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PAPER

Feasibility and performance analysis of bifacial module under extremely hot and dry climate

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Abstract

Solar panels with a bi-facial design provide energy from both sides; thus, it would be interesting to examine the viability of such modules in an extremely hot and dry city like Ahmedabad, Gujarat, India. This study assesses the temperature, efficiency, and bifacial gain of PV bifacial modules as a function of solar irradiation, ambient temperature, wind speed, and additional parameters. The global horizontal irradiance has been used in this study to calculate Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI) and Front and Rear Irradiance. The results show that an optimal tilt angle of 43.5° provides the best efficiency of 24% at ambient temperature. For a constant value of tilt angle, the bi-facial gain of the module increases linearly with albedo factor. It has also been discovered that continuing to raise the elevation beyond 1 meter will eventually diminish the bifacial gain because the reflected and diffuse irradiance will become less intense on the rear side of the bifacial module.

Introduction

Energy from fossil fuels has been a source for humans for centuries. Reliability and availability have contributed greatly to this long dependency. Electricity has become increasingly important in our modern world. Fossil fuels are still the primary source of our electricity. The Paris Agreement has brought together numerous countries to fight climate change on an international level. The UN Sustainable Goals include Affordable and Clean Energy, which shows perceptions and motivations among people globally for switching to clean energy sources. Hence, the primary reason for turning to renewable energy is to reduce the pessimistic environmental effects of traditional energy sources and to improve public health. The energy sources derived from renewable sources can be replenished within the lifespan of humans, making them practically inexhaustible. Furthermore, it does not produce greenhouse gases during the energy generation process, which makes it the most environmentally friendly and viable option for preventing climate change.

A solar cell generates electricity based on the principle of photovoltaic effect [1]. A photon from Sunlight strikes semiconductor material on solar cells and releasing outer electrons from atomic bonds. The electrons in a semiconductor are forced to flow in one direction, resulting in electrical current. Monocrystalline, polycrystalline, and thin-film solar panels are the three most popular PV technologies on the market. Both monocrystalline and polycrystalline silicon wafers are made from silicon wafers, but they differ in their composition. The materials used in thin-film solar cells include cadmium telluride (CdTe), amorphous silicon (a-Si), and copper indium gallium selenide (CIGS). Depending on how the module is constructed, monocrystalline and polycrystalline solar modules are further divided into monofacial and bi-facial modules. In monofacial modules, electrical power is generated exclusively by direct and diffused radiation captured on the front side of the panel. Bifacial modules, on the other hand, convert light captured on both the front and back sides into electrical power [2]. As a result of this unique feature, bifacial solar modules can produce more power than monofacial PV modules. Compared to monofacial modules, these modules have a higher power density, save money on the BOS, produce more energy, operate better in low light, and have lower temperature coefficients [3]. The use of bifacial solar panels reduces the number of panels required to produce the same

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Table 1. Specification of ELAN Series N-type PERT bifacial module [21].

Electrical Characteristics with 30% ground reflectance on rear side	
Maximum Voltage V_{mp} (V)	38.33
Maximum Current , I_{mp} (A)	12.4
Open Circuit Voltage V_{OC} (V)	46.72
Short Circuit Current , I_{SC} (A)	13.05
Mechanical date	
Length	1998 mm
Width	1010 mm
Height	40 mm
Weight	23 kg
Temperature Coefficient (TC)	
TC of open circuit voltage (β)	−0.31%/°C
TC of short circuit current (α)	0.065%/°C

amount of solar energy as a monofacial array. As a result, bifacial panels are suitable for residential use. Additionally, they have an aesthetic appeal, making them easy to integrate into the home's design.

In Sun *et al*'s study, the bifacial gain for ground-mounted modules was less than 10% at a 0.25 albedo [4]. Albedo is a measurement of diffuse solar energy reflecting out of total solar radiation. The bifacial gain could be increased by as much as 30% with improved albedo of 0.5 and clearance height of 1 meter. Furthermore, ground mounted, east-west facing modules will perform 15% better than south-north facing modules when latitude is below 30 degrees and the albedo is 0.5. Pelaez *et al* found that bifacial modules in 1-axis tracking systems can boost energy yield by 4% to 15% [5]. Single-axis tracking offers an energy savings of 15%–25% over fixed tilt deployments. Furthermore, according to Alam *et al* thermodynamic's calculations shows that bifacial panels outperform monofacial panels by 15%–20% [6]. Stein *et al* also conducted a study in Albuquerque, New Mexico, and discovered that bifacial modules outperform monofacial modules [7]. By altering tilt angle, the application of intelligent tracking algorithms can boost energy yield by more than 1 percent in overcast conditions.

A comparison was made among five solar rear irradiance models for bifacial systems [8], that is Prism Solar and Solar World, which are empirically fit, as well as PVSyst and NREL View Factor and the most complex NREL Radiance model. Several parameters were investigated, including tilt angle, row spacing, and clearance height, and some configurations could result in a bifacial gain of up to 20%. Furthermore, these models have a better agreement for a clearance that is less than 0.75 times of the module width. A higher clearance height, however, resulted in a better uniformity of rear side irradiance. In general, empirical models were less accurate, while the NREL View factor was the most accurate of the non-empirical models. In addition, field tests confirmed that measurement errors for most configurations were within 2%.

A recent study examined bifacial photovoltaic systems, looking at the principles of bi-faciality, the structure of modules, and various losses that occur during energy production [9]. The term 'bifaciality' refers to the relationship between the nominal efficiency of the rear side and the nominal efficiency of the front side. The system was analyzed through a numerical model, simulation in software, and future economic aspects, as well as parameters and performance. According to their findings, bifacial solar PV modules generate 5–30 percent more power than monofacial panels, resulting in a 2–6 percent lower levelized cost of energy (LCOE) [9]. It has also been reported that a tracking system, optimized tilt angle, higher albedo, and optimal elevation can all result in increased electrical production. Furthermore, basic information about non-uniform rear side irradiation energy production is presented that will assist further research and development in bifacial photovoltaics. Ozkalay *et al* studied the effect of non-uniformity on rear side irradiance [10]. The study found that white gravel can reduce non-uniformity in the ground surface by up to 10%. The central module values increased by about 10% in the early mornings and late afternoons. However, it is not guaranteed since module position and time of day affect non-uniformity. In addition, non-uniformity was observed to be lower on cloudy days than on clear days. Market research forecasts that the bifacial solar module market will grow from $2.5 billion in 2019 at an annual growth rate of 16.2% from 2020 to 2025 [11]. Market growth of bifacial solar is driven by new technologies in the solar industry. There are several other factors driving installation of bifacial solar panels, such as rising affordability, government support, and the clear advantages that bifacial panels offer over monofacial panels [12]. The power rating of solar panels is becoming more flexible with the help of manufacturers like LG, Solar, Lobgi, and CanadianSolar [13].

