

QUICK GUIDE – SOLAR PV ENERGY CALCULATION

Purpose:

The purpose of this quick guide is to help you to design and calculate AEP for a solar photovoltaic (PV) project. A special focus is inclusion of shading from a wind farm.

Outline of Guide:

1. Requirements
2. Defining areas for solar PV
3. Modifying panel characteristics
4. Setup – Meteorological data
5. Setup – Losses and inverters
6. Calculating AEP or period energy
7. Visualizing the calculated shading
8. Miscellaneous

1. REQUIREMENTS

The steps in this quick guide require windPRO with license to the Solar PV module. A license to the Meteo module is recommended.

Before creating your solar PV farm, you should establish a digital elevation model either as height contour lines or as an elevation grid. Also, ensure you have a background map with a satisfying resolution.

For more guidance on establishing background maps and a digital elevation model, read more here, or visit the [Start using windPRO](#) and the [BASIS](#) manual. Also in the [Solar PV manual](#), there are more specific hints about how to use digital elevation models along with Solar PV. Of special importance is handling of obstacles near solar panels, so shading is calculated correctly.

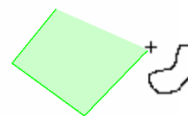
2. DEFINING AREAS FOR SOLAR PV

Start by inserting a  Solar PV object in the map window:



Place the Solar PV object near the area you want to establish solar panels (here we will design a solar plant at the light grey area NW of the WTG). The exact position is not important, but the map will automatically zoom into the area where the object is placed. It shall be mentioned that the Top of atmosphere radiation is calculated for the location of the object, so it must be placed near the project location.

Once placed, the cursor changes to a drawing cursor, so you can draw an area by left clicking:



To stop digitizing the area, right-click and select “Stop”.

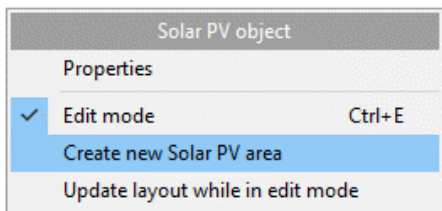
The area will automatically be filled with solar PV panels:

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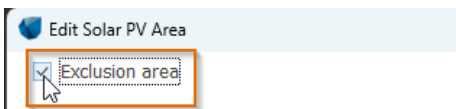


It's possible to define exclusion areas, where no panels are to be installed. This can be used to remove panels at substations, access roads, buildings etc.:

Right-click on the map and select "Create new Solar PV Area":



Then define the area as an Exclusion Area:

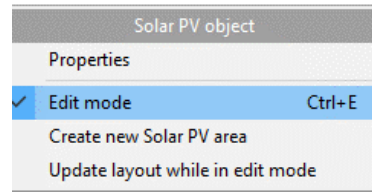


Click Ok, and start digitizing the exclusion area:

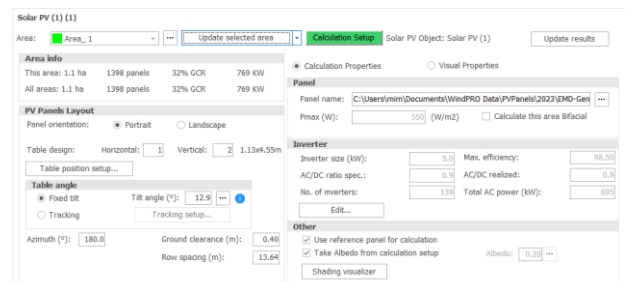


Multiple PV areas and Exclusion areas can be created within the same Solar PV object. Each area can have different properties - the panel layout, panel type and visual design.

Right-click on the map and exit edit mode when you are done digitizing the areas:



The properties of each area can be seen in the status window which appears above the map when inserting the Solar PV object:



The tilt angle of the PV array can be adjusted (where 0° is horizontally flat), along with the azimuth of the rows. The tilt angle is by default the one giving highest production for a panel free of shading. Often a lower tilt than the default will be used, partly to reduce array shading, partly to reduce wind loads with a very small production cost.

The azimuth follows the general conventions in windPRO, 0 degree is north, 90 degrees is east, 180 south etc. Thus, on the northern hemisphere, 180 degrees will make the panels face towards Equator and on the southern hemisphere, 0 degrees will make panels face Equator.

