Received: 12 April 2023 | Revised: 3 July 2023 | Accepted: 4 July 2023 | Published online: 7 July 2023

RESEARCH ARTICLE

Archives of Advanced Engineering Science
2025, Vol. 3(1) 11–21
DOI: 10.47852/bonviewAAES3202907

BON VIEW PUBLISHING

A Simulation Model Based on Experimental Data to Determine the Optimal Tilt Angle for a Fixed Photovoltaic Panel

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Abstract: The angle at which a photovoltaic (PV) panel is tilted has a significant impact on its performance, as it affects the amount of solar energy the panel can capture. This paper explores a new mathematical model, as well as simulation and experimental results, to determine the optimal tilt angle for PV panels. The optimal angle is determined by searching for the values that yielded the highest total solar radiation on the PV panel surface for a specific period, and this study introduces a new method to find the yearly optimal tilt angle for a fixed PV panel. The proposed model uses experimental data to simulate the performance of a fixed PV panel at different tilt angles and determine the angle that harvests the highest energy production. The results of the simulation model can be used to guide the installation and positioning of PV panels, allowing for more efficient energy production. Overall, the simulation model provides a valuable tool for optimizing the performance of fixed PV panels and increasing the use of renewable energy sources. The experimental site is located at Famagusta, Cyprus, and the ideal tilt angle for maximum solar radiation was found to be 27°, with a total solar radiation of approximately 2016.99 kWh/m^2. The simulation results were then compared to those of four different methods, and it was discovered that solar panels could be installed in that region at angles ranging from 21° to 32° in order to capture the maximum energy from solar radiation for a PV panel.

Keywords: photovoltaic, tilt angle optimization, simulation, experimental data, solar irradiance, renewable energy source

1. Introduction

Environmental affairs, as well as the increasing population, rising living standards, and rapidly growing industry division, have led to strong motives for research and investment funds in renewable resources. The interest in renewable energy sources is increasing rapidly; therefore, the development of renewable resources will continue. As it has been claimed in “Renewables 2022 Global Status Report,” the generation capacity that is afforded by solar photovoltaics (PVs) is estimated to be equal to 942 GW in 2021 [1]. Cyprus, as an isolated island, is dependent on imported fuels. Due to its geographical location and limited access to oil and natural gas reserved capacity, harnessing alternative sources of energy such as wind and solar is the only reasonable solution. Contemplating the enormous solar resources in Cyprus, it is such a meaningful issue to obtain the maximum energy that a solar panel can be generated [2]. As the sun’s position is changing during the day, the PV system must be set perpendicularly to the solar radiation to obtain the maximum possible energy [3]. Altitude and azimuth angle vectors can be used to represent the sun’s position. The azimuth angle is the inclination of the solar radiation’s horizontal projection with respect to the horizontal plane [4]. The default line between a place on the surface of the Earth and the sun can be used to depict the altitude angle as the angle between the location’s horizontal plane and that point [5]. Despotovic and Nedic [6] investigated the optimum tilt angle of solar collectors for Belgrade at the yearly, biannual, seasonal, fortnightly, monthly, and daily level by defining nine scenarios to make a comparison of them. Mehleri et al. [7] presented a noble technique to attain an optimum tilt angle and azimuth angle to enhance the amount of solar radiation captured by the array and to diminish the tolerance of the produced power. Kacira et al. [8] deduced maximum energy by finding optimum tilt angles and orientations of PV in Sanliurfa, Turkey, followed by a comparison study between PV panels with two-axis solar tracking systems and fixed panels.

Yilmaz et al. [9] focused on comparing three distinct types of PV panels, including mono-crystalline, thin-film, and poly-crystalline silicon panels to identify the best panel type for Kahramanmaras, Turkey. Stanciu and Stanciu [10] carried out an analytical research on the optimum tilt angle for flat plate collectors based on ten different locations from 0°N to 80°N to calculate the amount of absorbed incident by flat plate collectors with one glass cover. As they found, the optimum tilt angle (β_{opt}) for both maximum absorbed and incident radiation is the same. Soulayman [11] disputed the proposed equation for β_{opt} in Tamoor et al. [12], though. He challenged that their method is not a practical equation, since not only it is discountable on φ> 66.5° but also it did not have any idea for negative obtained tilts and the days on which the sun does not rise. In contrast with this, Stanciu and Stanciu [13] claimed that for negative obtained tilt angles

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they considered zero values, exactly like what Soulayman and Sabbagh [14] investigated for latitudes less than 40°. Besides, they claimed that although for φ> 66.5° there are some days when the sun does not rise, its effects are negligible. Pourgharibshahi et al. [15] measured the value of the optimum tilt angle experimentally. Due to the significant impact of dust deposition on the reduction of PV module performance, there exists a disparity between the optimal tilt angle as determined through computational analysis and the optimal tilt angle as determined through experimentation. Especially, at lower β Kamanga et al. [16] investigated an experimental method using a pyranometer to find the optimum tilt angle in Zomba District, Malawi. As they investigated, the best time to make seasonal adjustments is when the sun crosses the equator, that is, the sun moves northward. All in all, β_{opt} was found to be 0° or 25° relying on the time of the year. As Nijegorodov et al. [17] claimed, the influence of temperature, pressure, and humidity on the optimum tilt angle is very low. Furthermore, they considered the optimum tilt angle equal to zero for cloudy days.