Accessibility and affordability are two of the most important reasons for the rapid rise of solar energy as a global energy source. Ever since it was first developed in the 1960s, the PERC (Passivated Emitter and Rear Cell)

Table 2. Orgill and Hollands correlation [22].

DHI/GHI = 0.177	$K_t > 0.75$
DHI/GHI = 1.577–1.84 * K_t	$0.35 < K_t < 0.75$
DHI/GHI = 1–0.249 *K_t	$0 < K_t < 0.35$

Table 3. Recommended days by Klein for each month [25]. Reprinted from [25], Copyright (1977), with permission from Elsevier.

Month	Date	Day of the Year
January	17 January	17
February	16 February	47
March	16 March	75
April	15 April	105
May	15 May	135
June	11 June	162
July	17 July	198
August	16 August	228
September	15 September	258
October	15 October	288
November	14 November	318
December	10 December	344

technology has allowed monofacial and bifacial PV modules to operate at higher efficiencies. The price difference between monofacial and bifacial modules has narrowed over the last two decades due to technological developments [14–19]. By 2028, bifacial PV modules are expected to make up 40% of the global market due to their higher efficiency and lower price [20]. That is why we looked at whether bifacial modules may be employed in Ahmedabad.

Evaluation methodology

Specification of bifacial module

In this study, Adani Solar's ELAN Series N-type PERT Bifacial Photovoltaic modules specifications were used. The manufacturer's Data Sheet for this particular bifacial module appears in table 1 [21], which includes the following information:,

Procuring meteorological data

The date used in this work has been procured from India Meteorological Center in Ahmedabad and Pune, which provided us with daily meteorological data, such as Ambient Temperature, Wind Speed, Global Irradiance and Humidity for a period of one year (2020).

Data filtering

Meteorological data that was procured was unstructured and difficult to process. The data of each month has been sorted and filtered properly for the entire dataset. All data entries with a global irradiance of less than 200 W m^{-2} were removed because they contributed the least to power production during the day. In addition, we removed blank and unwanted entries that resulted from equipment errors made by the IMC organization during the data collection process. The final step was to tabulate the data of ambient temperature, wind speed, and global irradiance for each month and to calculate the averages for the period of 06:00HRS to 20:00HRS.

DNI & DHI

Following the proper filtering of the Global Horizontal Irradiance (GHI), there are two other components that must be computed: the Direct Normal Irradiance (DNI) and the Diffuse Horizontal Irradiance (DHI). The empirical correlation described by Orgill and Holland [22] is used to determine the DHI from the GHI. Table 2 shows the Orgill and Hallands correlation factors.The relationship with sky clarity index (Kt) is as follows:

The sky clearness index (Kt) values for Ahmedabad are taken from a study by R. C. Srivastava and Harsha Pandey [23]. The GHI and DHI have already been calculated; so, for the calculation of DNI, there is a correlation between these three parameters, which is reflected in [4].

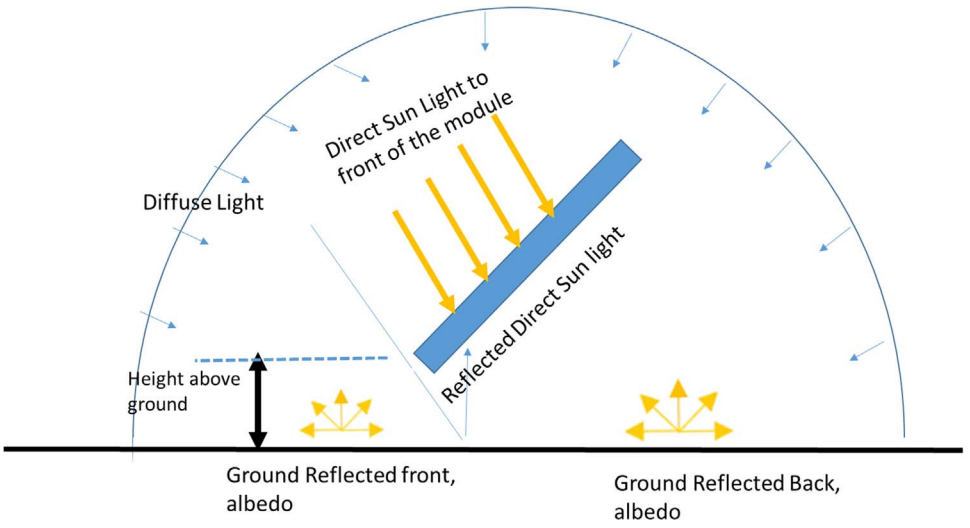


Figure 1. A description of the components of solar irradiation on a bifacial photovoltaic module [27–29].

$$I_{GHI} = I_{DNI} \times \cos\theta_Z + I_{DHI} \tag{1}$$

$\text{Cos}(\theta_Z)$ represents the angle that can be seen between the Sun's beams and the vertical, which is also referred to as the Zenith angle. Calculating the zenith angle requires first calculating the three other angles, which include the declination angle, the hour angle, and the Sun azimuth angle. Only after this can the zenith angle be determined. The angle of declination changes throughout the course of the year and is described in the following manner [24]:

$$\delta = 23.45^\circ \sin\left[\frac{360(d_n + 284)}{365}\right] \tag{2}$$

It would be tedious work to calculate the declination angle for every day for the duration of a year, since the declination angle changes every day, and the albedo in each month differs. Based on the work of Klein *et al* a particular day of each month is used [25]. Klein notes that the average daily global radiation for a month is equal to a certain date within that month as mentioned table 3.

The next step is to calculate the Hour Angle. An hour angle differs according to the time of day. The hour angle for each hour for particular day of the month has been calculated using equation (3). The equation is as follows [24]:

$$\omega = (720 \text{ min} - LST \text{ in min } from \text{ } midnight) \ldots 4 \text{ min deg}^{-1} \tag{3}$$

Where, LST = Standard Time ± 4 (Standard Time Reference longitude—Longitude of location) + Time Correction factor.

