Optimization Implementation for Terrestrial Module & Concentrator Solar Cell Material in Conjunction with a Realistic Radiation Model for Solar Energy Applications

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Abstract: The fossil-based energy sources are being depleted quicker than ever before, yet it still remains as the main power resource of the world. Thus, finding alternatives for these fossil-based energy sources has become even more essential, and sun power proposes a solution. Sun irradiation is a significant determinant of sun energy system feasibility, which needs to be considered before the installation process. Numerous mathematical models have been applied to project radiation values due to the meteorological data available for various reasons. Nonetheless, these models' appropriateness highly depends on the environmental and climatic parameters. This is, in fact, the primary reason that elevates the available model numbers. In recent years, search into sun power has permitted the improvement of photovoltaic cells that can access about 0.20 power transformation performance when sold traditionally and at minimum pair while being analyzed in labs. By utilizing characteristic Si (crystalline) photovoltaic cells in mixture with Ga-As combinations, photovoltaic cells have the potency to access up to 0.50 transformation performance. Using plan methods, such as a light concentrator in conjunction with multi-junction cells, photovoltaic cells with theoretic performances of close to 0.80 are composed. By applying this industry into photovoltaic cells' commercial production, solar power is a reasonable replacement for fossil-based sources as the world's main resource of power. In the market, there is a wide range of photovoltaic cells. In the last years, new generation photovoltaic cells from various products have taken their place in the market. In a solar cell, the primary operating characteristics are performance, field, and density characteristics. This research first focuses on determining the applicable models for geographical locations chosen in certain climatic regions under investigation to plan solar systems for the greatest performance with certain climatic terms. For terrestrial modules and concentrator solar cells, this paper's secondary target is to determine the solar efficiency and compare the photovoltaic cells produced in various kinds with respect to main operating characteristics.

Keywords: Data Analysis; Solar Energy; Solar cell; Renewable Energy; Photovoltaic Systems; Panel Efficiency.

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1. Introduction

The limited amount of conventional energy sources is the leading factor that leads the researchers, engineers, governments, and all other shareholders to study and increase the renewable energy sources’ efficiency to satisfy the rising requisition for energy. Solar energy keeps increasing its share among the sources of energy supply on a global scale. Its popularity stems from the environmental and cost advantages and its availability worldwide and a wide variation of application areas. However, to fully exploit the solar energy potential, it is crucial to determine the distribution of solar radiation over geographical locations that are examined for energy investments.

Researchers have recently started to emphasize more on quantitative models of sun irradiation for the photovoltaic system design. A significant number of studies have also indicated that the artificial neural network strategy is superior to the empirical ones [1-3]. Qin et al. applied the Levenberg-Marquardt method using various inputs (variation in superficies temperature from day to night, mean superficies temperature, day number, air pressure rate, monthly basis rains, and vegetation indicator). Seven years of information from twenty-two sites were used to develop ANN [4]. To get the most effective input properties for the forecast, Yadav and co-workers utilized the Waikato environment software. Minimal and maximal temperature, mean temperature, altitude, and sunshine period were chosen as entry properties. In contrast, latitude and longitude were reported to be the minimum efficient properties. The forecast was on a monthly basis, for the mean global solar radiation. Based on the ANN methodology, the maximal MAPE (mean percent error) is calculated to be 6.89% [5, 6]. Khorasanizadeh and co-workers used six models for a number of cities [7, 8]. Two of these models were exponential and polynomial, while the remaining ones were based on sine and cosine. The root means square error (RMSE) values of their modelings were reported to be within the range of 1.26 and 0.72 MJ/m² day, while the MAPE changed between 5.72% and 3.38%. Piri and co-workers examined a modified SDF modeling (Sunshine Duration Fraction) together with three SDF modelings for 2 locations. The support vector regression method was applied in the study. RMSE term changed from 2.14 to 3.70 MJ/m²-day. The highest and lowest temperature values, sunshine period, and relative air moisture were chosen as input values for the kernel function [9].