Moreover, as it is reported in Yakup and Malik [18], it does not seem to be feasible to change the tilt angle to its daily and even monthly optimum values during the year. As a result, it seems that finding the seasonal and yearly optimum tilt angle is a very significant issue. Saraf and Hamad [19] reported that changing the tilt angle eight times during a year can approximately generate useful energy instead of daily changing it. Lau et al. [20] explain the effects of tilt angles and orientations on PV systems under equatorial latitudes at three different places with different latitudes, and the results proved that increasing tilt angle can reduce PV electricity by about 55%. Moreover, as it is explained, PV systems were achievable over the standalone system under equatorial climates conditions just if the tilt angle were less than 60°. Lunde [21] indicated that the optimum tilt angle for the locations which have a latitude less or equal to 15° is equal to the latitude of that location; however for the locations with a latitude more than 15°, the optimum tilt angle is equal to the latitude of that location plus 10. Demain et al. [22] reported an experimental method to find global solar radiation on a tilted surface using both isotropic and anisotropic models mainly for the places where solar data are not easily reachable. It is confirmed that the tilt angle and the latitude affect solar radiation received by a PV panel.

Lave and Kleissl [23] determined the optimal azimuth and tilt angles for solar panels across the continental United States using the National Solar Radiation Database (NSRDB-SUNY), which has a grid resolution of 0.1° by 0.1°. Solar radiation at a fixed optimum tilt angle is enhanced with increasing latitude and by 10%–25% per year. Khahro et al. [24] evaluated the solar energy resources by installing diffuse solar radiation experimental models. The optimum tilt angle for monthly and yearly adjustment was defined for the southern region of Sindh, Pakistan. The monthly optimum tilt angle varies from 0° to 49°; however, the optimum tilt angle of the year was close to the latitude of the studied location which is 25°. Quinn and Lehman [25] expressed a definite and straightforward method to estimate the yearly optimum tilt angle for both fixed and dual-axis tracking systems. They used Typical Meteorological Year that is obtainable by National Renewable Energy Laboratory. Darhmaoui and Lahjouji [26] introduced another method that was used in measuring the ideal tilt angle for 35 countries in the Mediterranean region. They proposed a quadratic regression model to anticipate the annual optimum tilt angle regarding the location of the experimental site. The proposed method is suitable for the range of latitudes between 25°N and 46°N. Skeiker [27] investigated one of the most significant things to determine the correct tilt angle is to record the sun's solar radiation number of various locations, since it is necessary to maximize the quantity of extraterrestrial radiation. As it is shown in Jacobson and Jadhav [28], 1-axis horizontal tracking is suggested for optimal utility PV output; nevertheless, for the places with higher latitude, establishing a fixed optimal PV panel is sufficient. Therefore, the installation of a PV panel, whether it is installed as a fixed or as a single-axis tracker, is the most effective factor to determine the optimal output power.

Barbón et al. [29] investigated the optimal tilt angle of systems with no solar trackers and compare them with those of systems with solar trackers in 39 cities around the world regarding the energy production and the levelized cost of energy (LCOE) factor. When comparing fixed-tilt solar systems with daily updates to East-West oriented systems, the maximum energy loss is 3.76%. The difference in energy harvesting of systems with a fixed tile angle in daily adjustment updating and monthly adjustment updating is minimal, which could have significant budgetary implications for design and maintenance costs. Regarding the systems without any solar trackers, it is mentioned that they perform much worse than ones with monthly adjustment, resulting in typical losses of around 3.5% and up to 6.1%. However, the LCOE is much better, up to 20% better.

The research carried out by Tamoor et al. [12] aimed to optimize the design and performance of ground-mounted PV systems by evaluating different tilt angles and interrow spacing in Pakistan. The optimal angle and spacing were chosen to minimize costs and maximize energy production. The study found that a tilt angle of 15 degrees and a 4-foot interrow spacing were the most efficient, as they provided the highest total collector irradiance, performance ratio, and annual energy output. Ye et al. [30] developed a novel approach to optimize the energy output of solar farms based on data analysis. The approach focuses on power-based optimization and has been proven to yield different tilt angles compared to conventional irradiance-based optimization. The study also investigated the impact of different optimization horizons on the return on investment, showing that hourly optimization could lead to significant cost savings. Although the approach requires a higher initial investment in adjustable panels, it can generate 22.43% more power using the exact number of PV panels, and consequently, it increases the revenue of the system. Chinchilla et al. [31] proposed a polynomial model to determine the annual ideal tilt angle by maximizing the incident solar irradiance at any latitude per year. The regression-based model used all the data from two public databases encompassing 2603 sites around the world regarding all the calculated optimum tilt angles. The proposed model has been validated against other existing regression models and published optimum tilt angle calculations and measurements, showing consistent and good performance. Al-Shohani et al. [32] investigated the best angle at which to install PV modules and solar collectors in Baghdad, Iraq, to collect the maximum amount of solar radiation and generate the highest amount of energy. The study analyzes the mathematical model for the optimal tilt angle, which is an important factor in the design of solar energy systems. The simulation was validated with previously published results and demonstrated good agreement, with a deviation of 3.4 to 10.3%. The study concludes that the optimal yearly tilt angle for PV modules and solar collectors in Baghdad is 30.6°. Using predicted models to solve optimization challenges with the help of Artificial Intelligence, especially, machine learning regression methods are growing rapidly [33]. Some of these topics are including modeling of solar energy systems [34, 35], PV system design and control [36], electrical energy and power forecasting [37–42], solar radiation prediction [42–47], PV size, tilt, and azimuth estimation [46], mathematical models of optimum tilt angle of systems with solar collectors and PV panels [31], and solar generation forecasting [46, 48, 49].