The Standard Time Reference Longitude for Ahmedabad (72.5 degrees East) is Mirzapur (82.5 degrees East). For ease of calculation, the equation of Time correction factor has not been taken into account. Now, the zenith angle (Cos (Z)) has been calculated using equation (4) in [24].

$$\cos\theta_{ZS} = \sin\delta \sin\varnothing + \cos\delta \cos\varnothing \cos\omega \tag{4}$$

Front side irradiance

The front irradiance was calculated using Liu and Jordan's isotropic diffuse model [26]. The intensity of diffuse irradiation is homogeneous throughout the sky, according to the isotropic diffuse model. The irradiance on a tilted photovoltaic module is calculated using three components: direct, diffuse, and reflected irradiation.

The amount of diffuse irradiation reaching the module after scattering through the sky is the diffuse irradiation. It is difficult to predict this component since it is determined by cloud density and the sky clearness index (Kt). The reflected component is comprised of the irradiance reflected from the ground and nearby objects. The amount of light reflected depends on the surface's albedo value and the material it is made of. The components of Sun irradiation are depicted in figure 1. Liu and Jordan used all three of these components to derive the total solar irradiance on a tilted surface, which is denoted as follows:

$$I_t = I_b R_b + I_d\left(\frac{1 + \cos\beta}{2}\right) + I\rho_g\left(\frac{1 - \cos\beta}{2}\right) \quad (5)$$

Where β is the angle of tilt of the PV module. ρg is the albedo value of the surface of the ground. Total Sun irradiance on a horizontal surface is denoted by I. I_d represents the diffuse hourly Sun irradiance on a horizontal surface. I_b is the hourly horizontal surface beam radiation. R_b represents the ratio between the hourly beam radiation on a horizontal surface and that on an inclined surface.

Rear side irradiance

Durusoy *et al* [29] use a modified Liu and Jordan's isotropic model to determine the rear side irradiation. The same model has been used in the present article. It has all three components of solar radiation, direct, diffuse, and reflected, in accordance with Liu and Jordan's model; however, instead of tilt angle, complementary angle of β is utilized. As a consequence of this, the back side is considered to be the front side, and the angle of tilt is $(\pi-\beta)$.

The component of reflected solar irradiation has also been modified. As the bifacial module is tilted, different parts of the module will have different elevations from the ground. This will result in different parts of the module receiving different amounts of reflected light. The component of solar reflected irradiation is multiplied by a correction factor to account for these differences. For this reason, the modified model for calculating the rear side irradiance is as follows:

$$I_{b,back} = I_b\, R_{b,back} + I_d\left(\frac{1 - \cos\beta}{2}\right) + I\rho f(h)\frac{(1 + \cos\beta)}{2} \quad (6)$$

f (h), the height function, is used to integrate the correction factor over the module's minimum and greatest height above the ground [29]. This function can be expressed as,

$$f(h) = 1 - e^{\frac{-l}{l_C}} \quad (7)$$

Where l_c is the critical length constant, which can be determined based on the height in the middle of the length. Additionally, the value of $R_{b,back}$ is determined by taking the ratio of beam irradiation on the front surface, denoted as fRb,front, for angles of incidence (AOI) that are greater than 90 degrees. It can be deduced from the fact that the angle of incidence (AOI) is greater than 90 degrees that the Sun is shining on the rear of the module; hence, the value of $R_{b,back}$ is the same as the value of $R_{b,front}$ in this situation.

Bifacial gain

This feasibility study's primary purpose is to conduct an investigation into the amount of additional power that can be generated by the bifacial module in comparison to the monofacial module. Bifacial Gain is the indicator used to calculate this. For simplicity of calculation, the Bifacial gain can also be calculated taking into consideration the optical parameter, that is, the front and rear irradiances G_{front} and G_{rear} [8].

$$BG_E\ [\%] = \varnothing_{Pmp} \times \frac{G_{rear}}{G_{front}}(1 - \eta_{loss}) \quad (8)$$

There are η_{loss} losses here owing to shade or non-uniformity in the irradiance on the module's rear side. Φ_{pmp} is the bifaciality factor; every bifacial module is characterized by its bifaciality factor, which is provided by the manufacturers in their PV module datasheet. Typically, bifaciality value in commercially available modules ranges from 60%–90% [8]. In this study, for the simplicity of calculation, we have considered $\Phi_{pmp} = 100\%$ and $\eta_{loss} = 0$.

Module temperature using Kurtz model

Having computed front and rear side irradiance, it's time to see how the temperature and wind speed of the site in question affects temperatures in the bifacial modules and cells under discussion. As module temperature increases, the output voltage is assumed to decrease.

Sandia National Laboratories' study verified that the module temperature model for monofacial modules can be used for bifacial modules as well [30]. Therefore, the Kurtz model to predict bifacial module temperature is used and is expressed as follows:,

$$T_{mod} = (E_f + E_r) \times [e^{a+b.WS}] + T_{amb} \quad (9)$$

Where, E_f and E_r are the font and rear side irradiance (W/m^2). T_{mod} is the module temperature. T_{amb} and WS are the ambient temperature and wind speed (m/s). a and b are empirical constants and there suggested values are −3.47 and −0.0594 [29]. From the module temperature, cell temperature (T_c) can be calculated using the formulae,

$$T_C = T_M + \Delta T(E_f + E_r)/1000 \quad (10)$$

Here, ΔT = 3 degree Celsius for open racking structure.

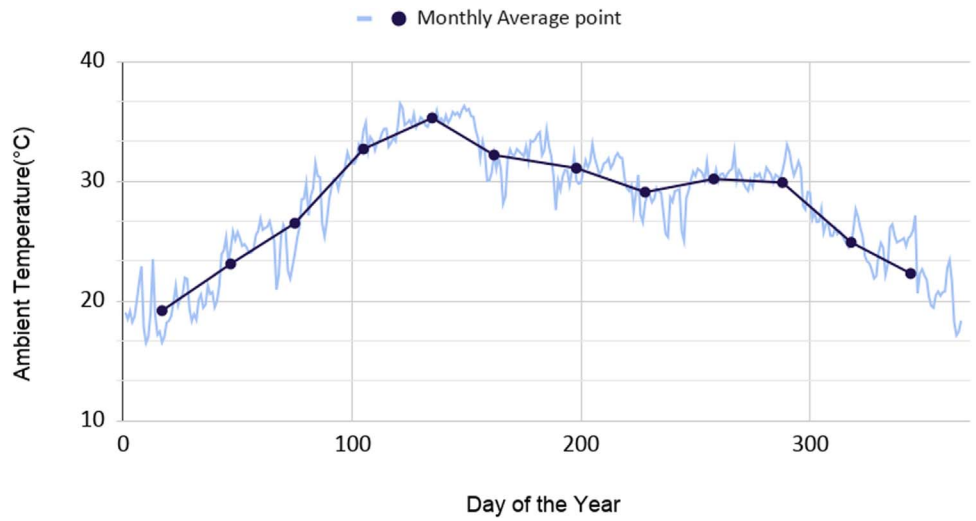


Figure 2. Profile of Ambient Temperature over a year in Ahmedabad.