Jiang et al. used Pearson correlation coefficients according to priority organization to select the related entry properties. Wind velocity, precipitation, mean opaque sky cover, lowest-highest temperature, daylight temperature, heating-cooling degree-days, relative moisture, mean temperature were selected as characteristics [10]. Khorasanizadeh and co-workers evaluated three non-sunshine periods and three average sunshine period fraction modelings to forecast the mean on a monthly basis worldwide solar exposure for six cities. In models with a medium sunshine period, relative moisture and the temperature were annexed as characteristics. As per models with sunshine duration fraction, overall modelings’ quadratic average error ranged between 0.82 and 0.47 MJ/m²-day [11]. In Turkey, Ozgoren et al. applied multi-nonlinear regression in an ANN (artificial neural network) modeling as an effort to determine the most appropriate independent properties for the entry sheet. For this purpose, they chose ten properties (annual month, ground temperature, sunshine duration, altitude, cloud cover, lowest and highest atmospheric temperature, average atmospheric temperature, wind velocity, and latitude). The Marquardt-Levenberg optimization algorithm is used to develop ANN [12]. Lam et al. applied artificial neural networks, adaptive neuro-fuzzy inference systems, gene expression programming, and temperature-sourced empiric modelings and provided a comparison of them. 2855 observations obtained from four different points were used for test purposes. 4420 observations were also obtained to train the models using the characteristics’ five combinations (lowest-highest air temperature, extraterrestrial radiation, day number and clear sky irradiation). The quadratic mean error of the optimized GEP varied between 3.31 and 3.49 MJ/m²-day. The mean square error of the corresponding optimized adaptive neuro-fuzzy inference system changed from 3.33 to 3.14 MJ/m²-day. The quadratic mean error of the optimized artificial neural networks when using the other three combinations as inputs changed within the range of 2.97 and 2.93 MJ/m²-day [13].

For sixty-nine locations in China, Jin and co-workers analyzed six SDF modelings and utilized three modelings to estimate the average sun irradiation. The height and latitude were included in
the modified models as parameters, while the coefficients' values were obtained separately. The sunshine duration's proportion was between 1.634 and 1.636 MJ/m² day [14]. For forty-one locations in China, Wan and co-workers used the linear Prescott-Angstrom modeling to forecast worldwide on a daily basis of solar radiation. Depending on diverse criteria, these locations are divided into 7 sun climatic regions and 9 thermal climatic regions. They implied the ANN modeling with the altitude, longitude, latitude, daytime, sunshine period, and daytime average temperatures as input values [15]. In the Iranian province of Bandar Abbas, Mohammadi and co-workers utilized Wavelet Transformation Algorithm and Support Vector Machine. Ten years of information were utilized for training purposes. The lowest and highest ambient temperature difference, water vapor pressure, sunshine duration fraction, mean environment temperature, extraterrrestrial global solar radiation, and relative moisture were chosen as the model parameters. The root means square error value was reported to vary within the range of 1.81 and 1.79 MJ/m²day. They utilized elementary particle swarm optimization to develop the ANN model. Latitude, longitude, sunshine period, height, and month variables were chosen as entries.

Nonetheless, the forecast was on a monthly basis, mean worldwide sun irradiation. The information from thirty-one locations was utilized to develop artificial neural networks. The mean real percent error was reported to be 8.85% [16]. Li and co-workers evaluated 8 sunshine fraction modelings for four locations. Values for 11 years were utilized for calibration purposes, while four years of information were used for validation purposes. The root means the square error was utilized as a statistical determiner. The linear RMSE modeling varied within the range of 0.72 and 1.26 MJ/m²day. The RMSE of the 8 modelings varied from 0.7 to 1.33 MJ/m²day [17].

Almorox and co-workers examined 8 models without the sunshine period, mainly dependent on the minimal and maximal temperature for seven locations. In several models, the latitude, altitude, year's day, and average temperature were contained. The average square error of the eight modelings varied from 3.25 to 2.70 MJ/m² day, and the average percent total error ranged from 16.37% to 29.18% [18]. For Saudi Arabia, El-Sebaii and co-workers applied 3 MSDF modelings, 3 SDF modelings, and non-sunshine duration modelings to predict the mean on a monthly basis worldwide solar radiation. The parameters classed in modelings with medium sunshine fraction were temperature, relative moisture, and cloud cover. The data from nine years were used to reproduce new empirical parameter values. The nine modelings’ quadratic mean error ranged from 0.02 to 0.15 MJ/m²day [19, 20]. In Tunisia, Chelbi and co-workers examined 5 empiric modelings for 4 sites [21]. For Gaize in Tibetan, Liu and co-workers examined 3 NSDF, 2 SDF, and 3 modified SDF modelings. 1085 days were analyzed for calibration. Data from seven hundred thousand days were utilized for validations. The RMSE ranged between 1.68 and 3.13 MJ/m² day. At different times, they researched that it was not necessary to derive coefficient values [22]. Shamshirband and co-workers utilized the extreme learning machine algorithm and ANN for Shiraz in Iran. The relative moisture, the temperature variation, the mean air temperature, and the proportion of sunshine periods were used as entries. The 3 years of data were utilized for test purposes. The RMSE changed between 0.86 and 0.93 MJ/m²day [23].