Row spacing is a fixed value (but changeable) regardless of the size of the panels:

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PV Panels Layout

Panel orientation: Portrait Landscape

Table design: Horizontal: Vertical: 1.13x4.55m

Table position setup...

Table angle

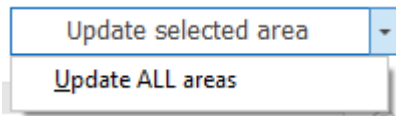
Fixed tilt Tilt angle (°):

Tracking

Azimuth (°): Ground clearance (m):

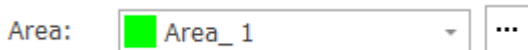
Row spacing (m):

When changing any of the properties seen above from the status window, the impact on the layout can be quickly seen on the map by clicking the Update area button:



If all design parameters shall be used for all areas, the option Update ALL areas should be selected.

You can switch between the areas from the dropdown:



If the PV object is in edit mode, selecting an area on map will make this area the viewed area in the status window.

3. MODIFYING PANEL CHARACTERISTICS

A PV layout can consist of a number of tables in each row. Each table can contain a number of panels, e.g. arranged by 10 panels horizontal and 4 panels vertical. This will mean that within the design area, the total number of panels will be a multiple of 40 panels, which helps controlling the design, so it matches a specific number of inverters.

A good choice for a project in northern Europe could be this configuration, used in our validation project which is optimized for a Danish site:

PV Panels Layout

Panel orientation: Portrait Landscape

Table design: Horizontal: Vertical: 19.60x3.96m

Table position setup...

Table angle

Fixed tilt Tilt angle (°):

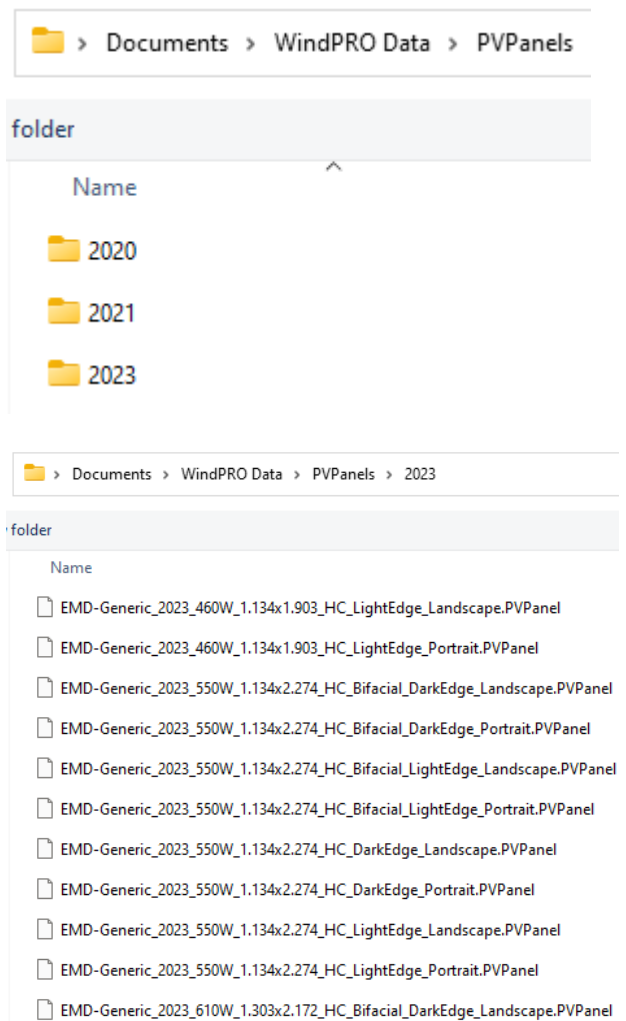
Tracking

Azimuth (°): Ground clearance (m):

Row spacing (m):

Sites at other latitudes will require different tilt and distances.