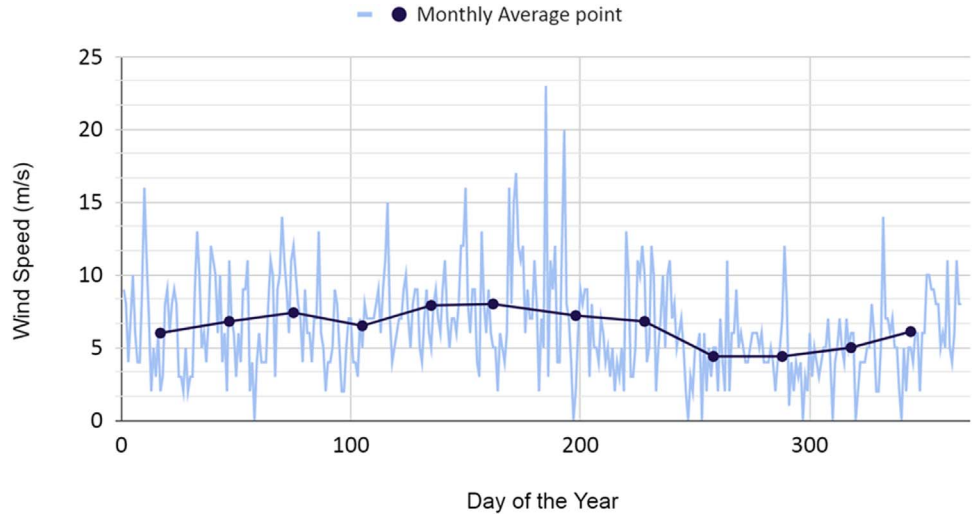


Figure 3. Profile of Wind Speed over a year in Ahmedabad.

Efficiency based on cell temp and irradiance

To evaluate a module's efficiency, the operating voltage and current must be calculated under a given climatic situation. The temperature of the cell has already been calculated. Thus, the Temperature coefficient of open circuit voltage (β) and Temperature coefficient of short circuit current (α) can be used to estimate voltage and current. Table 1 contains the values for the bifacial module used in this study. A set of equations from [31] was used to calculate Voc, Isc, Vmp, and Imp, and they are expressed as follows:

$$I_{SC}(G,\ T_C) = I_{SCS}.\frac{G}{G_S}[1 + \alpha.(T_C - T_S)] \tag{11}$$

$$I_{MP}(G,\ T_C) = I_{MPS}.\frac{G}{G_S}[1 + \alpha.(T_C - T_S)] \tag{12}$$

$$V_{OC}(T_C) = V_{OC} + \beta.(T_C - T_S) \tag{13}$$

$$V_{MP}(T_C) = V_{MPS} + \beta.(T_C - T_S) \tag{14}$$

Where, Iscs, Imps, Vocs, and Vmps are obtained from the datasheet of a bifacial module provided by the manufacturer. G and Tc stand for the total irradiation and the temperature of the cell, respectively. Irradiation, measured in watts per square meter, and temperature, measured in degrees Celsius, are both referred to as Gs and Ts, respectively, when standard testing conditions ($G = 1000\ W\ m^{-2}$ & $T_s = 25$ degree Celsius) are used. Next, we need to calculate the fill factor and Power for the bifacial module. Its equation is expressed in [24] as,

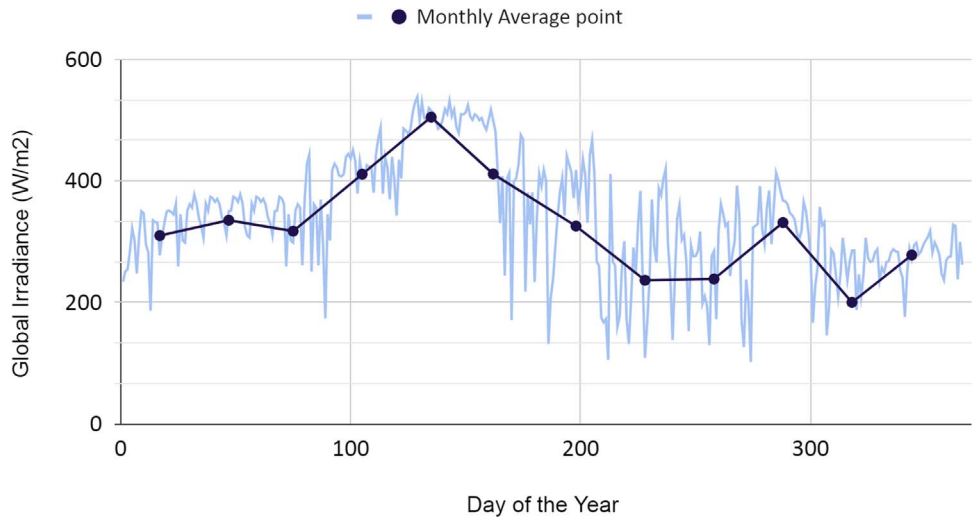


Figure 4. Profile of Global Irradiance over a year in Ahmedabad.