Senkal applied an ANN model that uses height, latitude, longitude, 2 different superficies emissivities, and field superficies temperature as inputs. Surface emissivities and surface temperatures were obtained from satellite data. Data from ten locations were used for one year for the purpose of training the artificial neural networks. RMSE values in the test and developing phases were given as 0.16 and 0.52 MJ/m²day [24]. Zang and co-workers examined the selfsame model with 2 different parameters for thirty-five locations [25]. The RMSE and the MAPE for the thirty-five locations varied from %4.33 to 16.22% and between 1.10 and 1.88 MJ/m²/day. To predict solar radiation, Sun and co-workers analyzed the impact of the auto-regressive moving mean modeling. They examined 20 years of data obtained from two locations [26]. Bakirici examined 7 diverse fraction modelings for the sunshine duration with information gauged at eighteen locations in Turkey. In order to predict the long-term average global sun irradiation, he utilized various modelings, with linear, quadratic, logarithmic, and exponential formulas. For identical locations, the modelings' performance was defined with little differences [27]. In one year, Ayodele et al. applied a function to
represent the clarity indicator's distribution. Utilizing seven years of data on the daily basis, the parameter values determined sun exposure data. With the exception of October, the effectiveness was achieved every month. The RMSE changed from 0.221 to 0.213 MJ/m²day [28]. Katiyar and co-workers looked for square, linear, and cubic modelings for predicting average on the monthly basis irradiation utilizing yearly information for four locations. The results were reported to be between 0.8 and 0.43 MJ/m²day [29]. For twenty-two locations in Korea, Park, and co-workers applied linearly related empirical modeling [30].

Senkal and co-workers used an ANN model for a number of cities. Average beam irradiation, average diffuse irradiation, the height, the latitude, and the longitude were utilized as entries. The satellite-sourced methodology for estimating the average radiation was suggested. The quadratic average error term varied between 2.32 and 2.75 MJ/m²day [31]. To predict daily radiation, Lu and co-workers utilized the model of ANNs. The RMSE values of ANN models have been reported to be in the range of 1.24–4.20 MJ/m²day [32]. For seventy-nine locations in China with information for ten years, Li and co-workers [33] implied mixed modeling (cosine-sine functions). The MAPE ranged between 4.00% and 15.43%, while the RMSE varied from 1.83 to 1.03 MJ/m²day. In order to forecast the mean on the hourly basis of solar exposure, Janjai and co-workers took advantage of satellite-sourced modeling. The relative RMSE from 15 to 9 ranged between 7.5% and 10.7% [34]. Bakirci examined sixty empirical models designed to forecast worldwide on the monthly basis mean solar exposure, with most of the forecasts having the identical equations, but with different regressive constant parameters. Thus, according to many articles' results, these constant parameters are usually based on the study fields [35]. Dumas and co-workers built a linear formula for correlating sun radiation temperature fluctuations and the sunshine period product utilizing the energy balance between the neighboring atmospheric sheet and the soiled sheet [36]. For four provinces in Turkey, Teke and co-workers examined cubic, linear, and quadratic empirical models [37]. For nine locations in China, Zhao and co-workers explored the linearly related modeling. The RMSE ranged from 1.72 to 5.24 MJ/m²day [38]. Duzen and co-workers examined 5 models of the sunshine period fraction to forecast on a monthly basis mean irradiation for 7 sites in Turkey [39]. Wan Nik and co-workers analyzed the 6 mathematical formulas on the hourly basis for sun irradiation rate to daily irradiation. The forecast was made for the monthly mean hourly irradiation. At 3 locations in Malaysia, information was used for 3 years to analyze the modelings. They recorded that the RMSE ranged between 8.22% and 26.49% [40].

Korachagaon et al. examined 16 models without the sunshine period to forecast mean clarity levels. Humidity, wind velocity, length, relative moisture, altitude, and 5 temperature-based properties were utilized as inputs. Variable values for 875 locations were assessed to analyze the models [41]. Fortin et al. examined 2 assist vector regression modelings. The lowest and highest temperature, sunshine period and relative moisture were chosen as entries for 2 sites in Iran. RMSE was reported to be between 1.63 and 4.47 MJ/m²day [42]. Behrang and co-workers examined the radial basis function system and multilayer perceptron system for Dezful in Iran. The 6 integrations of the characteristic properties used were wind velocity, sunshine duration, days’ number, mean air temperature, relative moisture, and evaporation as entries. 1388 days were utilized to develop the modelings. 214 days were utilized for analyses. The average actual percent error ranged between 5.21% and 22.88%. [43]. Chen and co-workers examined five sun fraction modelings for three locations in Liaoning of China. Information was collected from each of the locations for thirty-five years, and 70 percent of the information was analyzed to develop empiric coefficient values. 30 percent of the information was utilized for analyzing. The empiric parameter values were defined for each station. For Chaoyang, the root means square error ranged from 2.73 to 1.98 MJ/m²day [44]. Gouda and co-workers assessed 89 monthly mean irradiation modelings for Shanghai in China. Utilizing different parameters, many modelings were used with identical mathematical formulas. New adaptation coefficients were derived for five models of the sunshine duration fraction in Shanghai [45]. For 4 sites in Thailand and 5 locations in Cambodia, Janjai and co-workers explored satellite-sourced modeling. The root means square error was computed to be 1.13 MJ/m²day [46]. In Isfahan of Iran, Mohammadi and co-workers worked on 4 solar fraction modelings with values for 9 years. The 4 years of data were utilized to analyze the information. The root means a square error of them.
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2. Materials and Methods

