

# PVsyst Optimization Tool Introduction and Case Analysis on The Secondary Optimization of The Best Inclination Angle

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**Abstract:** For a fixed grid-connected photovoltaic (PV) power generation system, the selection of inclination angle should aim to maximize the annual irradiance received by the PV array's inclined surface, thereby maximizing power generation. However, if a secondary optimization of the inclination angle is performed, further improvements in power generation can be achieved, leading to enhanced overall project revenue. This paper introduces three methods for secondary optimization of the tilt angle by constructing a 3D shading model in PVsyst, which provides valuable guidance for PV project design.

**Keywords:** Grid-connected photovoltaic power generation system; Fixed type; optimal tilt angle; secondary optimization; PVsyst.

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## 1. The Importance of Optimizing Inclination

For fixed grid-connected photovoltaic power generation systems, the inclination angle should be optimized to maximize the annual radiation exposure on the inclined surface of the photovoltaic array [1]. However, this approach neglects the impact of shading between the front and rear rows of components. Consequently, when the total annual radiation on the solar-collecting surface reaches its peak, the annual power generation may not necessarily peak. Therefore, a secondary optimization of the inclination angle is necessary [2].

The significance of secondary inclination angle optimization lies in three aspects: Firstly, it ensures that there is no obstruction from front-row components between 9:00 and 15:00 on the winter solstice, while maintaining the array spacing constant. This minimizes shadow obstruction before 9:00 and after 15:00, thereby enhancing power generation. By reducing the inclination angle, we can decrease the radiation received by the array surface at noon. However, by increasing the duration of sunlight due to reduced obstruction, we can compensate for the reduced power generation during noon. Secondly, decreasing the inclination angle reduces the steel required for the support structure, particularly in projects with high wind pressure, enhancing the stability of the support. Lastly, optimizing the inclination angle can improve land utilization efficiency, reduce the area of leased land, and ultimately save overall investment [3][4].

## 2. PVsyst Optimization Tool Introduction

### 2.1. Overview

This tool helps to easily find the optimal values for some of the design parameters of a PV installation (especially shed-type installation for now).

It performs automatically a set of simulations, where one or more parameters are varied systematically according to a specified range.

The results of all simulations are stored, and can be viewed in a separate tab, which will plot several simulation variables as function of the varied parameters.

In contrast to the optimization tools of the 'Orientation' dialog, which perform approximations for their calculations, this tool will run a full simulation for each of the parameter settings, allowing an even more precise result.

So far, the optimization tool is only available for projects that use 'shed' PV fields in the 3D scene.

The Optimization Tool dialog contains two tabs, one to create new parametric scans, the other one to view the scans that have already been performed.

### 2.2. Create New Parametric Scan

To perform a new scan, you need to do the following Steps:

#### 2.2.1. Enter a Name for the Scan

Enter a name for the scan that will be performed. This name will appear in the list of executed scans, once the scan is finished.

#### 2.2.2. Select the Scan parameters

Use the combo-boxes on the left to select the parameters that should be used in the scan.

The available parameters depend on the type of project that is being used. The pitch parameter for example can be used only in projects where sheds are defined in the 3D near shadings.

The following parameters are available so far:

1. Tilt: This parameter is available for all projects with fixed tilt orientation or unlimited sheds.
2. Azimuth: This parameter is available for all projects with fixed tilt orientation or unlimited sheds.
3. Pitch: The pitch is the distance between two sheds (rows) of a PV installation. This parameter is available for projects where sheds are defined in the 3D near shading scene.
4. Ground Covering Ratio (GCR): In shed layouts, the GCR is defined as ratio of the width of the sheds and the pitch. This parameter is an alternative way to describe the Pitch.

For each parameter you have to define the start and end values (Min, Max) and the number of steps that should be performed. The sketches on the right side of the window

visualize the selected parameter ranges. The start and end values are drawn in gray, and the value used in the underlying variant is marked in blue.