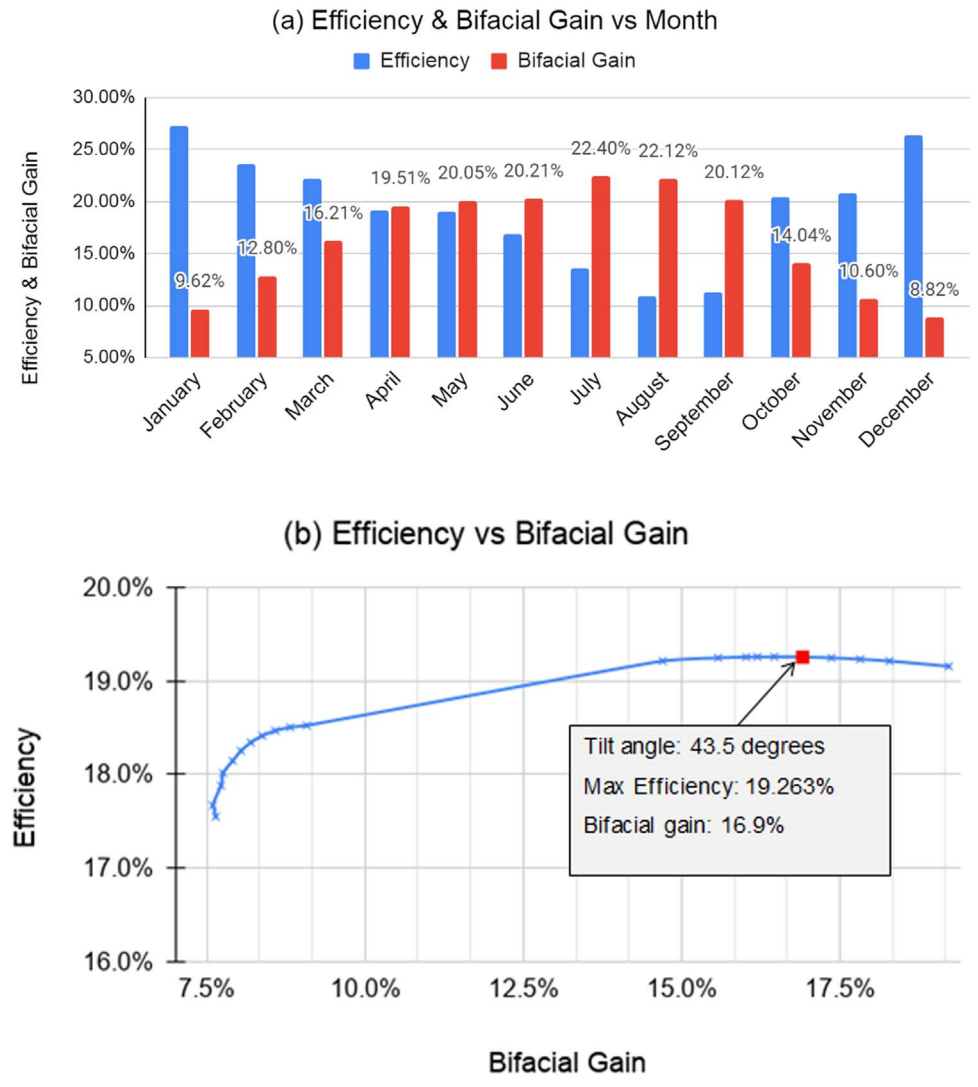


Figure 5. (a) Comparing Efficiency and Bifacial Gain throughout the year; (b) Relationship between Efficiency and Bifacial Gain for various angle of tilt.

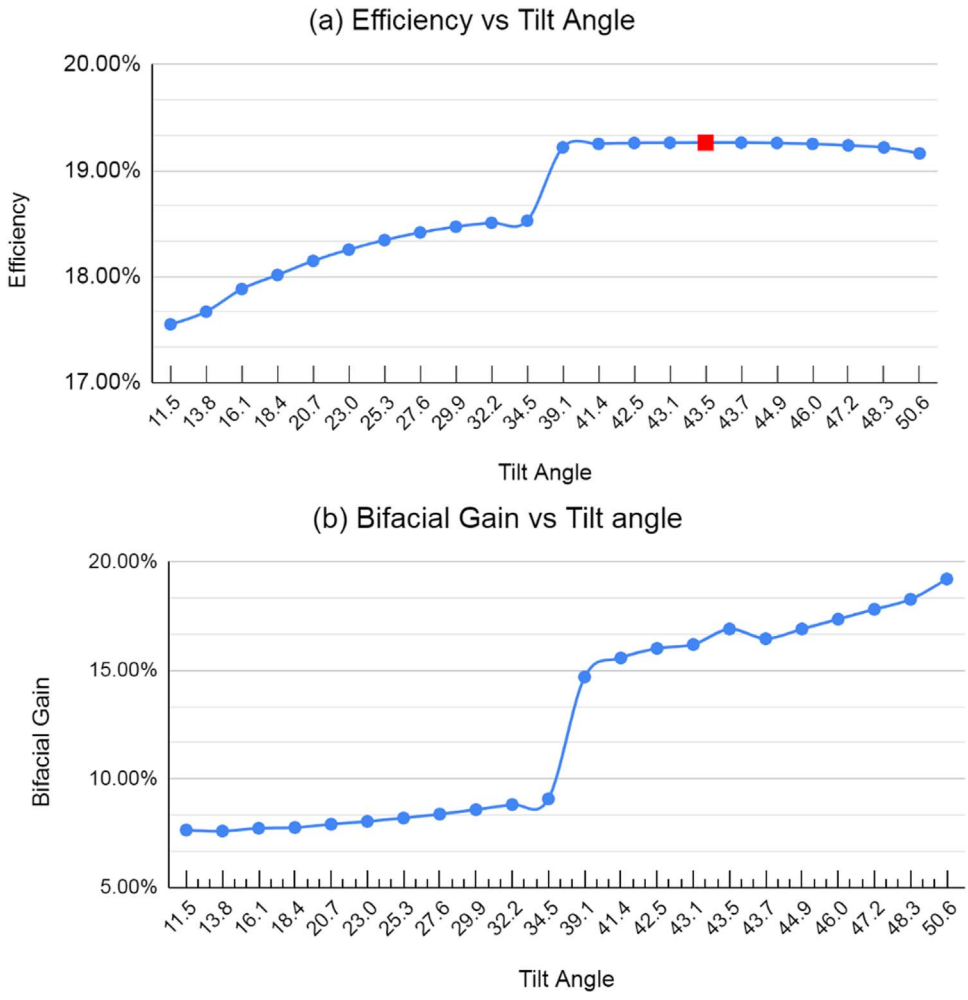


Figure 6. (a) Relationship between Efficiency & Tilt angle. (b) Relationship between Bifacial Gain & Tilt angle.

$$Fill\ factor\,(FF) = \frac{V_{mp}.I_{mp}}{V_{OC}.I_{SC}} \tag{15}$$

$$Power\,(P_m) = FF \times V_{OC} \times I_{SC} \tag{16}$$

Lastly, the efficiency is calculated by the equation expressed in [24] as,

$$\eta = \frac{P_m}{E \times A_C} \times 100\% \tag{17}$$

Where, E is the incident irradiation at STC (1000 W m^{-2}) and Ac is the area of the collector (m^2).