Potential, Production, and Climate of Bursa.

The period of solar and land irradiation has significant value for solar-related facilities.

<table>
<thead>
<tr>
<th>Location</th>
<th>$I_{\text{ort}}$ (MJ/m²·day)</th>
<th>FGI (MJ/m²·day)</th>
<th>Latitude</th>
<th>FK I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bursa</td>
<td>11.0</td>
<td>6.95</td>
<td>40.11</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Table 1. Levels of irradiation.

Therefore, extensive work on the environment, solar energy efficiency, and existing facilities in Bursa, which is the province under investigation here, needs to be undertaken. The radiation function frequency, latitude, mean solar irradiation, and irradiation function phase shift values for Bursa city are provided in Table 1.

3. Results and Discussion

Solar Radiation Intensity Calculation.

3.1. Horizontal Superficies.

3.1.1. On a daily basis, whole sun irradiation.

Whole sun irradiation on a horizontal superficies can be computed by the below formula [57]:

$$I = I_{\text{ort}} - FGI \cos \left[ \frac{2\pi}{365} (n + FKI) \right]$$

FGI: irradiation function periodicity,
FKI: irradiation function phase shift,
n: days,
$I_{\text{ort}}$: yearly mean of whole daily irradiation.
3.1.2. On Daily Basis Diffuse Sun Radiation.
On a daily basis, total diffuse solar radiation on horizontal superficies can be defined utilizing formula 2 [58].

\[ I_y = I_y (1-B)^2 (1+3B^2) \]

B: Transparency index
I_o: Out-of-atmosphere irradiation

3.1.3. Total Momentary Sun Irradiation.
The momentary whole sun irradiation on horizontal superficies can be calculated utilizing formula 3 [57, 59].

\[ I_v = \frac{24}{\pi} I \left( \cos(e) \cos(d) \sin(ws) + ws \sin(e) \sin(d) \right) f \]

e: latitude angle, I, (W/m²): sun constant, d: declination, f: sun constant correction factor, ws: sunrise hour angle are computed utilizing equations and tables.

Irradiation is computed using the formula below [58].

\[ I_x = A_y \cos \left( \frac{\pi}{t_y} (t-12) \right) \]

t_y: imaginary day length
A_y: sun irradiation

3.1.4. Direct and Diffuse Sun Irradiation.
Amount of momentary direct and diffuse sun irradiation on horizontal superficies can be defined utilizing equations 5 and 6 [57, 59].

\[ I_{dx} = A_y \cos \left( \frac{\pi}{t_y} (t-12) \right) \]

\[ I_{dy} = I_y - I_{dx} \]

where:
A_y is function frequency

3.2. On inclined superficies, computing sun irradiation intensity.

3.2.1. Direct Momentary Sun Radiation.
Direct momentary sun radiation on surfaces with various angles (30, 60, and 90°) is computed utilizing the below formulation as it follows [57, 59].

\[ I_{dx} = I_y R_p \]

\[ R_p = \frac{\cos \theta}{\cos \theta_c} \]

\[ \cos \theta = \sin d \sin e + \cos d \cos e \cos w \]

\[ \cos \theta_c = \sin d \sin (e - \beta) + \cos d \cos (e - \beta) \cos w \]

3.2.2. Diffuse Sun Radiation.
Diffuse radiation can be defined using the formulation as follows [57, 59]:

\[ I_{dy} = R_y I_{dy} \]

For diffuse radiation, conversion factor R_y can be obtained utilizing the formula below [20-24]:

\[ R_y = \frac{1+\cos(a)}{2} \]

R_y parameter determines the surface’s slope. For vertical superficies (a = 90°), R_y is 0.5. Using this value, diffuse irradiation values for 30°, 60°, and 90° surfaces in Bursa can be computed.