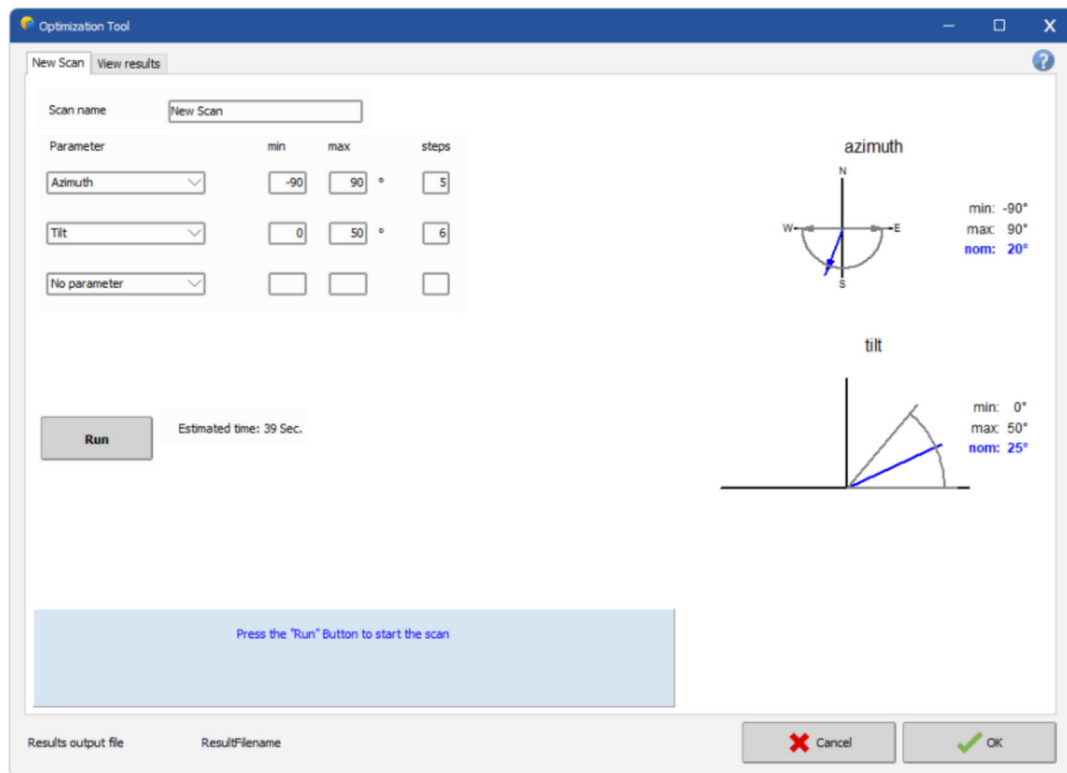


Figure 1. Create a New Scan

### 2.2.3. Check Time Estimate

When all the scan parameters have been defined, check the estimated time display on the bottom, to get an idea of how long the scan will take. This estimate is based on the last execution of the simulation. If the variant has not been simulated yet, the time estimate will not be available. Depending on the number of steps that were chosen for each parameter, the scan time can become very long. In this case, consider reducing the number of steps for the parameters. To save time, you can go in several iterations, by performing first a coarse scan in large steps, and then perform the subsequent scans in a more narrow range of the parameters with smaller steps.

### 2.2.4. Execute the Scan

When parameter ranges and numbers of steps have been defined, click on 'Run' to start the scan. On the right side of the parameter definitions a column with title 'Current' will appear, displaying the parameter combination that is currently being simulated. A double progress bar will show how much of the overall scan and of the current scan step has already been processed.

If during a scan, a combination of parameters is such, that a simulation is not possible (e.g. a pitch that is too short for a given tilt angle), this scan step will be skipped. In the results viewer, this step will be omitted in the one-dimensional plots and be grayed-out in two-dimensional plots.

When the scan starts, the label on the 'Run' button will change to 'Abort'. When clicking on it, a confirmation dialog will pop up, and if confirmed, the scan will be aborted. Any results that were calculated up to then, will be lost.

Once the scan is finished, the dialog will switch automatically to the 'View Existing Scan' tab and the results will be displayed.

## 2.3. View Existing Scan

The optimization viewer displays the results of the parametric scans performed with the 'Optimization tool'.

It helps in quickly identifying the optimal values of the parameters for a given simulation variable.

### 2.3.1. Scan Selection

The top left part in the tab gives an overview of the scans that have already been performed.

From the drop-down list on the left, a scan can be selected by its title. The parameter ranges that were used for the selected scan are displayed in five columns below the name.

The parametric scans are specific for each variant of the project, this is why the list will only display scans that have been performed for the current variant.

There is the possibility to remove the selected scan from the list by clicking on the 'Delete Scan' button. A message will pop up, asking to confirm the deletion of the scan.

The left part of the viewer allows to specify the parameters and plot options. The variable that is plotted can be chosen from a list on the top, next to the title of the plot. The plot itself is the square area, containing axes, the curve or color map and a legend in case of a two-dimensional plot.

### 2.3.2. Result Variable

During the simulation, several variables are computed for the final and intermediate results. The following variables are

stored in the optimization scans and can be selected from the variable list:

GlobInc: Global incident irradiance, also known as Plane of Array (PoA) irradiance in kWh/m<sup>2</sup>

GlobEff: Global effective irradiance

EArray: Effective energy at the array output

E\_Grid: Energy injected into the grid in kWh

By default the E\_Grid is selected for display.

### 2.3.3. Plot Type

The results can be displayed either in a one- or a two-dimensional plot. The 1D-version is a curve of the result variable as function of one of the parameters. The 2D-version is only available, if two or more parameters were scanned. It consists of a colored surface with one parameter on each axis and the variable value being color-coded. The color code ranges from dark blue for small values to dark red for high values.