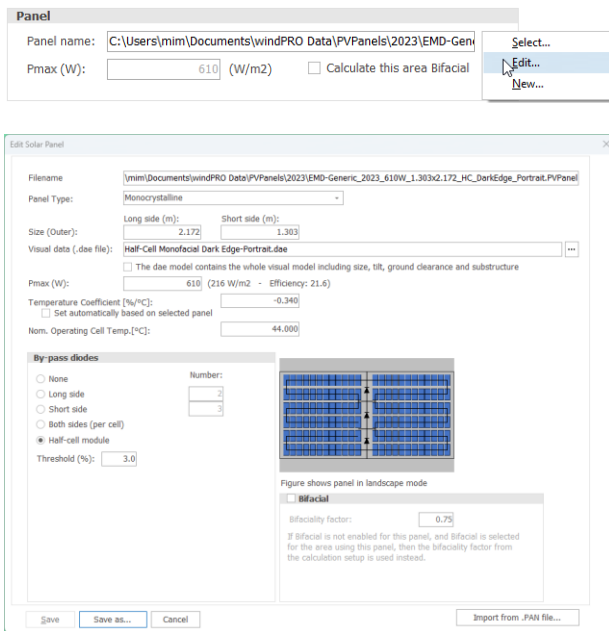
For the panel types, windPRO comes with a set of default panel presets, which are grouped into years:



Each panel dataset contains information about the width, height, 3D model, peak power, cell type and by-pass diodes of the individual panel. Each dataset can be

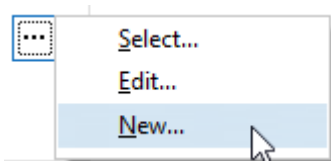
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viewed by clicking on the [...] button next to the Panel Name and picking “Edit”:



The size, Pmax and temperature specifications is used for the calculation of the power in each time step, while the by-pass diodes affect the shading reduction calculation. Panel type is only used to validate if Pmax is within reasonable limits for the panel type.

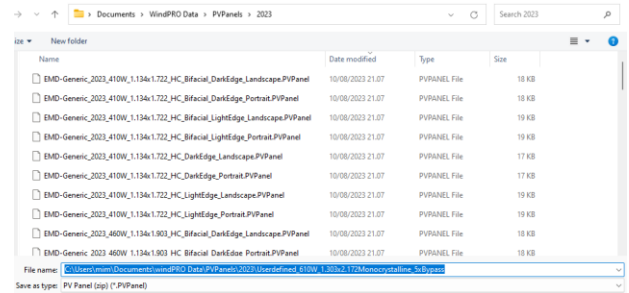
You can create your own panel presets by clicking the [...] button next to the panel preset and select “New...” or edit an existing and “Save as”:



Input information about the panels outer size and select a visual 3D model from the windPRO library folder or create your own .dae file in, for example SketchUp.

The selected .dae file will be scaled to the width and height properties given above.

Click “Save as...” to save the new panel as a pre-set template:



Click Preview, to see a 3D model of the table holding the number of specified panels within a table, here e.g. the 5 horizontal and 2 vertical:



These individual tables are used to fill out the digitized solar PV area. Changing the table size may change the number of panels fitted to the area.

The number of panels fitted to the selected area and all areas can be viewed in the Area info section of the solar PV status window, along with Ground-coverage ratio (GCR) and the peak capacity:

Area info			
This area:	2.4 ha	7020 panels	84% GCR 4 MW
All areas:	2.4 ha	7020 panels	84% GCR 4 MW

4. MODIFYING INVERTER CHARACTERISTICS

The inverter setup is specified for each PV area in the Solar PV status window. The main characteristics of the inverter setup are displayed in the inverter section, where the properties can be edited by clicking Edit...:

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This opened a new window where the properties of inverters per Area are shown in a table:

Areas	AC/DC spec.	DC-power (kW)	Inv. Size (kW)	No. Of inverters	AC power (kW)	AC/DC realized	Edit inv
Edit all	0.900		5.0				Edit inv
Area_1	0.900	4,282	5.0	771	3,855	0.90	Edit inv.
Area_2	0.900	4,209	5.0	758	3,790	0.90	Edit inv.
Sum or average	0.900	8,491	5.0	1,529	7,645	0.90	Edit inv.

The required number of inverters per area is calculated so the specified AC/DC ratio at least will be fulfilled.

In this quick guide we will use default settings. However, it is possible to specify the inverter size and efficiency clicking the “Edit inverter” button:

AC power (kW)	AC/DC realized	
		Edit inv
3,855	0.90	Edit inv.
3,790	0.90	Edit inv.
7,645	0.90	Edit inv.

5. SETUP – METEOROLOGICAL DATA

Meteorological data is stored in the Meteo object. A license for Meteo is recommended, but not strictly required.