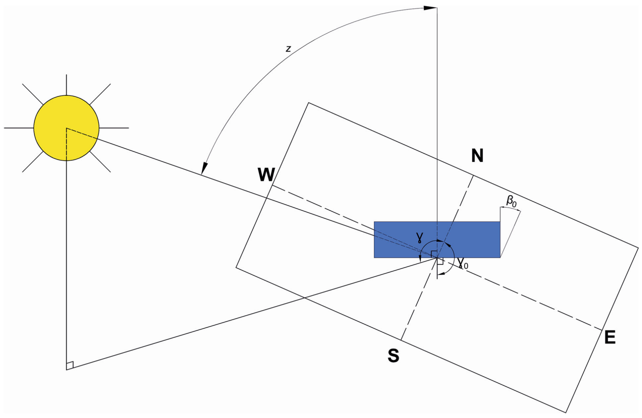
The primary objective of this research paper is to determine the optimal yearly tilt angle for a fixed PV solar panel in order to maximize its overall energy output. This is achieved through the use of a mathematical model based on experimental data. The model simulates the performance of a fixed PV panel at different tilt angles, allowing for the calculation of the angle that yields the highest energy production. Once the yearly optimum tilt angle has been determined, the study will compare its findings with previous research conducted by different researchers regarding the latitude of Cyprus. This comparison will provide insights into how the optimal tilt angle varies across different locations and time periods, which can inform the installation and positioning of fixed PV solar panels. In addition to calculating the yearly optimum tilt angle, the study will also employ the mathematical model to determine the optimal tilt angle for each month and day of the year separately. This will enable a more detailed understanding of how the optimal angle changes throughout the year due to variations in solar radiation and other environmental factors. Overall, the study aims to provide a comprehensive analysis of the optimal tilt angle for a fixed PV solar panel in Famagusta, Cyprus, and to develop a mathematical model that can be used to guide the installation and positioning of PV solar panels for maximum energy production. It is worth noting that the proposed model can be employed at different locations with different latitudes to find the optimum tilt angle of the PV panel at that specific location.

2. Methodology of Determining the Optimal Tilt Angle

To find the optimum tilt angle, it is crucial to consider the parameters with the highest impact on the energy production of the PV panel in the calculation. Also, it is important to use relevant and accurate data for this purpose. The data that is used in this study are obtained from one pyranometer and one pyrheliometer located on the roof of the Electric Vehicle Development Center at Eastern Mediterranean University for a period of one year, from the 1st of January 2022 to the 31st of December 2022. The integrated data logger that is used in this study is RAZON$^+$ which has two intelligent irradiance sensors: a shaded pyranometer for measuring DHI and a pyrheliometer for measuring DNI. The proposed method covers the most important factors that can directly impact the electricity production of a PV panel such as latitude, diffuse, and beam radiation. To calculate the total yearly solar radiation, it is required to have the hourly and daily solar radiation (I_T). Afterward, the optimum tilt angle can be found.

In this section, the optimization method is explained in detail. All the formulas to measure the daily beam, diffuse, and ground-reflected solar radiation are explained thoughtfully. The method introduces a reliable and efficient method with low complexity to implement. This method swipes all the tilt angles between 0° and 90° for a whole year, and the total daily solar radiation for each angle is measured. As a result, the yearly solar radiation can be measured as well. Accordingly, the tilt angle with respect to the maximum amount of total yearly solar radiation is the optimum tilt angle. Figure 1 represents the zenith angle (z), tilt angle (β_0), sun azimuth angle (γ), and fixed surface azimuth angle (γ_o) of the PV panel.

Figure 1
Solar and PV module characteristic angles: Zenith angle (z), tilt angle (β_0), sun azimuth angle (γ), and fixed surface azimuth angle (γ_o) are all in degrees



Regarding the diffuse solar radiation captured by a titled plane, Bahrami et al. [50] modified a model to extract that from the solar radiation on a horizontal surface with respect to plane tilt angle:

$$I_d = I_{dh}\left[\frac{1+\cos(\beta)}{2}\right], \tag{1}$$

where I_d is diffuse solar radiation hitting on a tilted surface (kWh/m^2), I_{dh} is diffuse solar radiation on a horizontal surface (kWh/m^2), and β is plane tilt angle (degree).

Additionally, beam solar radiation is that portion of the total incoming solar energy that is collected from the sun without being scattered by the atmosphere that is calculated as follows:

$$I_b = E_b \cos(\text{AOI}), \tag{2}$$

where I_b is direct solar radiation (kWh/m^2), E_b is beaming normal radiation (kWh/m^2), and AOI is the angle of the incident on the tilted angle.