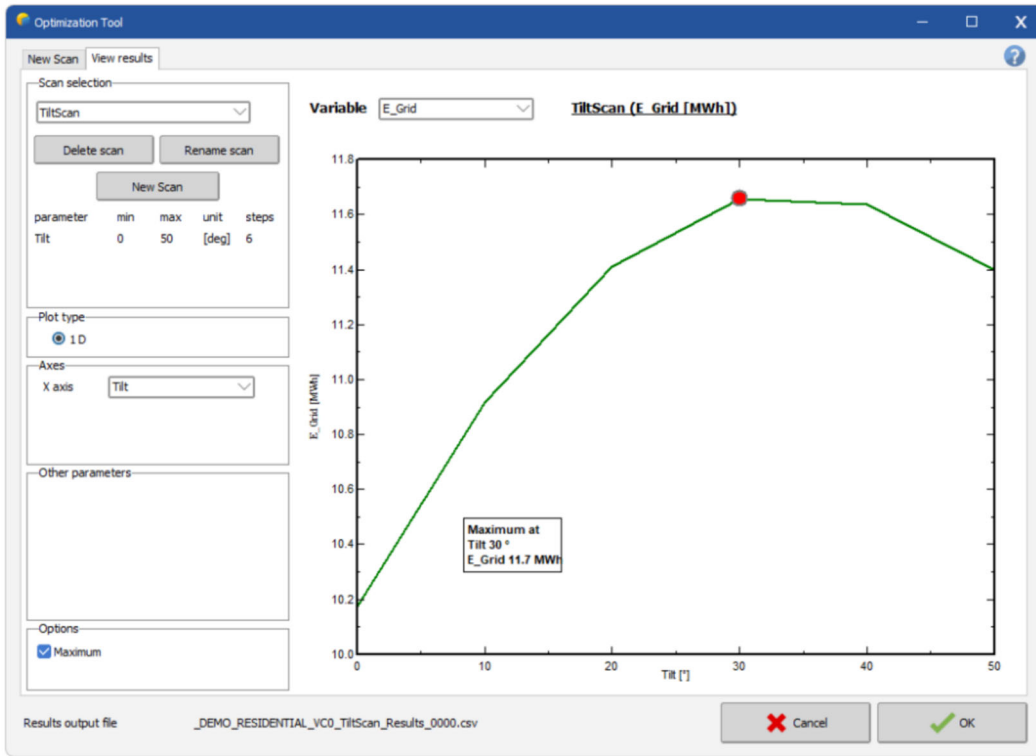


Figure 2. 1-Dimensional Plot

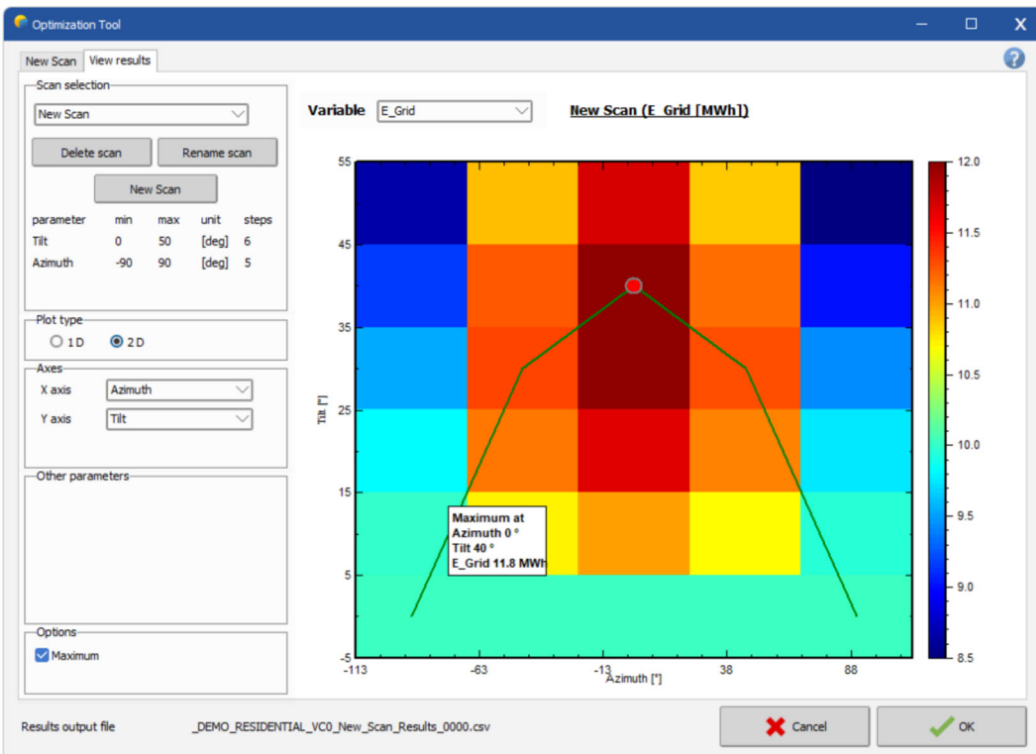


Figure 3. 2-Dimensional Plot

### 2.3.4. Axes

In this group the axes are associated to parameters that were varied in the scan. In a one-dimensional plot, only one parameter for the X-axis needs to be chosen, for two-dimensional plots, parameters have to be associated to both, the X- and the Y-axi.