If you have a license to the Meteo module, you can use the Meteo Analyser and Meteo object for detailed data analysis and manipulation of your own measurements and/or reference datasets:

Get even more accurate temperature and humidity data with a subscription to EMD-WRF datasets (mesoscale data), which has a higher spatial resolution compared to ERA5. Visit emd.dk/data-services/mesoscale-time-series/

In any case, the Solar PV license allows access to download of select datasets from the Online Data Service for Solar PV purposes.

Click the Calculation setup button in top of the Solar PV status window:

Here, the relevant data is selected in drop down boxes. If you do not already have meteo objects with solar data, click the “Download data” button to automatically download data (ERA5/Heliosat) into new meteo objects:

Tests show that the “Solar HelioSat (SARAH)” model dataset represents local measurements precisely. It is based on satellite measured cloud coverage, which makes the cloud representation much more accurate than other model data.

If the project is outside the regions covered by Heliosat data, it is recommended to use ERA5 data, which has global coverage and is reasonably well calibrated.

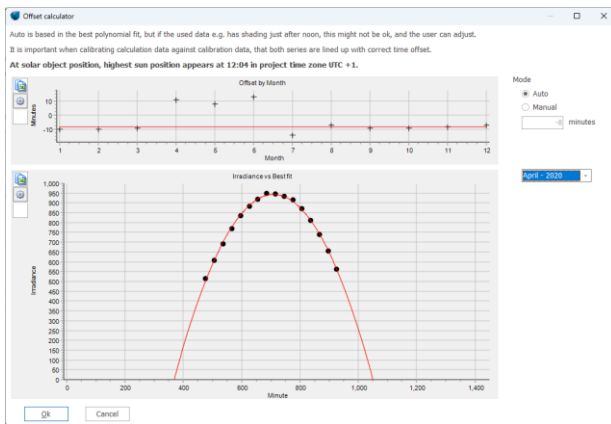
If no temperature data is available, a default value can be used. Humidity data are ONLY used for subdividing global irradiation into direct and diffuse when Reindl model is selected (a simplified Reindl model can still be used without humidity input). For the default Erbs model, humidity input is not needed.

No matter which dataset you use, a very important topic is the time offset. While the Top of Atmosphere(TOA) radiation is used when subdividing global irradiation into direct and diffuse, it is extremely important that TOA is aligned in time with the selected data.

Click the [...] button below the “Offset in minutes”:

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This opens a small time-alignment tool:



From all available data, days fitted best to the theoretical TOA radiation are found for every month. The upper half of the irradiation data is fitted to a 2nd degree polynomial, and the top point identified as highest sun position for the each day. It is then matched to the time where theoretical highest sun position at the specific site should be observed for each day. Comparing the two times for the selected 12 days, differences are found. The time offset is found as median of all 12 values to exclude possible outliers.

The solar irradiation data can be scaled/calibrated, which can be relevant if using model data to be long term corrected with short period local measurements. Use the time alignment tool to establish best possible conditions for the calibration.

The calculation period can be specified. But there will always be generated minimum ONE-year time series based on an advanced gap filler/data series extender. This establishes the ratios between TOA and data for nearest time period and use this for creating missing data. At the later explained AEP-setup, it can be decided NOT to use gap filled/extended data.

6. SETUP – LOSSES

In the Losses tab, the losses setup is available:

For shading losses each type can be deselected, which in an initial design phase will decrease calculation time significantly. It should be re-activated for the final calculation and might be needed in a layout optimization process.

For the panel shading, inclusion of shading from other areas might not be needed (if there are no shading interaction), so this can also be deactivated to reduce calculation time.

For the WTG rotor, the rotor swept disc can be reduced in the calculation to compensate for the swept rotor disc not being a solid structure. Experimentally a reduction of round 50% (default) seem to reproduce the rotor shading well.

In addition to shading losses, losses due to DC wiring, degradation, soiling/snow, constant loss representing e.g. mismatch loss etc. is before inverter loss and subtracted before the DC input to inverters are found.

After inverter loss are availability, substation loss etc.

7. CALCULATING AEP OR PERIOD ENERGY

In the Output tab you can specify if gap filled data is accepted and how to calculate if not.

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SOLAR PV (Photovoltaic AEP based on METEO)

Main | Meteo Solar Data | Losses | WTGs | Obstacles | Costs | Output | Description

The amount of gap-filling needed to establish a full year is shown here after performing a calculation

Gap filling

Gaps in data will be filled by advanced gap filling based on Top Of Atmosphere radiation and its ratio to nearest neighbor data samples.