In Equations (2) and (3), the angle between direct radiation and a line normal to the surface can be used to establish the values of angle of incident that can be calculated by the following equation (please note that both the sun's azimuth-tilt angle and the surface can affect it):

$$a = \sin(z)\cos(\gamma - \gamma_o)\sin(\beta_o) + \cos(z)\cos(\beta_o), \tag{3}$$

$$AOI = \begin{cases} \pi, & if \quad a < -1 \\ 0, & if \quad a > 1 \\ \cos^{-1}(a), & if \quad -1 \le a \le 1 \end{cases}, \tag{4}$$

where a is the hour angle, z is the zenith angle (degree), γ is the sun azimuth angle (degree), γ_o is the fixed surface azimuth angle (degree), and β_o is the fixed surface tilt angle (degree).

In addition, the following equation determines a ground-reflected component of the yearly incident solar energy for each angle:

$$I_r = \rho \, . \, I_g \, \frac{(1 - \cos\beta)}{2}, \tag{5}$$

where I_r is the ground reflection (kWh/m^2), ρ is albedo (ground reflectance), and I_g is global radiation on a horizontal surface (kWh/m^2).

The sum of the solar radiation from the beam, diffuse, and ground reflections that reaches the surface is known as the total solar radiation:

$$I_T = I_b + I_d + I_r, \tag{6}$$

where I_T is the total number of direct, diffuse, and ground-reflected solar radiation.

In this study, one pyranometer and one pyrheliometer are used to measure global solar radiation and diffuse solar radiation. To collect diffuse solar radiation, the pyranometer must be shaded. In the end, the direct solar radiation is calculated by the following equation:

$$I_g = I_b.\cos(\mathrm{z}) + \mathrm{I_d}. \tag{7}$$

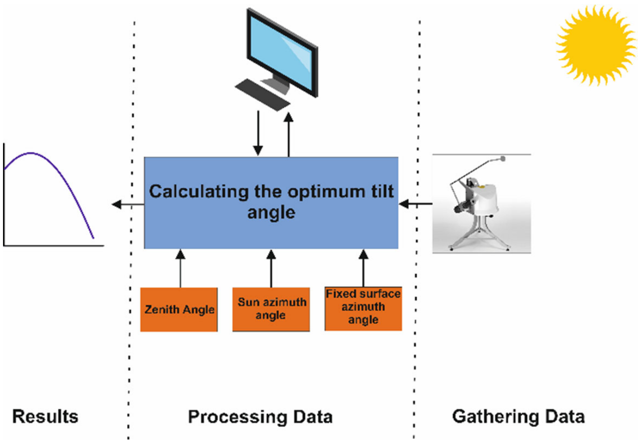
The proposed method in this paper to find the optimum tilt angle to maximize the cumulative energy output has two main steps. The first step is to collect relevant and accurate data on the location for 8760 h (one-year data). These data are then used to find azimuth, zenith angle, and the angle of the incident for each tilt angle between 0° and 90°. As a result, for all the angles in this range, the beam, diffuse, and ground-reflected solar radiation for every day in a year can be found. Figure 2 represents the workflow of the experiment starting with the RaZON$^+$ (Kipp & Zonen) device to collect the data, followed by a computer to process them.

In the second step which is shown in Figure 3, the beam, diffuse, and reflected solar radiation data are fed into the system to find the total solar radiation with respect to different tilt angles between 0° and 90°. As a result, the total solar radiation IT is calculated for each tilt angle by using Equation (5). The final information is analyzed to find out the maximum value of solar radiation with respect to the different tilt angles. Consequently, the optimum tilt angle is the angle that achieves the maximum value of solar radiation.

As discussed in this section, our research study presents a method to determine the optimal tilt angle for fixed solar panels to collect maximum solar radiation based on empirical data of a specific location. The study uses data collected from one pyranometer and one pyrheliometer for a during of one year. Accurate and relevant data are crucial for this method to be effective. The collected data from the data acquisition devices include beaming normal radiation and diffusing solar radiation on a horizontal plane with associated Zenith angle and Azimuth angle.

Figure 4 represents the flowchart diagram of the experiment and simulation using the mathematical model. The figure explains the workflow in detail, and it shows that the raw data from the sensors and receivers must be processed to provide meaningful information. According to Equations (1)–(7), the captured data from the acquisition devices alongside the solar zenith angle are processed to produce beam, diffuse, and global irradiance. The mentioned process is repeated for all the tilt angles between 0° and 90° for a period of one year (8760 h). Afterward, the results are analyzed by the optimization algorithm and the optimum tilt angle can be found.

Figure 2
Experimental models were used in the study



3. Result and Discussion

In this section, the results obtained from our experiments are presented and a comprehensive discussion of the findings is