3.2.3. Momentary Reflecting Irradiation.
Reflecting irradiation [20-24] is computed through the equation as follows:

\[ I_{ja} = I_y \frac{1+\cos(a)}{2} \]

The reflecting rate to the environment is displayed with q and utilized with a mean value of q = 0.2.

3.2.4. Whole Sun Irradiation.
Whole irradiation on inclined superficies is computed [64-65] using the equation as follows:

\[ I_t = I_{dx} + I_{dy} + I_{ja} \]

3.2.5. Data Analysis.
This section provides the results obtained from the analysis of data on simulation software. Figure 5 shows the values of (a) variation of current yearly average sun irradiation levels over a 24-hour cycle, (b) variation in current yearly diffuse sun irradiation values per hour, (c) variation of the current annual direct solar radiation levels over the city of Bursa. As shown in Figure 1, the momentary total sun irradiation’s maximum value on horizontal superficies in Bursa is 0.634 W/m² measured on the 355th day, at 12:00.

Figure 2 shows on a daily basis variation of:

a. total daily sun irradiation
b. sunrise declination angle
c. sunrise angle (hourly)
d. correction factor
e. atmospheric irradiation
f. function periodicity graph (A_y)
g. diffuse sun irradiation (A_y)
h. horizontal superficies transparency index (B) in Bursa.

For horizontal superficies, function frequency’s greatest level in Bursa is determined as 0.74. The declination angle’s highest levels, out-of-atmosphere radiation, and sunrise angle are founded to be
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23.4498°, 110.0186° and 288010 W/m², respectively, on the year’s 172nd day. While the transparency index gives its peak (0.0030) on the 80th day, its minimal value (0.0084) is obtained on the 266th day. For solar correction elements, minimum and maximum values consist of the 182nd and 365th days, respectively.

For a 24-hour time period, the direct momentary radiation levels on three angles (30°, 60°, 90°) were supplied in Figure 3.

The maximum levels of the angles were determined on day 355 at 12:00, while the minimal levels were defined on an identical day at 03:00.

For a 24-hour time period, the direct momentary radiation levels on three angles (30°, 60°, 90°) were supplied in Figure 3.

The maximum levels of the angles were determined on day 355 at 12:00, while the minimal levels were defined on an identical day at 03:00.

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Figure 1. On horizontal surfaces, yearly sun irradiation values’ variation.

![Figure 1](image1.png)

Figure 2. Sun irradiation on horizontal superficies.

![Figure 2](image2.png)

$I_{\text{dbmax}}$ values were obtained as 0.5212, 0.4891 and 0.2912 W/m² for 30°, 60° and 90°, respectively.
I_{bmin} values are -0.8231, -0.6123, and -0.4231 W/m² for the same angles.

Figure 3. Yearly momentary direct irradiation values.

(a) momentary direct irradiation values (30°)

(b) momentary direct irradiation values (60°)

(c) momentary direct irradiation values (90°)

Figure 4. For inclined surfaces, annual momentary diffuse irradiation values.

(a) momentary diffuse irradiation values (30°)

(b) momentary diffuse irradiation values (60°)

(c) momentary diffuse irradiation values (90°)

Figure 5. Annual whole momentary irradiation values.

(a) 30°

(b) 60°

(c) 90°

Figure 6. Total annual momentary radiation.

Yearly momentary diffuse irradiation values for 30°, 60°, and 90° are presented in Figure 4. The maximum values are obtained on the 355th day at 00:00 as 0.1897, 0.1991, and 0.1278 W/m², respectively. The whole momentary sun irradiation’s yearly values for daily periods are determined in Figure 5. Maximum values for 30°, 60° and 90° are obtained on the 355th day at 12:00 as 0.0256, 0.0921, and 0.1892 W/m², respectively. In Figure 6, the total momentary solar radiation levels can be observed.

3.2.6. Computational Results.

Table 2 provides the values for solar characteristics obtained from the analysis in previous sections that can be used to reflect the city’s potential under investigation in this study.
The next section aims to determine the solar efficiency for terrestrial modules and concentrator solar cells and compare the photovoltaic cells produced in various kinds with respect to main operating characteristics.