Gaps will be ignored (assuming it has no contribution to AEP). If data recovery rate is less than set below, AEP calculation is not an option.

Set data recovery rate threshold for AEP calculation to (%):

AEP (Not possible if gap filling not accepted and gaps larger than accepted threshold above)

Time series energy (The shown result is the sum for the entire time series, NOT scaled to AEP)

The simple solution is to accept gap filling, which based on the advanced method is quite a safe choice. It is informed how many percent is gap filled. Even with Heliosat data, some gap filling does occur. For this dataset the gap filling is although very precise, as the gaps are no larger than ½-1 hour and the neighbor samples are used together with TOA irradiation.

If Gap filling is ignored, you can set a threshold, e.g. maximum 3% gaps. If the number of gaps is within this threshold, an AEP calculation is performed WITHOUT gap filled data, but zero production in the gaps. This is the very conservative approach.

If the number of gaps is not within the threshold, AEP calculation is not an option, and energy will be calculated for the time period with the data available.

In reports, the AEP headers will be replaced with energy and it is shown how large a fraction of a year the time period represents.

Press “Ok” to close the calculation setup and hit “Update results”:

Calculation Setup Solar PV Object: Solar PV (1)

The results of the calculation will be shown in a table in the PV-Status window

Calculation name:

Areas	DC Capacity (kW)	AC Capacity (kW)	GROSS (MWh/y)	All losses (%)	Net AEP (MWh/y)	Cap. f. (%)
Area_1	4,282	3,855	7,567	23.21	5,810	17.2
Area_2	4,209	3,790	7,437	23.21	5,711	17.2
Show more results						
8491		7645	15004	23.2	11522	17.2

Degradation

Show loss / Net for 1. Year

Show loss / Net for 20 year average

Result data

Show last calculated result

Show last saved calculation

This can be copied to e.g. Excel by right-clicking on the table.

Areas	DC Capacity (kW)	AC Capacity (kW)	GROSS (MWh/y)	Array's losses (%)	Obstacles (%)	WTG's losses (%)	Topo losses (%)	Combiner losses (%)	Inverter clipping (%)	Before inverter (%)	DC/AC conversion (%)	After inverter (%)	All losses (%)	Net AEP (MWh/y)	Cap. f. (%)		
Area 1	324	295	371,09	18,2	0	1,1	3,4	NA	21,1	2	0	4,2	8	27,4	269,28	10,4	
Below percent losses as percent of gross, above as percent of "input".																	
Area d	324	295	371,09	18,2	0	1,1	3,4	NA	21,1	1,6	0	3,2	1,5	6,3	27,4	269,28	10,4
Below as average 20y output including annual degradation																	
Area d	324	295	371,09	18,2	0	1,1	3,4	NA	21,1	7,5	0	3,2	1,4	12	33,2	248,02	9,6

Here the two presentation variants, Year 1 (no degradation loss, and 20 y (with average degradation loss in 20-year lifetime) is copied to Excel for comparison.

A report can be generated by clicking “Create report”:

Calculation name:

Areas	DC Capacity (kW)	AC Capacity (kW)	GROSS (MWh/y)	All losses (%)	Net AEP (MWh/y)	Cap. f. (%)
Area_1	4,282	3,855	7,567	23.21	5,810	17.2
Area_2	4,209	3,790	7,437	23.21	5,711	17.2

This report can then be viewed from the Calculation list:

Calculations (1), Objects (1 / 4 / 4)

Calculations (1)

- Name
 - Solar PV: Test Panel Choise Solar Opti
 - Main
 - Time Varying production
 - Panels
 - Inverter(s)
 - Cost
 - Map

A (1) +

Calculations (1), Objects (1 / 4 / 4) × Solar PV (1) (1) ×

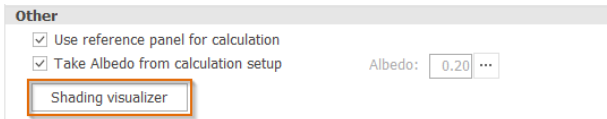
8. VISUALIZING THE CALCULATED SHADING

windPRO can calculate the shading from the following elements on the PV panels based on an accurate 3D model, respecting the terrain elevation variations:

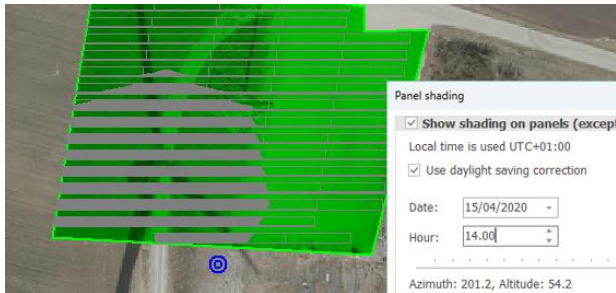
- Array's (panels shading)
- WTG tower/nacelle
- WTG rotor (separated while not the full rotor area shall be included – percentage can be set)
- Obstacles (defined by Obstacle object)

In the Solar PV status window, Other sections, click Shading visualizer:

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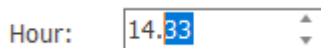
Here you can control the date and time you want to simulate on the map:



Any panel falling in the shade of a shading element (panel, obstacle and/or wtg) will be coloured darker.

Here the turbine with the real shade seen on background map is calculated with a 55% rotor area reduction. Panel shading can be seen in the bottom of most panels.

Tip: If you want to step in time on minute basis, simply highlight the minute numbers with your mouse:



And then use the step arrows (which also can be controlled from keyboard), for each 1 minute step.

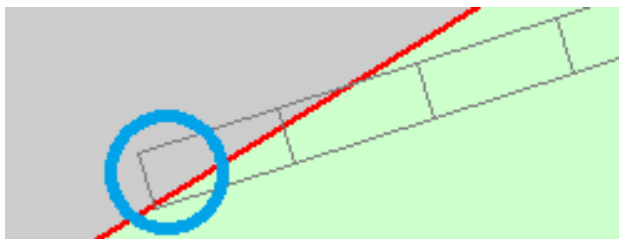
9. MISCELLANEOUS

Why do I only see lines in my Solar PV area?

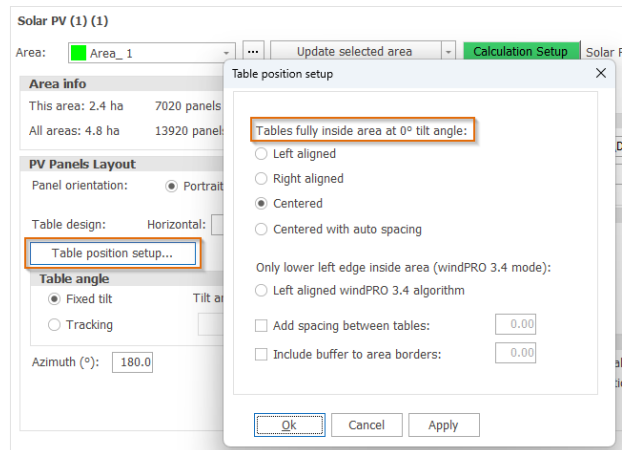
If there are too many panels, windPRO will reduce the drawing time by only displaying lines.

Why do some solar panels cross oblique sections of the Solar PV area?

Sometimes the solar panels will extend past the defined Solar PV area:

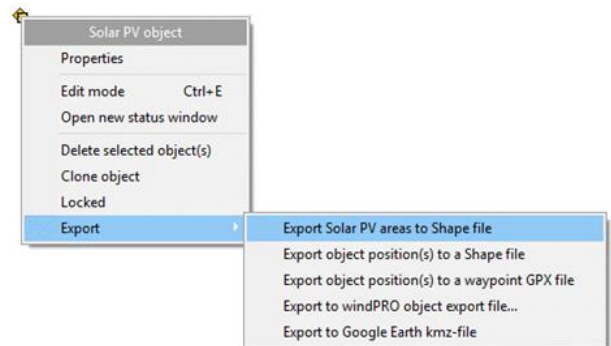


This can be avoided in windPRO 3.5 and newer by selecting in Design on of the options for having tabled fully inside an area:



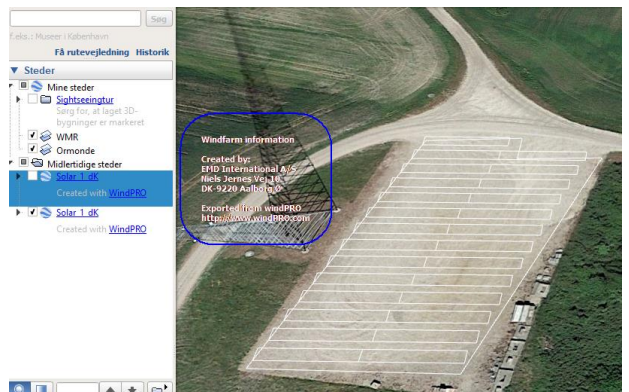
How do I export my layout?