Results and discussion

Site description

The Sabarmati River flows through Ahmedabad, a large metropolitan city in Gujarat. The city is located in western India at 53 meters above sea level at 23.03° N 72.58° E. Due to its tropical climate, Ahmedabad has a hot and humid climate (tropical savanna climate). Figure 2 shows the temperature profile over whole year for Ahmedabad city. The climate is drier in the city, with an average annual temperature of 27.1 °C, making it a great location for harvesting solar power. An yearly chart of Ahmedabad's temperature, wind speed (figure 3), and global horizontal irradiance (figure 4) is shown below. These results confirm our selection of Ahmedabad as the study location. The feasibility of bifacial modules in western India has not yet been studied. Gujarat is the only state in India with the highest amount of solar radiation, which means feasibility studies for bifacial modules in Ahmedabad create a lot of future opportunities for this technology.

In this study, power output, bifacial gain, and efficiency of a bifacial photovoltaic module are calculated using the described methodology. A power output and efficiency calculation has been made that is based on the influencing parameters that are listed in the report, and these parameters have been optimized to get a higher

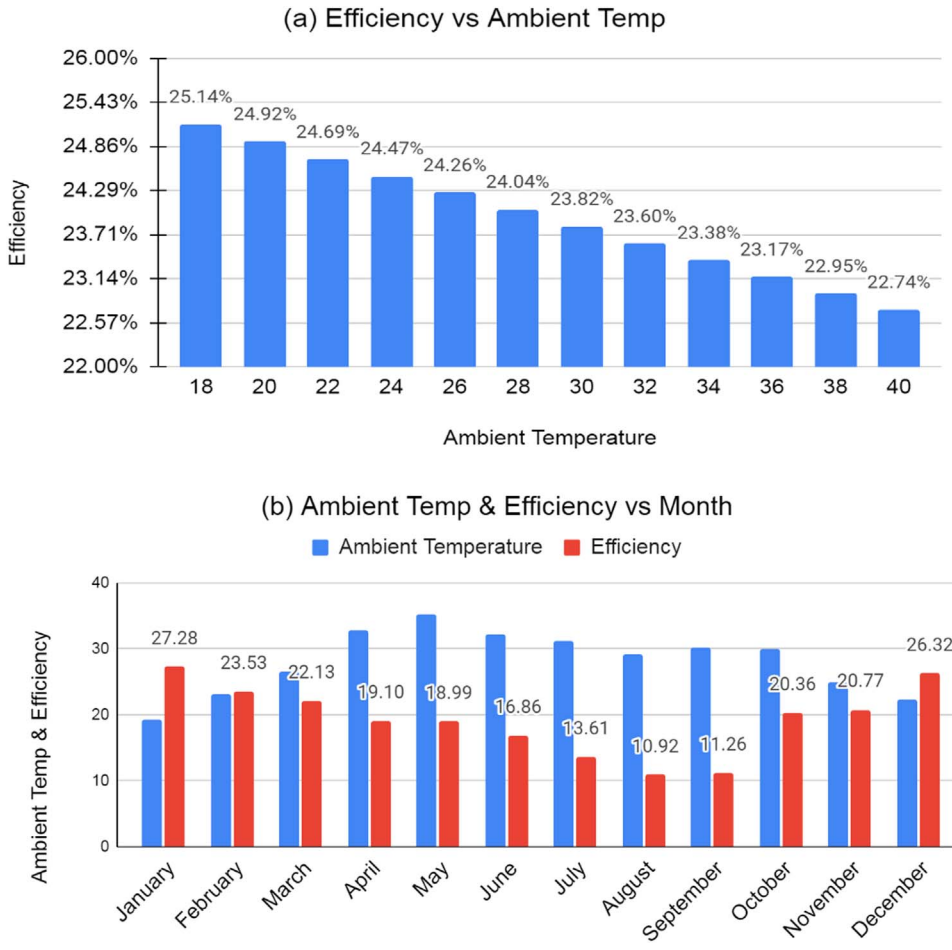


Figure 7. (a) Relationship between Efficiency and Ambient Temperature. (b) Comparing Efficiency and Ambient Temperature over a year.

power output and efficiency for the particular site Ahmedabad. To determine whether they are playing a major or minor role in the photovoltaic output, a few data points have been used to optimize the affecting parameters.

Comparing efficiency and bifacial gain

From figure 5(a) bifacial Gain and Efficiency are two factors that are critically important when observing the output of a Bifacial Module. A Bifacial Module's efficiency depends on the temperature of the cell and the ambient temperature. There is no correlation between efficiency and solar irradiance under cloudy skies or during the monsoon season, because other factors such as sky clarity index and humidity have a greater impact on efficiency.

Bifacial gain is dependent on irradiance. In monsoon season, there is a reduction in front irradiance, which causes a rise in Bifacial Gain. This optimal tilt angle for the location can be determined by plotting these two parameters, as shown in figure 5(b), which illustrates how to do so.

Effect of tilt angle on efficiency and bifacial gain

In determining a module's tilt angle, its efficiency is taken into account. Module efficiency increases as tilt angle increases (which is shown in the figure 6 with a red square), then becomes constant, then decreases. Optimal efficiency is achieved when the tilt angle is approximately 43.5 degrees, which is the recommended tilt angle for our site.

Because the relationship between tilt angle and bifacial gain in figure 6(b) is linear, which indicates that the gain increases as the tilt angle increases, it is impossible to determine the optimal tilt angle solely based on the relationship between the two. Instead, the optimal tilt angle must be determined by a combination of both the tilt angle and the bifacial gain.

