

## 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 3.4 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 correct.

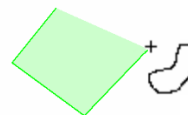
#### 2. DEFINING AREAS FOR SOLAR PV

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. And it shall be mentioned that the Top of atmosphere radiation is calculated for the location of the object, so it must be “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”.

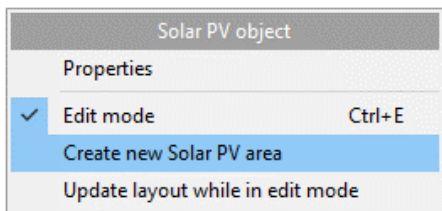
The area will automatically be filled with solar PV panels:

## QUICK GUIDE – Solar PV Energy Calculation

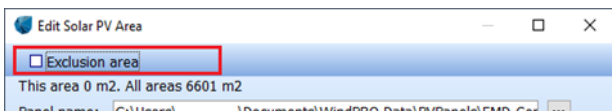


It's possible to define exclusion areas, where no panels are to be installed. This can be used to remove panels at substations, access roads, buildings etc.:

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



Then define the area as an Exclusion Area:

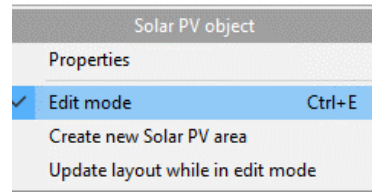


Click Ok, and start digitizing the exclusion area:

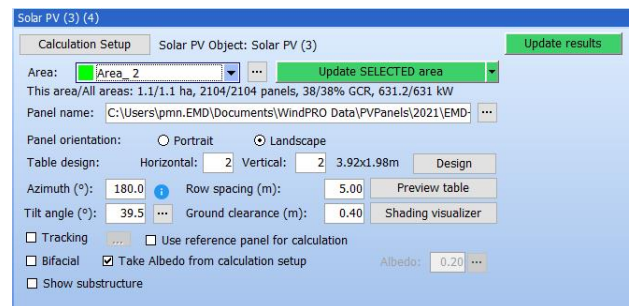


Multiple PV areas and Exclusion areas can be created within the same Solar PV object. Each area can have different properties to the panel layout, panel type and visual design.

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



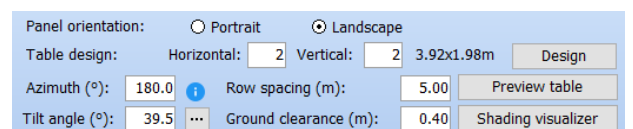
The properties of each area can be seen in the status window which appears above the map when inserting the Solar PV object:



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 "optimal" for the location, 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 degree 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:



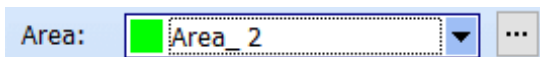
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When changing any of the properties seen above from the status window, the impact on the layout can be quickly seen on the map by clicking the Update area button:



If all design parameters shall be used for all areas, the drop down can change the button to “Update ALL areas”.

You can switch between the areas from the dropdown:

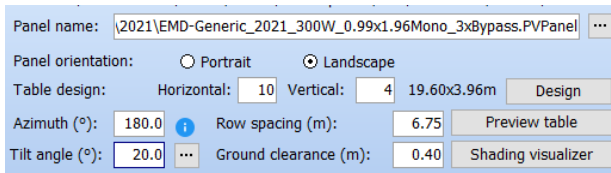


If the PV object is in edit mode, selecting an area on map will make this area the “viewed area” in the status window.

### 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:

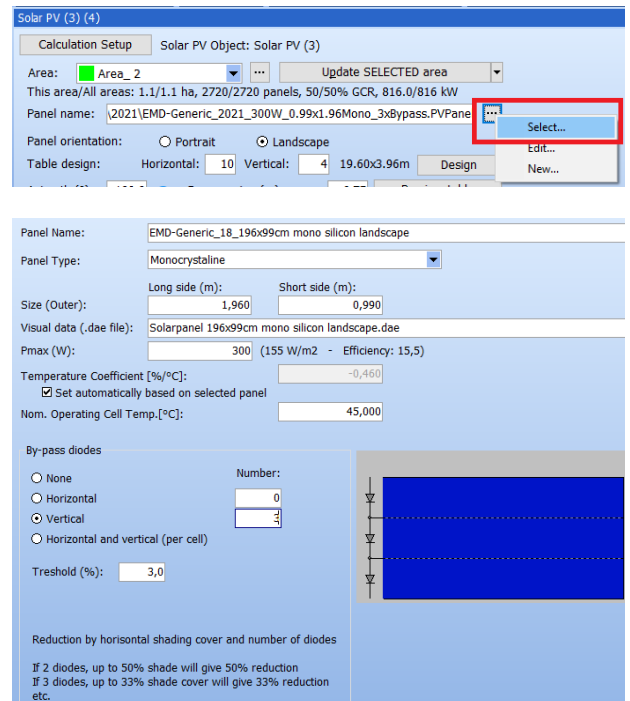


Sites at other latitudes will require different tilt and distances.