Figure 3
MATLAB/Simulink block diagram of the proposed mathematical model

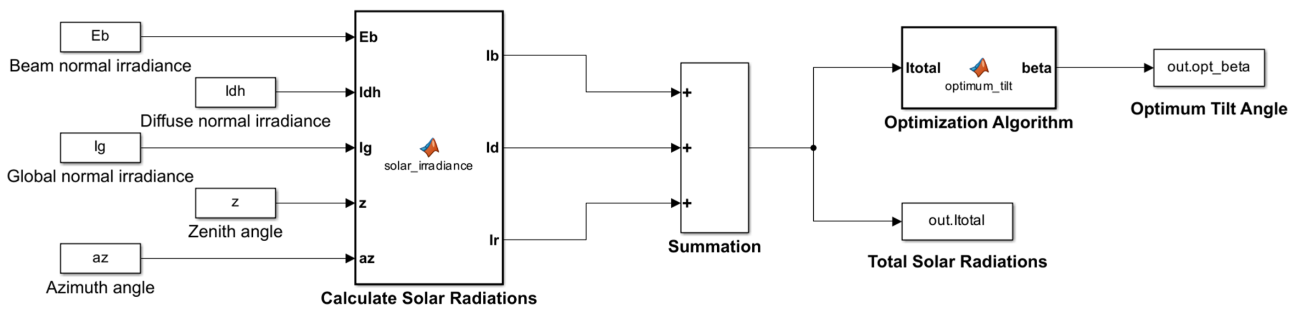
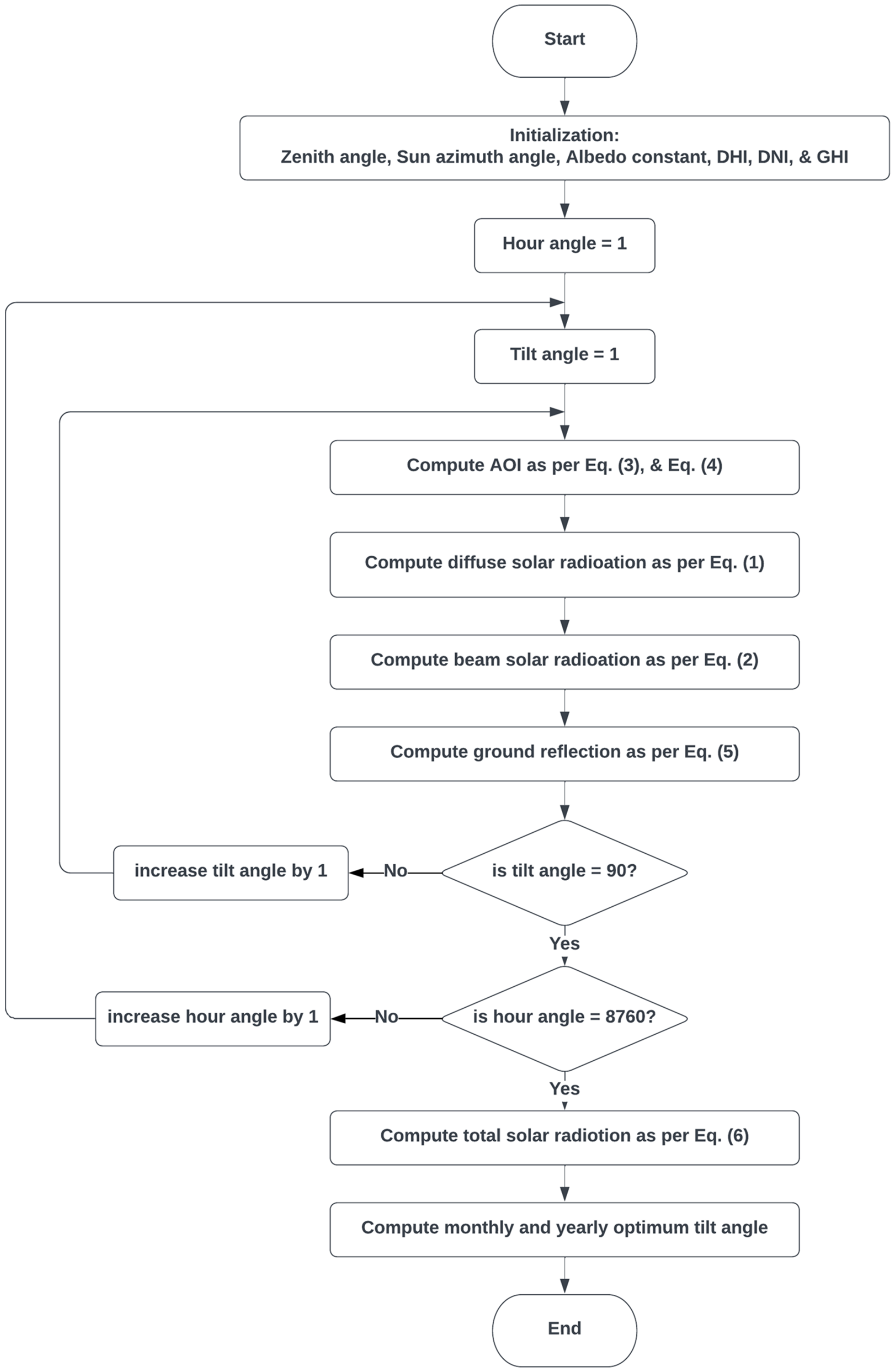


Figure 4
Flowchart diagram of the simulation model based on the data of the experiment



provided. Throughout a calendar year, the impression of the tilt angle on the maximum total solar radiation received by a surface facing south with the fixed surface azimuth angle equal to 160° was examined in this study. After analyzing the data, which is collected by two intelligent irradiance sensors: a shaded pyranometer for measuring DHI and a pyrheliometer for measuring DNI, according to the proposed method, for each angle between 1° and 90°, the hourly solar radiation was calculated. Afterward, the beam, diffuse, and ground-reflected for each angle for all 8760 h of one year are calculated. As a result, measuring the yearly solar radiation for all the angles between 1° and 90° is feasible.