### 2.3.5. Non-displayed parameters

If more than one parameter was varied within a scan, it can happen, that one or more parameters are not associated to any of the axes. These are the 'non-displayed parameters'. In this case, a field with a spin button and a slide bar will appear in this group for each non-displayed parameter. These controls allow to set a value for this parameters, and the plot will be updated accordingly.

### 2.3.6. Additional options

The additional options control some details in the plot region.

Maximum: If this option is checked, the maximum value in the plot will be marked with a red dot, and its values of the parameters and variable will be displayed in a text box

Full Range Scale: If this option is checked, the range of the scale for the variable will be chosen so that it covers all values from the scan. Changing the non-displayed parameters will have no effect on the displayed variable range. If on the other hand this option is unchecked, the range of the Y-axis for 1D

plots and the range of the color code for 2D-plots will adapt to best cover the values that are actually displayed. Changing the values of the non-displayed parameters will now change these ranges.

## 3. Case Analysis of Quadratic Optimization of Dip Angle

### 3.1. Project Overview

The photovoltaic power generation project is located in Yangliu Town, Xuancheng City, Anhui Province. It has a DC side capacity of 212.5 MWp and an AC side capacity of 170 MW, with a grid-connected voltage level of 220 kV. The photovoltaic modules use Topcon batteries with a power output of 585 Wp and dimensions of 2278 mm × 1134 mm × 30 mm. The photovoltaic array operates in a fixed inclination mode, utilizing a double-row vertical arrangement scheme with 2 vertical rows and 13 horizontal rows. The clearance between components is 20 mm. Three schemes were employed to optimize the design of the inclination angle.

### 3.2. Analysis of Optimal Inclination Angle Using Optimization Tools

Firstly, PVsyst was utilized to simulate the optimal inclination using NASA meteorological data, The simulation results are shown in Figure 4.

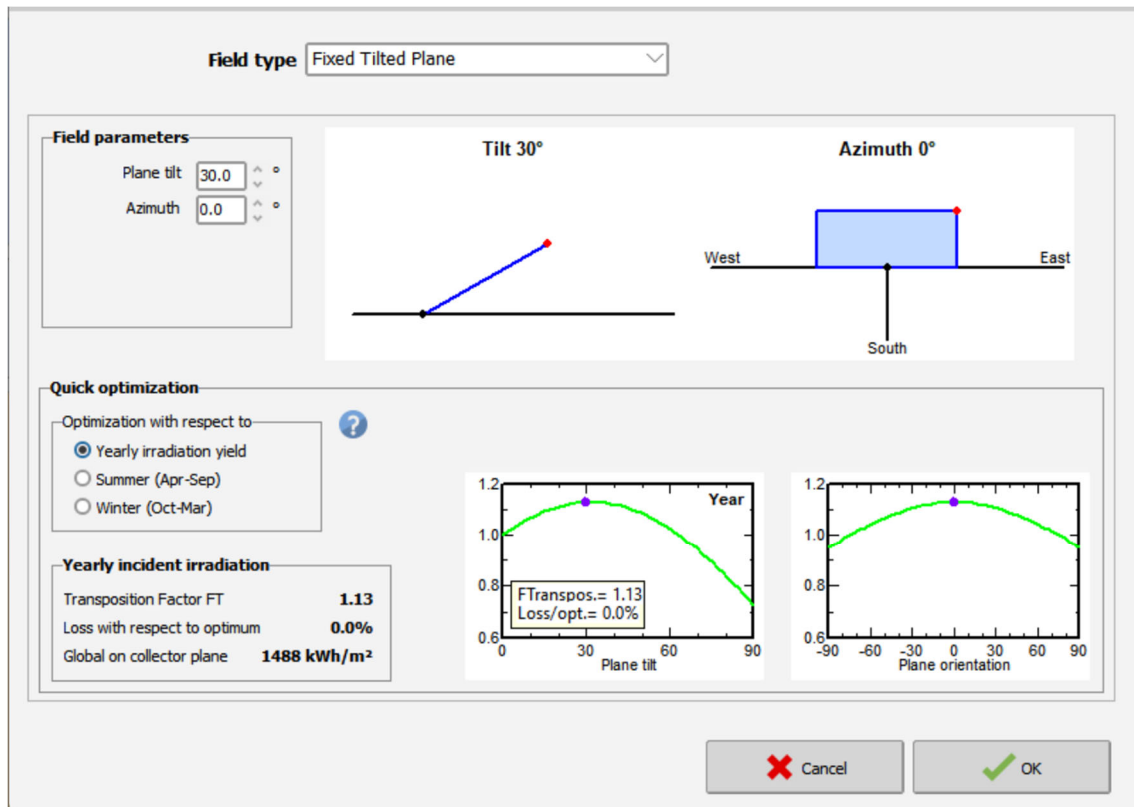


Figure 4. PVsyst software 30 degree inclination simulation results schematic diagram

(1) Through PV software simulation, it was determined that the optimal inclination angle for photovoltaic modules at the project site is 30°. According to the "GB 50797-2012 Design Code for Photovoltaic Power Stations," solar cell arrays should not be shaded during the period from 9:00 am to 3:00 pm on the winter solstice, requiring a minimum spacing of 8.3

m between installations. Based on this data, the modeled simulation power generation in PV is shown as item 1 in Table 1. The electricity connected to the grid is 258.11 GWh, with a land utilization rate of 55.1%.