Table 2. Values of Solar Radiation.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Bursa</th>
<th>Characteristics</th>
<th>Bursa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total radiation</strong></td>
<td>Max</td>
<td>4.0940</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>4.0540</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Declination angle</strong></td>
<td>Max</td>
<td>23.4498</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>23.4498</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Sunrise hour angle</strong></td>
<td>Max</td>
<td>110.0186</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>67.9814</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Out-of-Atmosphere Irradiation</strong></td>
<td>Max</td>
<td>288010</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>-176900</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Transp. Index</strong></td>
<td>Max</td>
<td>0.0030</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>-0.0084</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Total diffuse irradiation</strong></td>
<td>Max</td>
<td>4.093</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>4.051</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Function freq.</strong></td>
<td>Max</td>
<td>0.74</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>0.495</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Momentary total irradiation</strong></td>
<td>Max</td>
<td>0.634</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>-0.822</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Momentary Diffuse Radiation</strong></td>
<td>Max</td>
<td>0.712</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>0.431</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Momentary direct radiation</strong></td>
<td>Max</td>
<td>0.1231</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Min</td>
<td>-0.1541</td>
<td>Min</td>
</tr>
</tbody>
</table>

3.3. Optimization Implementation for Terrestrial Module & Concentrator Solar Cell.

Sustainable energy supplies include solar, wind, hydroelectric, etc. Wind and solar power will make an important contribution to the next generation of energy. The sun energy is a solar power that can be considered a pronounced source of power to generate electrical power because it is a clean energy source and can contribute to large-scale power generation [60].

Solar cell technology has been the fastest-growing technology of energy production in the world as renewable energy in recent years. Solar cell history starts in the 19th century when it is noted that sunlight’s presence can generate utilisable electricity power. After the development of a 6% effective silicon-based solar cell in 1954, PV systems were used in a wide variety of implementations [61, 62]. Solar cell invention has played a significant role in sustainable power technology innovations. The solar cells make it simpler for us to use the tremendous sustainable power resource. Throughout the solar cell history, its durability, price, and reliability have been extremely important subjects to consider. Solar cells are p–i–n (or pn) semi-conductor junction appliances turn event light straight into electrical energy utilizing the “photovoltaic (PV) impact” phenomenon. PV modules and solar cells are generated for:
- Large-scale energy production, most frequently in building modules (building embedded PVs, BIPV) but also in centralized energy plants;
- Providing energy to non-supply grid-connected villages and cities in developing nations, such as water pumping and lighting systems;
- Remote energy supply, e.g., for weather surveillance or communications appliances;
- For space and satellites appliances;
- Providing energy for consumer products, such as night lights, toys, clocks, and calculators [63].

The design of the solar cell array is aimed at optimizing the output of electrical power and either minimizing weight for use in space or minimizing the cost of land use. The concentrator solar cells are utilized for the production of electricity in a lens-sourced concentrator scheme that focuses sunlight on the cells.

When operating under focused illuminations, concentrate solar cells can be economically feasible for terrestrial applications. In concentrator arrays,
the greatest energy conversion performances are generated by particularly these types of cells [64]. Typically, the compound solar cells deliver elevated conversion efficiency while using layers of photo-absorption produced from multi-element compounds such as gallium and indium. For example, concentrator triple-junction solar compound cells use a technology that enables the efficient conversion of sunlight into electricity through a stack of three layers of photo-absorption, the bottom of which is obtained from indium gallium arsenide (InGaAs). To obtain a concentrated conversion performance of approximately 44.4 percent, these solar cells are worked on widening the efficient concentrate cell surface and ensuring uniform width at the electrodes interface and linking concentrate cell. Until now, compound solar cells have been used mainly on space satellites due to their elevated conversion performances. Successful recent advances make the compound solar cells’ use in terrestrial implementations more viable [65].

The terrestrial modules and the features of the concentrator solar cell are highly appealing and can be used as a major resource that can be attached to networks. In this research, the terrestrial modules’ values and concentrated solar cell features are assessed using a multi-criteria decision method by concentrating on a technical comparison between the distinct terrestrial module and concentrate solar cell types. AHP methodology is used to create a comparison.

3.4. AHP modeling.

AHP (Analytic Hierarchic Process) is a measurement and modeling methodology in addition to an academic approximation to gauge intangibles and tangibles that are utilized to obtain the relative significance of a series of criteria. This approach’s distinction is that by utilizing it, the sides are able to organize and prioritize any complex, multi-period, multi-person, and multi-criteria scheme as hierarchic. Using a method that can be based on the participants’ priorities, judgments are produced for the elements in each of the standards of the organization with respect to an element in the next larger standard.

To determine decisions, the activities’ pairwise comparisons are obtained in a matrix type where the entries display the activity with which sole element domineers another with respect to certain criteria. The formula of scaling is transformed into a main eigenvalue problem, which concludes in a standardized and precedence weights’ single vector for each of norms (according to a factor in the subsequent norm above-mentioned), which concludes in the weights’ only one composite vector for the whole structure. This vector gauges all entities’ notional precedence in the minimum norm that activates the hierarchy’s maximum objective.