Figure 5(a) illustrates the total beam solar radiation values with respect to the tilt angles ranging from 1° to 90°. The image shows that the maximum total beam solar radiation occurs at a tilt angle of 30 and is about 1421.33 kWh/m^2, while the minimum amount occurs at a tilt angle of 90 and is approximately 702.16 kWh/m^2. Figure 5(b) shows the total diffuse solar radiation values on a tilted surface with respect to the tilt angles ranging from 1 º to 90 º. As it is comprehended, the highest and lowest amount is approximately 610.17 kWh/m^2 at 1º and 305.11 kWh/m^2 at 90º, respectively. Figure 5(c) represents the total ground-reflected solar radiation on an inclined surface with respect to the tilt angles vary from1º to 90º. According to the figure, the ground-reflected level increased sharply between 1º and 90º, starting at 1º with 0 kWh/m^2 and finishing at 90º with 184.63 kW/m^2. Subsequently, the final values of the sun irradiance are calculated by adding the total beam, diffuse, and ground-reflected irradiance on a tilted surface. In addition, by considering the results of the summation for each hour at each angle, the yearly total solar radiation for every angle in the range of 1º to 90º is obtained.

Figure 5(d) shows the total solar radiation received by a slanted surface for tilt degrees ranging from 1º to 90º. Based on the figure below, the value of total solar radiation starts at approximately 1858.09 kWh/m^2 in 1º and it reaches to highest point at almost 2016.99 kWh/m^2 at around 27º, later it decreases and reaches to the lowest point at around 1191.9 kWh/m^2 in 90º. As it is observed, between 21º and 32º, the amounts of total solar radiation are relatively the same. The difference between the amount of total solar radiation at these two points is less than 2.7 kWh/m^2. It means that the PV panel can be installed at any angle between the range of 21º and 32º toward the south to obtain the maximum solar radiation in one year. Ultimately, considering all values of total solar radiation for different tilt angles, although at the range of 21º to 32º the solar radiation is approximately equal, at the angle of about 27º the most yearly solar radiation is captured. Consequently, the optimum tilt angle is 27º under Cyprus conditions. Figure 6 represents the different optimum tilt angles and total solar radiation of each month of the year. Instead of calculating the optimum angle of one year, it is calculated separately for each month.

Figure 7 represents part of the experiment that includes the data acquisition device (RaZON$^+$) that is installed on the roof of the EVDC laboratory. The acquisition data can be reached by a Web-based interface application and can be saved on a computer connected to it via an Ethernet cable (Cat.5 or Cat.6 cables). It is also possible to store the data on a flash drive connected to RAZON$^+$.

In Figure 8, the saved data of 24 h are presented. The data are captured by the data acquisition device on a cloudy day, and as it is

Figure 5
Beam (a), diffuse (b), ground-reflected (c), and total (d) solar radiation in one year period regarding the tilt angle of the PV panel

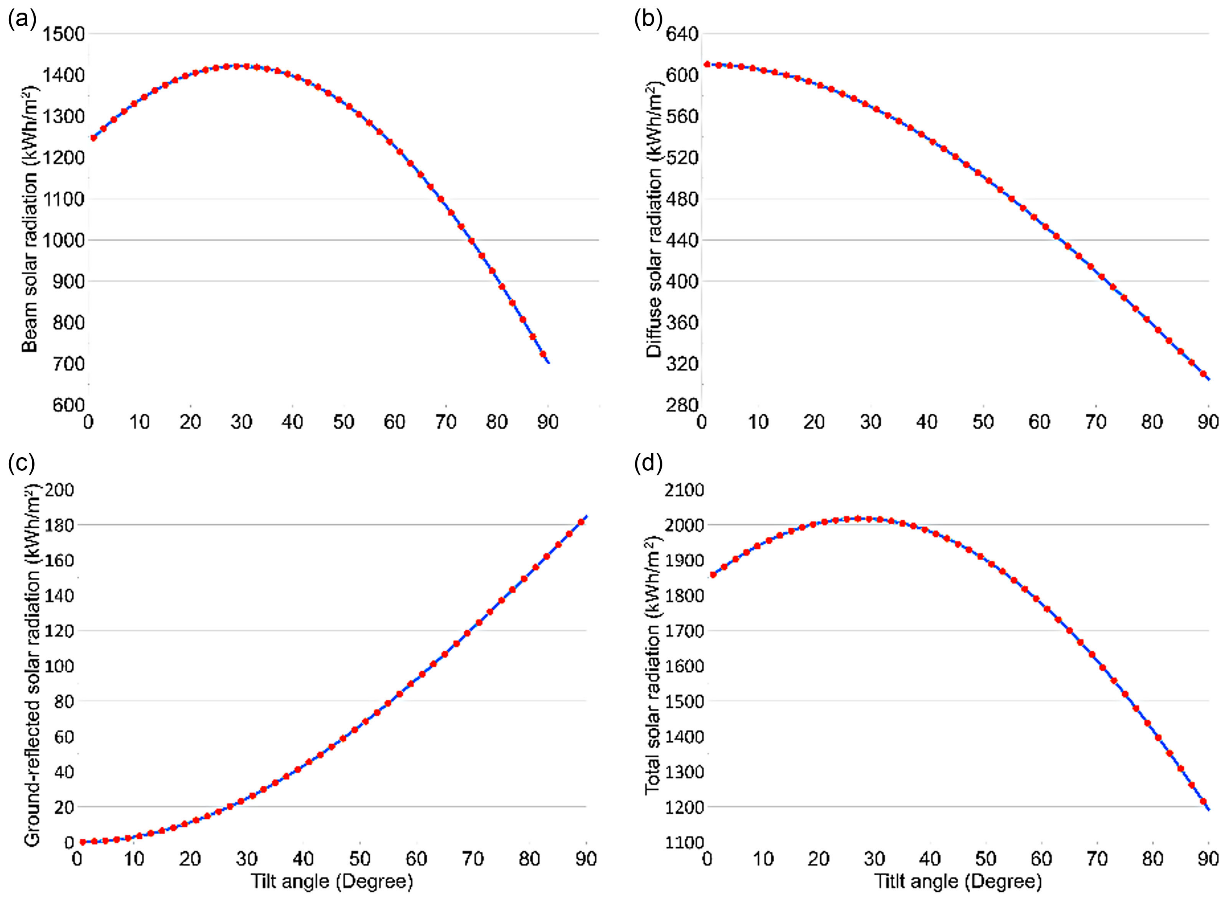
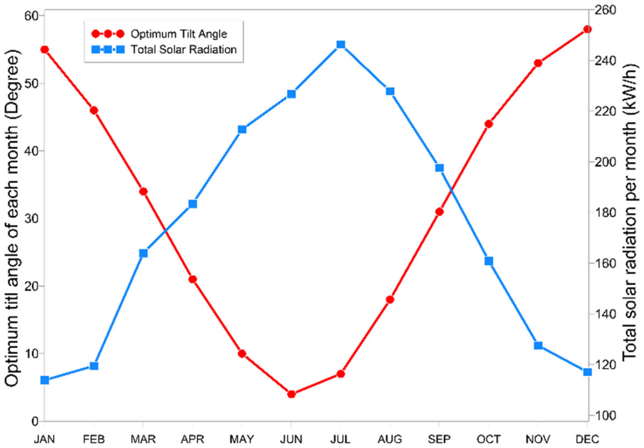