(2) Using the optimization tool, the photovoltaic array spacing (8.3 meters) and azimuth (0 degrees) were kept

constant while only varying the inclination within the range of 0° to 50°. The simulation results are illustrated in Figure 5. When the inclination is 20°, the maximum power generation is 259.5 GWh, and the land utilization rate remains at 55.1%. This indicates that although the amount of radiation received by the lighting surface decreases slightly, the reduction in shading losses extends the power generation time, thereby improving overall power generation. Detailed simulation data can be found in item 2 of Table 1.

(3) According to the "GB 50797-2012 Design Code for Photovoltaic Power Stations," solar cell arrays should not be shaded during the period from 9:00 am to 3:00 pm on the winter solstice. When the inclination of the photovoltaic module is 20°, the minimum spacing between front and back installations is 7.3 m. Based on this data, the modeled and simulated power generation in PV is shown as item 3 in

Table 1. The electricity connected to the grid is 257.99 GWh, with a land utilization rate of 62.7%.

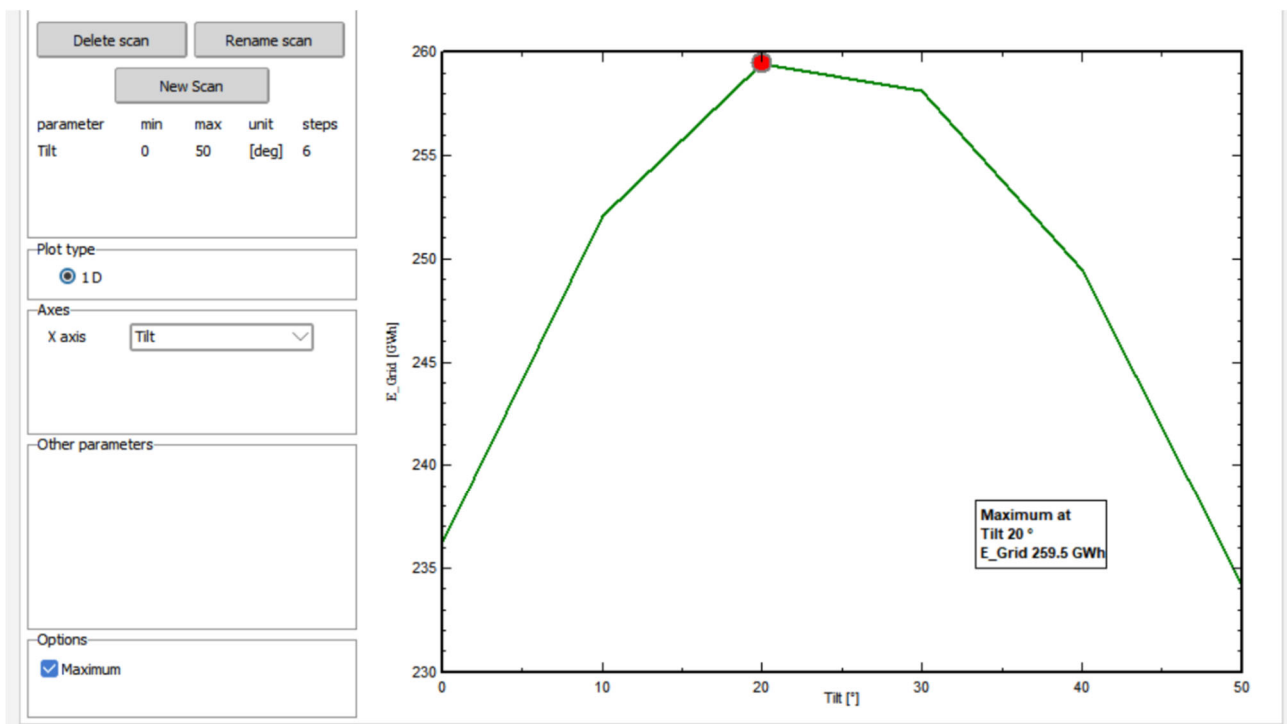
(4) Comparing the data in Table 1, when the inclination angle of the component is 20° and the distance between front and rear components is 7.3 m, compared to an inclination angle of 30° and a distance of 8.3 m, the advantages are as follows:

- ① Lower wind load, enhancing safety;
- ② Although power generation decreased by only 0.05%, the land utilization rate increased by 13.79%. Consequently, the project lease area decreased, significantly impacting the overall project yield due to reduced land rent.