At the hierarchy’s lesser norms, these notional precedence weights can ensure guides for the sources’ share among the beings. When structures are planned to react probable corporate objectives, ecological scenarios, proposed and current market/product options, and diverse marketing tactic alternatives, the Analytic Hierarchic Process can ensure a methodology and framework for the decision of a few of the firm’s marketing decisions and key corporate ones [66, 67].

Through more detailing, each pair through comparison is assessed several times to the level to which one element of a double predominates the other in connection with each element (or property) in the hierarchy’s next higher degree. The smaller one is utilized as the unit, and the larger one is forecasted as multiple of it. To ensure the numerical reasoning in doing this, a reliable measure is required. It is assumed that the factors contained in these comparisons are homogeneous by taking the magnitude’s identical order; for example, their notional weights vary up to nine. On the contrary, they are parted in groups with a common factor from one group to another. The scale of nine-point utilized in characteristic AHP works is displayed in Table 3 [68]. It is supposed that a factor with zero weight is removed by comparison, as zero can be implemented to all factors.

3.5. Application of AHP Methodology to Terrestrial Concentrate Cell and Module.

The terrestrial implementation of high-efficiency concentrate solar cell is within high concentration photovoltaic systems. Highly efficient solar cells concentrate the sunlight through lenses or mirrors, thus improving the produced electricity while reducing the expensive cell surface. The high concentration photovoltaic systems give its greatest advantage to High Direct Normal Irradiation regions, where high concentration photovoltaic systems are an appealing option to traditional solar power because a reduced leveled energy cost can be accomplished by reducing production expenses and enhancing effectiveness through technological innovation.
Optimization implementation for terrestrial module & concentrator solar cell material in conjunction with realistic radiation model for solar energy applications

Optimum concentration optics design in high-concentration photovoltaic devices is essential to attaining high-energy conversion. The primary lens’s chromatic aberration can limit the optic effectiveness and admission angle at an elevated geometric concentration. Multi-element refractive ingredients, multi-material, hybrid diffractive/refractive components, or refractive and diffractive multi-element structures can be intended to correct chromatic aberration. Developing a cost-effective manufacturing, the array design method is critical to achievement. Array modules shall supply cell interconnections with voltage and present matching, enable repair and substitution during manufacturing, maintain the fragile cells integrate, align the concentration lens to close tolerance, and dissipate heat associated with cell unit operation. [65]. Table 4 demonstrates the highest outcomes for concentration cells and concentration modules (Table 4 also includes a lower amount of significant notables for concentration modules and cells).

Table 4 data is an enhancement in the effectiveness of a tiny region, two junctions, and two terminal tandem GaInAsP/GaInAs concentration cell to 35.5 percent below 38-suns concentration (38 kW / m2 direct radiance).

### Table 3. Absolute numbers’ fundamental scale.

<table>
<thead>
<tr>
<th>Definition</th>
<th>Value</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal significance</td>
<td>1</td>
<td>2 activities contribute equally to the objective</td>
</tr>
<tr>
<td>Slight or weak</td>
<td>2</td>
<td>Experience and judgment slightly favor sole activity over another</td>
</tr>
<tr>
<td>Moderate significance</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Moderate plus</td>
<td>4</td>
<td>Experience and judgment strongly favor sole activity over another</td>
</tr>
<tr>
<td>Strong significance</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Strong plus</td>
<td>6</td>
<td>An activity is favored significance very strongly over another; its dominance demonstrated in practice</td>
</tr>
<tr>
<td>Very strong or demonstrated</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>favored significance very strongly</td>
<td>8</td>
<td>The evidence favoring sole activity over another is of the maximum possible order of affirmation</td>
</tr>
<tr>
<td>Extreme significance</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4. Terrestrial concentrate and cell performances gauged at 25 °C cell temperature under the ASTM G-173-03 direct beam module AM1.5 spectrums [67].