Figure 6
Optimum tilt angle and total solar radiation of each month of the year



showing, almost all irradiance is coming from the diffuse solar radiation.

Table 1 summarizes the performance of all previous studies on optimum tilt angles for the PV panel power harvesting for the latitudes between 30º and 36.59º. It also compares the previous results of the optimum angles with the proposed method based on the latitude of Cyprus which is 35º. Therefore, to obtain the maximum solar radiation and as a result, maximum energy during the year in the given region, the PV panel must be installed at the best optimum tilt angle.

The values of the optimal tilt angle for the various investigations, based on the table, vary between 15º and 45º. The average value of the 14 studies shows an optimum tilt angle of 31.45º. Furthermore, concentrating on the most relevant values and not including tilt angles 15º and 45º, the average value for 12 studies is 31.57º. According to the simulation results and by looking at Figure 5(d), PV panels mounted with tilt angles at the ranges between 21° and 32° can obtain the maximum solar radiation. The results obtained from our study confirm the

Figure 7
The integrated data logger, RAZON$^+$, has two intelligent irradiance sensors: a shaded pyranometer for measuring DHI and a pyrheliometer for measuring DNI

Figure 8
Sample data of a 24-hour experiment captured by RAZON$^+$ data acquisition device

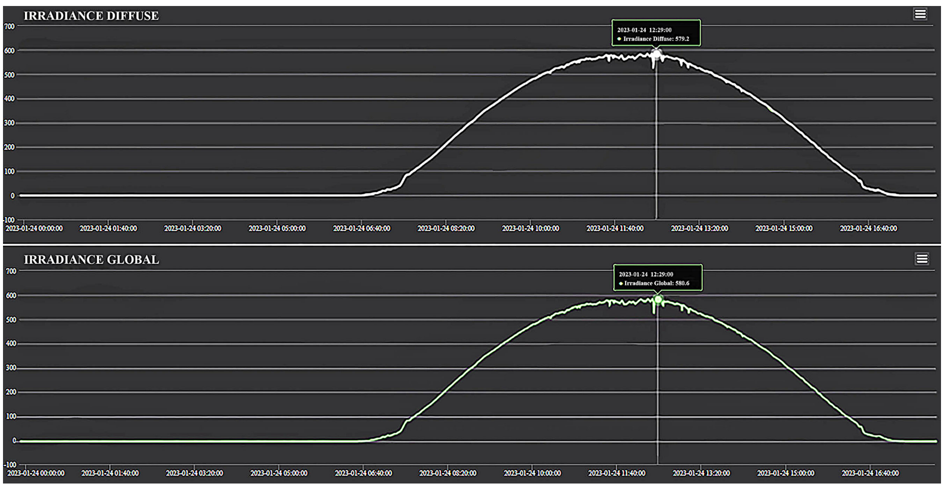


Table 1
Comparing the recommended approach with the other methods to get the ideal tilt angle