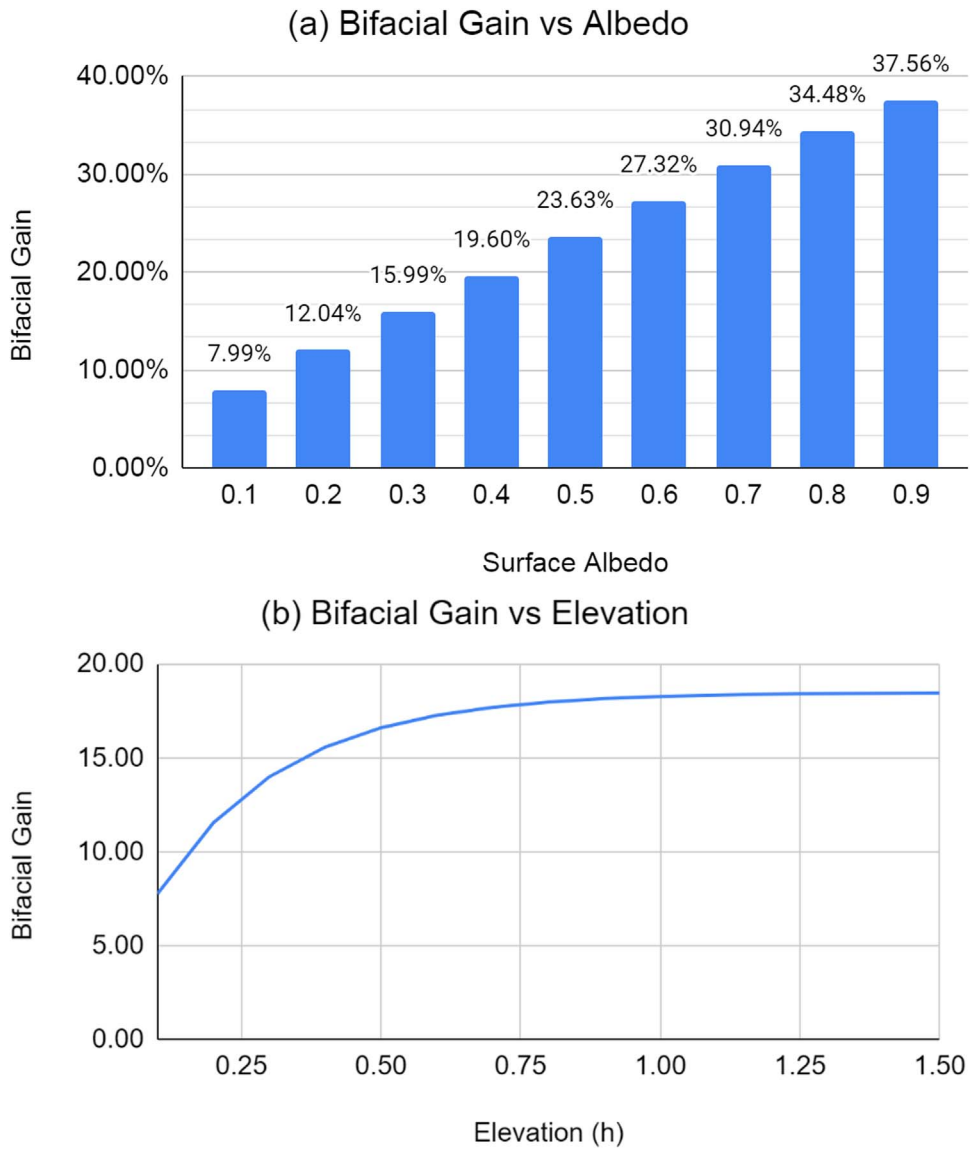


Figure 8. (a) Relationship between Bifacial Gain & Albedo. (b) Relationship between Bifacial gain & Elevation.

Effect of ambient temperature on efficiency

It is evident from figure 7(a) that Efficiency and Ambient Temperature are inversely proportional. In this case, higher ambient temperatures produce a larger amount of current, resulting in a lower voltage, which decreases efficiency as a result. When the ambient temperature is lower, bifacial solar panels perform well than when the ambient temperature is higher.

Furthermore, it is also apparent from figure 7(b) that module efficiency is higher in the winter when ambient temperatures are lower than during the summer and monsoon.

Effect of albedo and elevation on bifacial gain

As defined in the methodology, the albedo plays an essential role in determining the bifacial photovoltaic output power and efficiency since it represents reflected irradiance. Figure 8(a) shows the relationship between bifacial gain and albedo. From figure 8(a), an increase in Albedo can have a positive impact on Bifacial Gain. A greater Albedo can lead to a greater Bifacial Gain, since Albedo and Bifacial Gain are linearly related. To come to this conclusion, the tilt angle has been held constant, and the Bifacial Gain has been calculated with different values of albedo. For a better albedo, it is advised that one use products (white roofs, white paint, and other light colored materials) that reflect more Sunlight. Additionally, this will reduce the surrounding temperature so that a greater amount of efficiency can be obtained.

From figure 8(b) the relationship between bifacial gain and elevation is linear. The maximum elevation, however, should be around 1 meter. As elevation increases, diffuse and reflected irradiance decreases, making it

impossible to get more solar energy from the rear. It is taken that 0.5 m is the elevation here, but with increasing elevation (up to 1 m) the bifacial gain will also increase.

The analysis is performed for both front and rear irradiation data for the bifacial module, taking into account the tilt angle (43.5°), the albedo of concrete (0.3), the elevation (0.5m) and the other electrical characteristics outlined in the methodology. The calculations included here demonstrate some of the seasonal variations,

The winter season has been observed to have a greater amount of solar irradiance than the other two seasons due to the Sun being closer to Earth's northern hemisphere, so the bifacial module is more effective in this period. During the monsoon season, Bifacial Gain is greater than it is during the other two seasons. A lower direct (front) radiance is caused by clouds during the monsoon season, which results in a lower difference between the front and rear irradiances, thus increasing the ratio of back irradiance to front irradiance. During the monsoon season, however, there is less solar radiation, causing the temperature, power and efficiency of the cells to decrease.

In this way, by taking into account both the atmospheric and weather conditions and using the observations and calculations made at the site, it is possible to design a bifacial photovoltaic or solar plant that fully utilizes the rear side output.

Conclusion

The feasibility of bifacial solar panels in Ahmedabad is examined using a comprehensive framework. In this study, a variety of existing methods for calculating the efficiency, temperature, and bifacial gain of a PV bifacial module were put to the test and analyzed depending on the amount of solar irradiation, the ambient temperature, the wind speed, and a number of other variables. Using the most common approaches, the wind cooling effect plays a crucial role for a better estimation of PV bi-facial module outputs.