Therefore, 20° is recommended as the optimal inclination angle.

**Table 1.** Power generation simulation results of PVsyst software

Parameter variable					Result variable					
No.	Tilt (degree)	Azimuth Angle (degree)	Pitch (m)	GlobInc (kWh/m <sup>2</sup> )	Near Shadings: irradiance loss(%)	IAM factor on global(%)	Soiling loss factor(%)	GlobEff (kWh/m <sup>2</sup> )	E_Grid(GWh)	GCR(%)
1	30	0	8.3	1476	-3.56	-1.91	-3.00	1354	258.11	55.1
2	20	0	8.3	1456	-1.64	-2.08	-3.00	1361	259.46	55.1
3	20	0	7.3	1456	-2.21	-2.05	-3.00	1353	257.99	62.7



**Figure 5.** Quadratic Optimization with Invariant Array Spacing and Azimuth

### 3.3. Analysis of Optimal Inclination Angle through Traversal Angle

In PVsyst software, a three-dimensional scene model was established (either directly modeled in PVsyst or imported from Candela3D into PVsyst), setting the inclination angle and minimum array spacing according to design specifications. The inclination range varied from 0° to 40°, simulating grid-connected electricity and land utilization rates, as shown in Figure 6. Considering the local on-grid electricity price of 0.3693 yuan/kWh and land lease fee of

720 yuan/(mu·year) (including compensation for green seedlings), the total income for different angles is shown in Figure 7 and Table 2.

The following conclusions can be drawn from the above chart:

- (1) As seen in Figure 6, although the power generation at a 20° inclination is lower than at 30°, the total income is higher due to improved land utilization, reaching 92.396 million yuan.

(2) If only net power generation income is considered without accounting for land lease costs, it can be seen from Figure 6 that power generation reaches its maximum at an inclination of 25°, achieving 259 GWh.

(3) Considering both power generation income and land lease costs, it can be seen from Figure 7 that total income reaches its maximum at an inclination angle of 24°, achieving 92.571 million yuan. At this point, 24° is the optimal inclination angle.