<table>
<thead>
<tr>
<th>Classification</th>
<th>Efficiency (%)</th>
<th>Area, (cm²)</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single cells</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GaAs</td>
<td>29.3 ± 0.7a</td>
<td>0.09359</td>
<td>49.9</td>
</tr>
<tr>
<td>Si</td>
<td>27.6 ± 1.2c</td>
<td>1.00</td>
<td>92</td>
</tr>
<tr>
<td>CIGS (thin film)</td>
<td>23.3 ± 1.2d</td>
<td>0.09902</td>
<td>15</td>
</tr>
<tr>
<td>Multijunction cells</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GaInP/GaAs; GaInAsP/GaInAs</td>
<td>46.0 ± 2.2f</td>
<td>0.0520</td>
<td>508</td>
</tr>
<tr>
<td>GaInP/GaAs/GaInAs/GaInAs</td>
<td>45.7 ± 2.3g</td>
<td>0.09709</td>
<td>234</td>
</tr>
<tr>
<td>InGaP/GaAs/InGaAs</td>
<td>44.4 ± 2.6h</td>
<td>0.1652</td>
<td>302</td>
</tr>
<tr>
<td>GaInAsP/GaInAs</td>
<td>35.5 ± 1.2i</td>
<td>0.10031</td>
<td>38</td>
</tr>
<tr>
<td>Minimodule</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GaInP/GaAs; GaInAsP/GaInAs</td>
<td>43.4 ± 2.4j</td>
<td>18.2</td>
<td>340k</td>
</tr>
<tr>
<td>Submodule</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GaInP/GaInAs/Ge; Si</td>
<td>40.6 ± 2.0k</td>
<td>287</td>
<td>365</td>
</tr>
<tr>
<td>Modules</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>20.5 ± 0.8l</td>
<td>1875</td>
<td>79</td>
</tr>
<tr>
<td>Three junction (3j)</td>
<td>35.9 ± 1.8m</td>
<td>1092</td>
<td>N/A</td>
</tr>
<tr>
<td>Four junction (4j)</td>
<td>38.9 ± 2.5n</td>
<td>812.3</td>
<td>333</td>
</tr>
<tr>
<td>“Notable exceptions”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si (big field)</td>
<td>21.7 ± 0.7</td>
<td>20.0</td>
<td>11</td>
</tr>
<tr>
<td>Luminescent minimodule</td>
<td>7.1 ± 0.2</td>
<td>25</td>
<td>2.5a</td>
</tr>
</tbody>
</table>

In this study, the terrestrial concentrate cell and module properties that are given in Table 4 are assessed by expert views. Using the scale in Table 3, the decision matrix is composed as in Table 5. Secondly, the definition of the issue to be explored in the research is given. A decision-matrix is...
established between the criteria for selecting the options and the relative priorities of those criteria. In the third stage, those calculations, percent precedence values are defined by assessing each criterion’s options. The most efficient alternative is obtained utilizing the distribution arising. The criteria’s relative priorities are displayed in Figure 7.

<table>
<thead>
<tr>
<th>Table 5. Decision Matrix.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency (%)</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Efficiency (%)</td>
</tr>
<tr>
<td>Area</td>
</tr>
<tr>
<td>Density</td>
</tr>
</tbody>
</table>

Figure 7 The criteria’s relative priorities.

4. Conclusions

The sun irradiation’s values on horizontal and inclined superficies are obtained using the MATLAB simulation program. The above calculations indicate that the potential of the photovoltaic systems corresponds to the anticipated grades. An intrinsic part of designing PV systems is the comparison of the anticipated results with the actual ones. System performance is based on different characteristics. The use of rational radiation values is of big significance to the design of the optimal system. This research is designed to provide a reference for optimum sun panels’ choice through the use of real values of solar irradiation determined for an effective solar system plan. The solar radiation values are evaluated with admissible efficiency ratios in designing a photovoltaic system.

Concentrator Photovoltaic technology has been introduced to the market as an alternative to generating 370 MWp solar power in cumulative facilities, including several locations with more than 30 MWp. Concentrator Photovoltaic technology modules, however, continue to attain efficiencies far beyond what is feasible with conventional flat-plate industry and have space to push even greater efficiencies in the future, offering a potential pathway for system expense cuts. So, the high efficiency of multi-junction concentrator cells has the capacity to revolutionize the cost structure of producing photovoltaic energy, and it is possible to achieve higher efficiencies. In the markets, there are many types of terrestrial concentrate cells and modules. Lately, there has been a market place for terrestrial concentrate cells and modules from distinct metals. The main working parameters in the terrestrial concentrate cell and module are the features of effectiveness, region, and density. It is within the scope of this research is to determine the efficiency of photovoltaics and to compare the terrestrial concentrate cells and modules manufactured by main working parameters in distinct kinds.
The secondary purpose of this research is to shed light on comparing the photovoltaic cells manufactured in various forms with respect to key operating parameters and determining the optimal photovoltaic alternative, among other available ones. Thus, it is a valuable contribution from three aspects: evaluating a set of criteria required in the evaluation of concentrator solar cells, defining their comparative priorities based on expert views, and providing a straight-forward quantitative analysis. In future research, it is possible to increase the number of variables and modify their relative priorities based on novel views.

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Conflicts of Interest
The authors declare no conflict of interest.

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