple inclination and azimuth angles. This data will enhance the accuracy of solar energy predictions and aid in the optimization of solar power systems, particularly those that require tracking or concentration.
7. Create a centralized database for solar radiation data in the study area and several other locations. Select these sites strategically in various geographic regions to facilitate future experimental or applied solar energy projects. A comprehensive database will help researchers and developers access valuable solar resource information for their specific locations.
8. Calculate the albedo coefficient for several other cities in addition to the one studied. Different cities and regions may exhibit varying ground reflectivity, and obtaining albedo values for various locations will improve the accuracy of solar radiation modeling and energy assessments.
9. Conduct a thorough comparison of a larger number of mathematical models and publicly available weather databases with the recorded data. This analysis will help identify the most reliable models and databases that accurately represent weather data. Making these verified models and databases readily available to students and researchers will foster collaboration and knowledge sharing in the field of solar energy research.

By implementing these recommendations, stakeholders can enhance the understanding of solar energy resources, optimize renewable energy projects, and promote the widespread adoption of clean and sustainable solar power technologies in Libya and beyond.

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