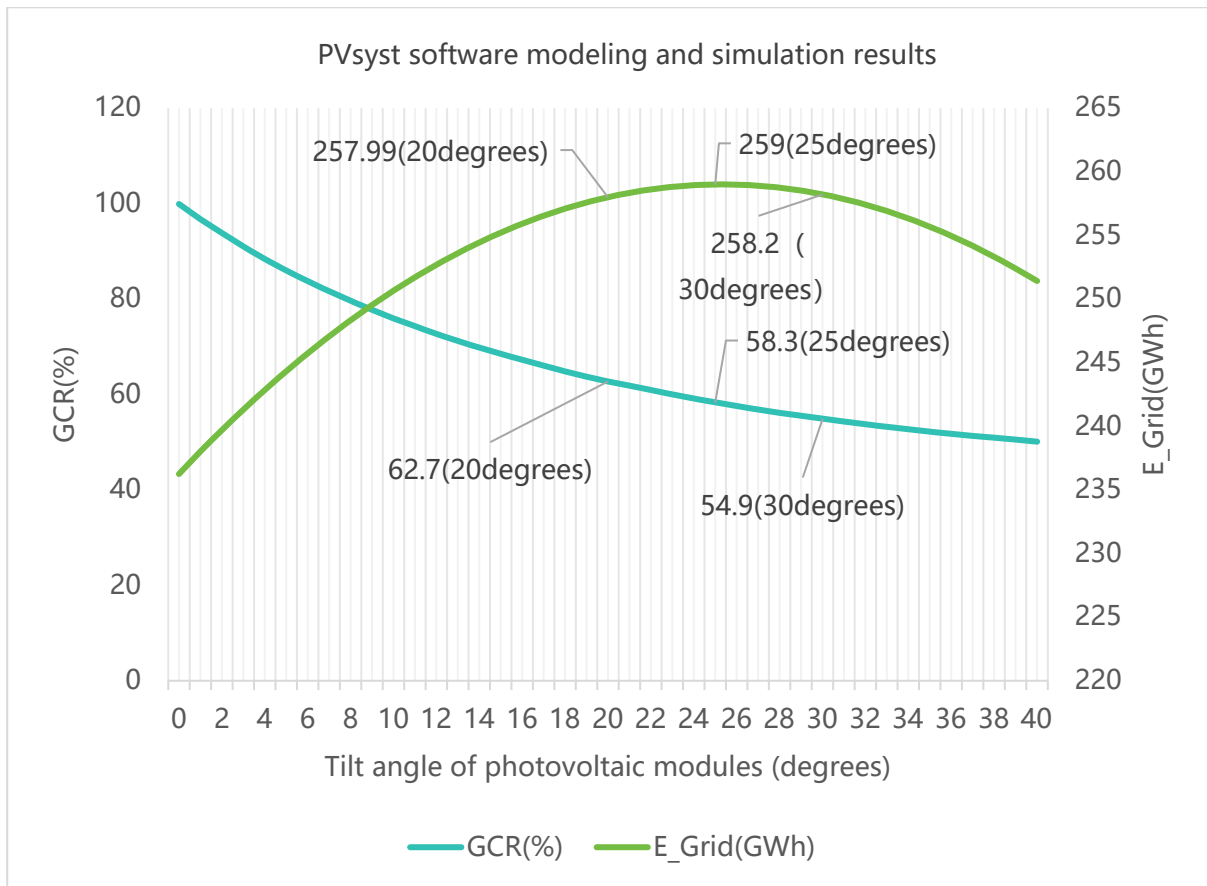


Figure 6. PVsyst software simulates grid connected electricity and land use efficiency

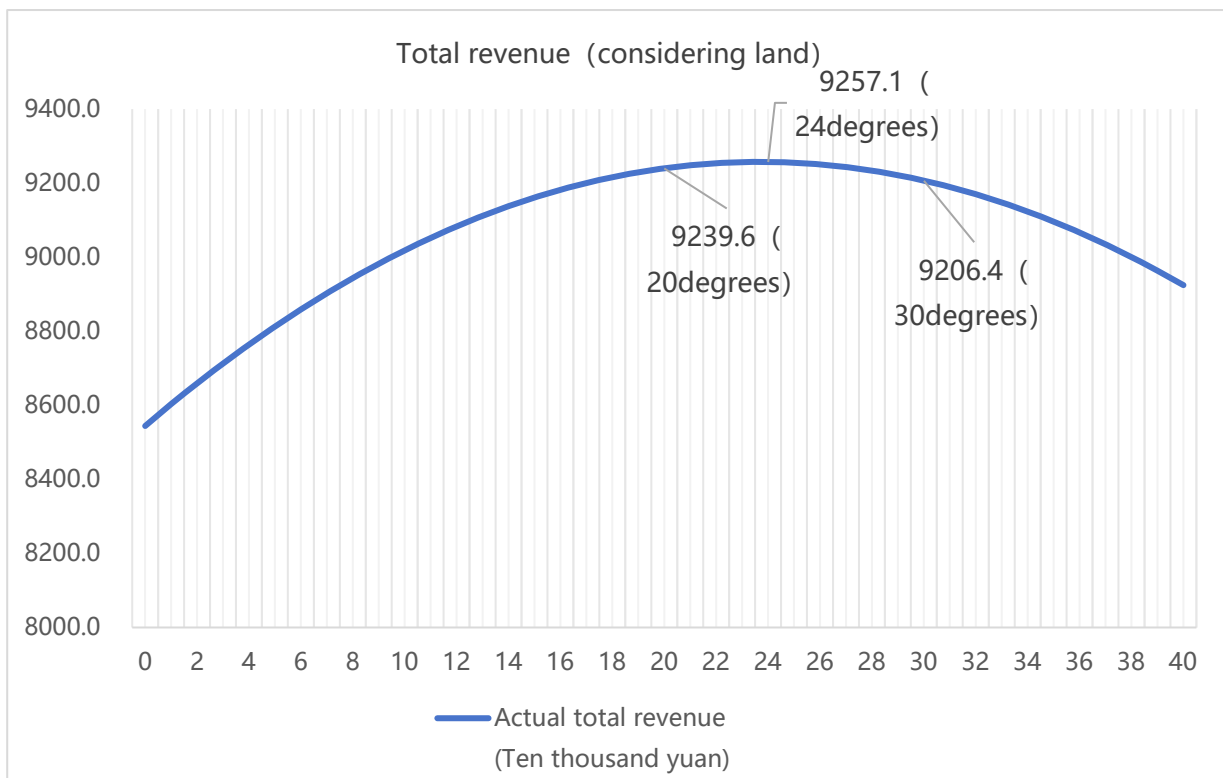


Figure 7. Total revenue at different inclinations after considering land costs

**Table 2.** Total income statement corresponding to different inclinations

Tilt (degree)	Azimuth Angle (degree)	Pitch (m)	E_Grid(GWh)	GCR(%)	Land area occupied (mu)	Electricity generation revenue (Ten thousand yuan)	land cost (Ten thousand yuan)	total revenue (Ten thousand yuan)
20	0	7.29	257.99	62.7	4000	9527.6	288.0	9239.6
21	0	7.41	258.34	61.8	4058	9540.5	292.2	9248.3
22	0	7.52	258.61	60.9	4118	9550.5	296.5	9254.0
23	0	7.63	258.81	60.0	4180	9557.9	301.0	9256.9
24	0	7.74	258.94	59.1	4244	9562.7	305.5	9257.1
25	0	7.85	259.00	58.3	4302	9564.9	309.7	9255.1
26	0	7.95	258.98	57.6	4354	9564.1	313.5	9250.6
27	0	8.05	258.89	56.8	4415	9560.8	317.9	9242.9
28	0	8.15	258.74	56.1	4471	9555.3	321.9	9233.4
29	0	8.24	258.50	55.5	4519	9546.4	325.4	9221.0
30	0	8.34	258.2	54.9	4568	9535.3	328.9	9206.4