This study concludes that:

1. Solar cell temperatures affect solar cell efficiency. It is less efficient during the monsoon season and cloudy sky, i.e. from June to September, because of other factors, such as solar radiation, sky clearness index, and humidity. As a result, August had the lowest efficiency of 10.92%, while January had the highest efficiency of 27.28%.
2. The bifacial gain varies inversely with the module efficiency, peaking in July at 22.4%. The effect of wind on PV bifacial modules is also significant.
3. Optimizing the tilt angle of a bifacial module will increase its efficiency. Higher ambient temperatures result in higher current and lower voltage. As a result, energy efficiency decreases. At standard temperatures (25 °C), 24% of the efficiency can be achieved.
4. Based on the calculations, elevation and bifacial gain are linearly related. The maximum elevation is, however, 1 meter. Continuing to raise the elevation will eventually diminish the bifacial gain as the reflected and diffuse irradiance will become less intense on the rear side of the bifacial module.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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References

[1] Photovoltaics *SEIA*. (https://seia.org/initiatives/photovoltaics) (accessed May 04, 2021)
[2] Gambone S What Are Bifacial Solar Panels (https://paradisesolarenergy.com/blog/what-are-bifacial-solar-panels) (accessed May 07, 2021)
[3] Garcia J L, Pavanello D and Sample T 2018 Analysis of temperature coefficients of bifacial crystalline silicon PV modules *IEEE J. Photovolt.* **8** 960–8
[4] Sun X, Khan M R, Deline C and Alam M A 2018 Optimization and performance of bifacial solar modules: a global perspective *Appl. Energy* **212** 1601–10

[5] Pelaez S A, Deline C A, Greenberg P, Stein J and Kostuk R 2018 model and validation of single-axis tracking with bifacial photovoltaics: preprint *National Renewable Energy Lab. (NREL)* (United States: Golden, CO) NREL/CP-5K00-72039. Accessed: May 09, 2021. [Online]. Available: (https://osti.gov/biblio/1478728)
[6] Bifacial Photovoltaic Modules and Systems: Experience and Results from International Research and Pilot Applications; Report IEA-PVPS T13-14:2021 April 2021; ISBN 978-3-907281-03-1 (https://iea-pvps.org/wp-content/uploads/2021/04/IEA-PVPS-T13-14_2021-Bifacial-Photovoltaic-Modules-and-Systems-report.pdf)
[7] Stein J and Stein J 2017 *Field Performance of Bifacial PV Modules and Systems* United States (https://osti.gov/servlets/purl/1457936)
[8] Comparison of Bifacial Solar Irradiance Model Predictions With Field Validation | IEEE Journals & Magazine | IEEE Xplore (accessed Apr. 28, 2021) (https://ieeexplore.ieee.org/document/8534404)
[9] Gu W, Ma T, Ahmed S, Zhang Y and Peng J 2020 A comprehensive review and outlook of bifacial photovoltaic (bPV) technology *Energy Convers. Manag.* **223** 113283
[10] Ozkalay E, Lopez-Garcia J, Pinero-Prieto L, Gracia-Amillo A and Kenny R P 2019 Evaluation of the non-uniformity of rear-side irradiance in outdoor mounted bifacial silicon PV modules *AIP Conf. Proc.* **2147** 020011
[11] Bifacial Solar Panel/Bifacial Solar Module Market– Forecast (2020-2025); by IndustryARC (https://industryarc.com/Report/19375/bifacial-solar-panel-bifacial-solar-module-market.html)
[12] Kopecek R and Libal J 2021 Bifacial photovoltaics 2021: status, opportunities and challenges *Energies* **14** 2076
[13] (https://solarreviews.com/blog/bifacial-solar-panels)
[14] SHARK Bi-Facial Solar Panel, 440–530 Watt, 144 Cells, 9 Bus Bar (pack of 2) *LOOM SOLAR* (https://loomsolar.com/products/shark-bifacial-front-back-power-generation-solar-panel) (accessed May 08, 2021)
[15] I-V characterization of solar cells and panels using a source-measure unit *Eval. Eng.* 2017 (https://evaluationengineering.com/instrumentation/components/article/13015152/iv-characterization-of-solar-cells-and-panels-using-a-sourcemeasure-unit) (accessed May 07, 2021)
[16] Effect of Temperature | PVEducation (https://pveducation.org/pvcdrom/solar-cell-operation/effect-of-temperature) (accessed May 09, 2021)
[17] Mekhilef S, Saidur R and Kamalisarvestani M 2012 Effect of dust, humidity and air velocity on efficiency of photovoltaic cells *Renew. Sustain. Energy Rev.* **16** 2920–5
[18] Bifacial_design_guide_Full_ver.pdf Accessed: May 08, 2021. [Online]. Available: (https://lg.com/global/business/download/resources/solar/Bifacial_design_guide_Full_ver.pdf)
[19] Solar panel orientation | alternative energy tutorials (https://alternative-energy-tutorials.com/solar-power/solar-panel-orientation.html) (accessed May 07, 2021)
[20] Kankiewicz A 2016 Quantifying the variability of solar energy forecasts *SolarAnywhere.* (accessed May 09, 2021) (https://solaranywhere.com/2016/quantifying-variability-in-solar-energy-forecast)
[21] Downloads (https://adanisolar.com/Downloads#2) (accessed May 08, 2021)
[22] Orgill J F and Hollands K G T 1977 Correlation equation for hourly diffuse radiation on a horizontal surface *Sol. Energy* **19** 357–9
[23] Srivastava R C and Pandey H 2013 Estimating angstrom-prescott coefficients for India and developing a correlation between sunshine hours and global solar radiation for India ' *ISRN Renew. Energy* **2013** 1–7
[24] Tiwari G N, Tiwari A and Shyam 2016 *Handbook of Solar Energy: Theory, Analysis and Applications.* (Singapore: Springer Singapore)
[25] Klein S A 1977 Calculation of monthly average insolation on tilted surfaces *Sol. Energy* **19** 325–9
[26] Liu B Y H and Jordan R C 1963 The long-term average performance of flat-plate solar-energy collectors. With design data for the U.S., its outlying possessions and Canada *Energy Sol.* **7** 53–74
[27] Perry M Bifacial Plane of Array (BPOA), solarenergy's newest irradiance expression (https://www.campbellsci.in/blog/albedo-resource-assessment)
[28] Deline C, Peláez S A, Marion B, Sekulic B, Woodhouse M and Stein J 2019 *Bifacial PV System Performance: Separating Fact from Fiction* United States (https://osti.gov/servlets/purl/1532646)
[29] Durusoy B, Ozden T and Akinoglu B G 2020 Solar irradiation on the rear surface of bifacial solar modules: a modeling approach *Sci Rep.* **10** 13300
[30] Clifford H, Daniel R, Chris D and Toor C 2017 *A Detailed Performance Model for Bifacial PV Modules* United States (https://www.osti.gov/servlets/purl/1478165)
[31] Ayaz R, Nakir I and Tanrioven M 2014 An improved matlab-simulink model of PV module considering ambient conditions *Int. J. Photoenergy* **2014** e315893