Method	Latitude (Degree)	Parameters or location	Optimum tilt angle
Despotovic and Nedic [6]	35	$\beta_{opt} = \varphi - \delta$ $I_T = 1353$ (kWh/m^2)	29.9
Siraki and Pillay [51]	35	Clearness index = 0.5	31.94
Bakirci [52]	36.59	$\beta_{opt} = 32.619 - 1.3629\ \delta$ $I_T = 1706$ (kWh/m^2)	31.2
Stanciu and Stanciu [10]	35	$\beta_{opt} = \varphi - \delta$ $\beta_{opt} = \begin{cases} 0 \ , & 0^\circ \le \varphi < 30^\circ \\ \varphi - 20 \ , & 30^\circ \le \varphi < 60^\circ \\ \varphi - 10 \ , & 60^\circ \le \varphi < 80^\circ \end{cases}$	15
Lunde [21]	35	$\beta_{opt} = \begin{cases} \varphi, & \varphi \le 15 \\ \varphi + 15 & \varphi > 10 \end{cases}$	45
Lave and Kleissl [23]	33.4	Phoenix	33.4
Quinn and Lehman [25]	35	$I_T = 1772$ (kWh/m^2) $\beta_{opt,yearly} = \cos(\gamma)\tan(\varphi)\left[\frac{1}{1 + \frac{((\tau\alpha)_d g(k_T) - (\tau\alpha)_r \rho_g}{2(1 - g(k_T))}}\right]$	26.45
Darhmaoui and Lahjouji [26]	35	$I_T = 2187$ (kWh/m^2) $\beta = 1.25351\,\varphi_i - 0.00728944\varphi_i^2$	34.1
Skeiker [27]	35	$I_T = 3577$ (kWh/m^2)	31.94
		$I_d = \frac{24}{\pi} I_o \left[1 + 0.034\cos\left(\frac{2\pi n}{365}\right)\right] . \left[\cos(\varphi - \beta)\cos(\delta)\sin(h_{ss}) \ + h_{ss}\sin(\varphi - \beta)\sin(\delta)\right]$	
		$\beta_{opt,d} = \varphi - \tan^{-1}\left[\frac{h_{ss}}{\sin(h_{ss})}\tan(\delta)\right]$	
		$\beta_{opt,m} = \varphi - \tan^{-1}\left[\frac{\sum_{n=n_1}^{n=n_2}\left[1 + 0.034\cos\left(\frac{2\pi n}{365}\right)\sin(\delta) h_{ss}\right]}{\sum_{n=n}^{n=n_2}\left[1 + 0.034\cos\left(\frac{2\pi n}{365}\right)\sin(\delta)\cos(\delta)\right]}\right]$	
Duffie et al. [53]	35	$\beta_{opt} = \varphi$	35
Talebizadeh et al. [54]	35	$\beta_{opt} = 7.203 + 0.6804\ \varphi$	31
Mraoui et al. [55]	32	$\beta_{opt} = 24.125 + 70.5\ K_T$	29.3
Le Roux [56]	30	$I_T = 1734$ (kWh/m^2)	29
Yasin et al. [57]	35	Nicosia	35.7
Simulation results	35	$I_T = 2016.99$ (kWh/m^2)	27

effectiveness of the proposed method in improving energy efficiency and promoting the integration of renewable energy sources.

4. Conclusion

This study aimed to determine the annual optimal tilt angle to maximize total energy production by using a mathematical model to calculate and estimate the total solar radiation based on empirical data. The study compared its findings with earlier work done by other scholars addressing the latitude of Cyprus after determining the yearly optimal tilt angle. The installation and positioning of fixed PV solar panels could be guided by the comparison's insights on how the ideal tilt angle changes in various settings and over time. Later, the mathematical model was modified to calculate the ideal tilt angle for each month and day of the year independently in addition to estimating the ideal tilt angle for the whole year. This made it possible to comprehend how the ideal angle varies throughout the year as a result of differences in solar radiation and other environmental conditions in more detail. The overall goal of the study was to produce a mathematical model that can be used to direct the installation and positioning of PV solar panels for optimum energy production, as well as to offer a thorough analysis of the ideal tilt angle for a fixed PV solar panel in Famagusta, Cyprus. The value of the optimum tilt angle was 27°, and the total maximum solar radiation is near 2016.99 kWh/m^2. It is important to mention that the proposed method in this study can be used as a general optimization technique to determine the optimal tilt angle for different locations and latitudes.

Symbols

β Tilt angle
β_0 Optimum tilt angle
γ Sun azimuth angle
γ_o Fixed surface azimuth angle
a Hour angle
z Zenith angle
ϕ Latitude
I_d Diffuse solar radiation
I_{dh} Diffuse solar radiation on a horizontal surface
E_b Beam normal solar radiation
I_b Direct solar radiation
I_T Total solar radiation
ρ Albedo coefficient

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Davut Solyali: Conceptualization, Methodology, Software, Validation, Investigation, Writing – original draft, Writing – review & editing, Supervision. **Amir Mollaei:** Methodology, Software, Validation, Writing – original draft.

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How to Cite: Solyali, D., & Mollaei, A. (2025). A Simulation Model Based on Experimental Data to Determine the Optimal Tilt Angle for a Fixed Photovoltaic Panel. *Archives of Advanced Engineering Science*, *3*(1), 11–21. https://doi.org/10.47852/bonviewAAES3202907