Right-click on the Solar PV object and select Export and Export Solar PV areas to Shape file:



The lines (not renditions) of the areas and panels can then be imported to Google Earth Pro, QGIS, etc.

Direct export from object list to Google Earth is also an option like for all other windPRO objects:



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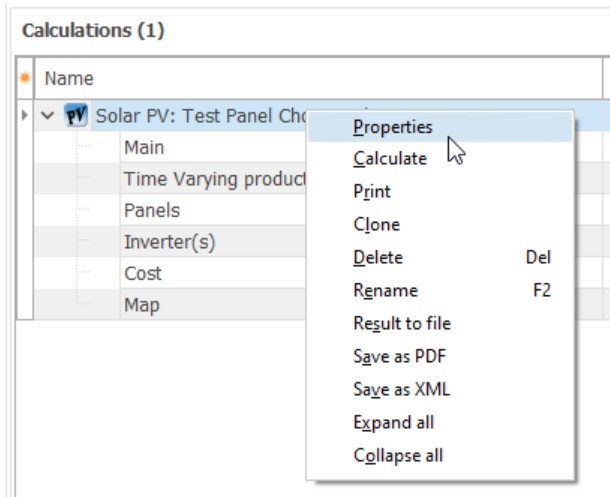
Note that both panels and design areas are shown on e.g. Google Earth. But these are in separate layers, and it is possible to switch off one or them to get a nicer view.

How do I visualize my Solar PV farm?

Visit the other Quick guide: “Creating and visualizing solar pv layouts”

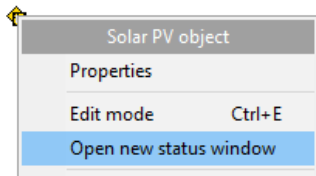
How do I revisit the calculation setup of a previous PV calculation?

If you have created a report (page 7), the calculation setup can be revisited by right-clicking on the report and selecting Properties:



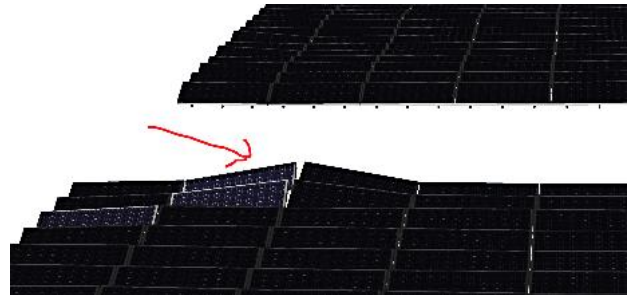
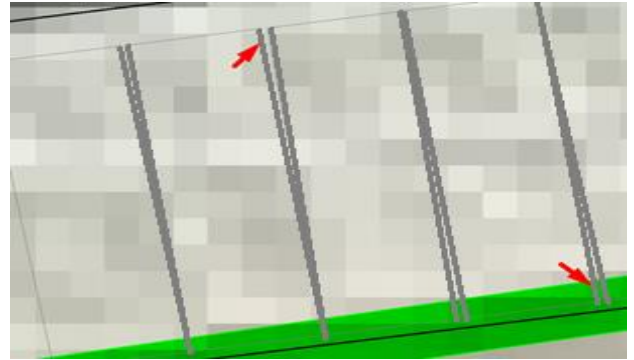
Then the object data and as the saved calculation setup will reappear.

When opening the Solar PV status window from the right-click menu of the Solar PV object, n calculation setup is defined:



Why are my panels not mounted straight?

Panels may be placed in a skew layout on the map and in a photomontage:



This can occur when using very high resolution elevation data (0.4m) with some noise. Since the panels follow the terrain, any bump in the elevation data will result in a bump in the panel layout. A solution is to post-process the elevation data and remove the noise. For typical low resolution elevation data, this problem will be rare.