### 3.4. Analysis of Optimal Inclination Angle Based on Total Radiation Amount of Lighting Surface

By querying PVsyst meteorological software (using NASA meteorological data), the annual average solar irradiance for different inclined planes was calculated as shown in the table

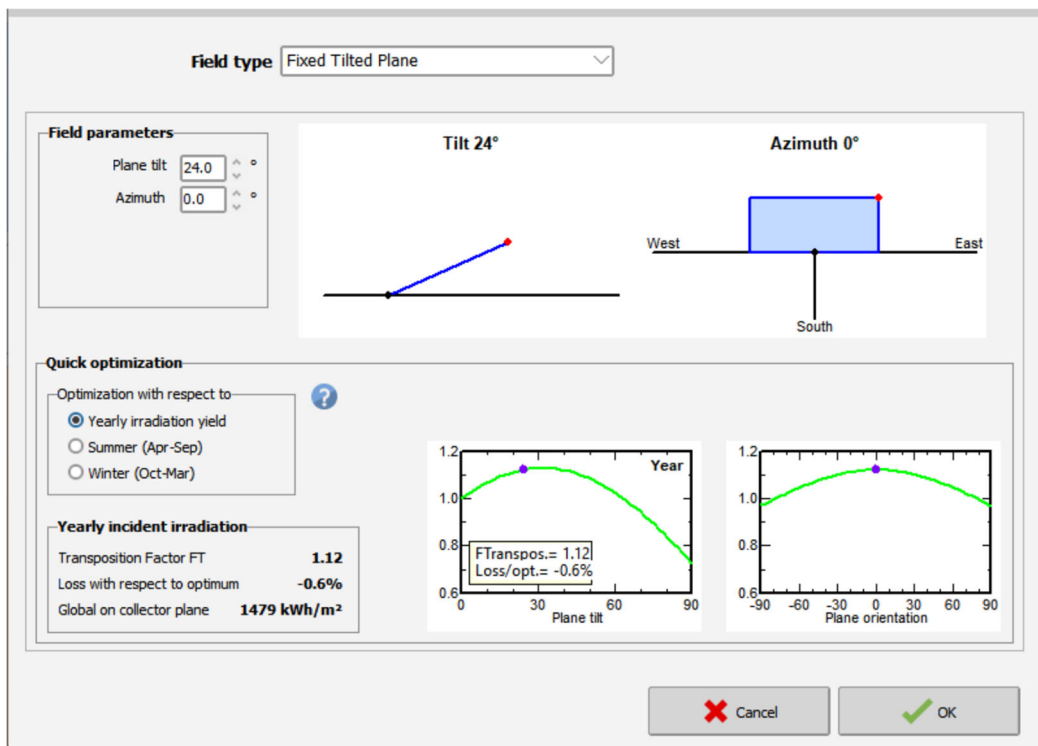
**Table 3.** Annual average solar radiation on arrays with different inclinations(kWh/m<sup>2</sup>)

Tilt (degree)	21	22	23	24	25	26	27	28	29	30, 31, 32, 33, 34	35	36
Global on collector plane (kWh/m <sup>2</sup> )	1470	1473	1476	1479	1481	1483	1485	1486	1487	1488	1487	1485
Pitch (m)	7.41	7.52	7.63	7.74	7.85	7.95	8.05	8.15	8.24	8.34	8.77	8.85

Considering factors such as wind load and land utilization rate, the 24° inclination angle only loses 0.6% relative to the optimal inclination angle of 30° but reduces the land area occupied by 7.2% compared to a 25° inclination angle. Additionally, the wind load is lower, enhancing the safety and

3. After comparison, it was concluded that the maximum solar irradiance is obtained at an inclination of 30°.

stability of the bracket structure, and reducing the amount of bracket material required. Therefore, it is recommended that the inclination of the photovoltaic module be set at 24°. As seen in Figure 8.



**Figure 8.** Schematic diagram of simulation results for PV software tilt angle of 24 degrees

## 4. Summaries

The selection of the inclination angle for photovoltaic array installation depends on various factors. For fixed arrangements, the optimal inclination angle should be designed based on local multi-year monthly average irradiance, direct component irradiance, scattered component irradiance, wind speed, rainfall, snowfall, and other climatic conditions, as well as load power supply requirements. For a fixed grid-connected photovoltaic power generation system, the inclination angle should maximize the annual radiation received by the tilted surface of the photovoltaic array. However, this method does not consider the impact of shading between components, so the annual energy generation may not reach its maximum even when the total annual radiation of the lighting surface is maximized. Therefore, the optimal

inclination angle can be obtained by establishing a three-dimensional scene model of close occlusion and using the three schemes described in this paper. The analysis results of these three schemes differ slightly, and actual application should be combined with specific project cases.

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