For the panel types, windPRO comes with a set of default panel presets:

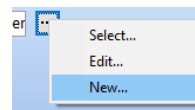
- EMD-Generic\_2021\_150W\_0.99x1.96Thin\_3xBypass.PVPanel
- EMD-Generic\_2021\_250W\_0.99x1.96Poly\_3xBypass.PVPanel
- EMD-Generic\_2021\_300W\_0.99x1.96Mono\_3xBypass.PVPanel
- EMD-Generic\_2021\_330W\_0.99x1.96Mono\_3xBypass.PVPanel
- EMD-Generic\_2021\_1200W\_2.4x4mMono\_3xBypass.PVPanel

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



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”:

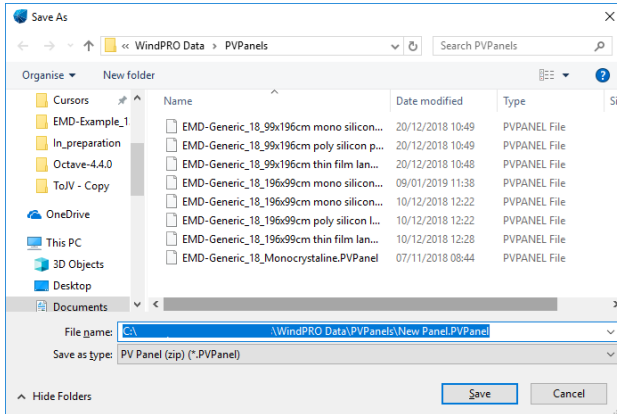


Input information about the panels outer size and select a visual 3D model from the windPRO Collada folder or create your own .dae file in, for example SketchUp.

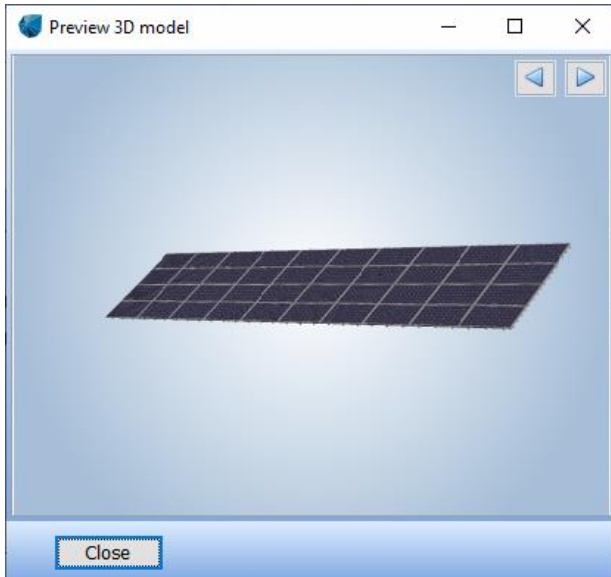
## QUICK GUIDE – Solar PV Energy Calculation

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:

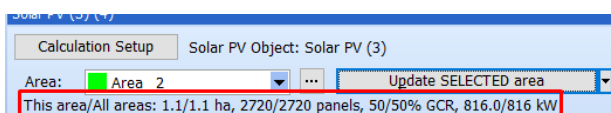


Click Preview, to see a 3D model of the table holding the number of specified panels within a table, here e.g. the 10 horizontal and 4 vertical:



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 also all areas can be viewed below, along with Ground-coverage ratio (GCR) and the peak capacity:



### 4. SETUP – METEOROLOGICAL DATA

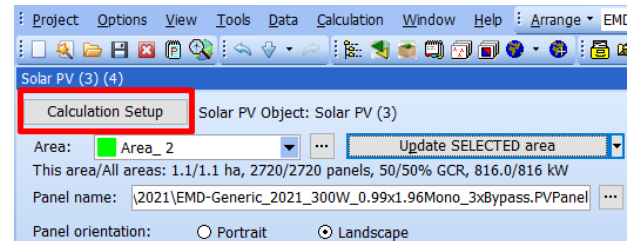
Meteorological data is stored in the Meteo object. A license for Meteo is recommended, but not strictly required.

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:

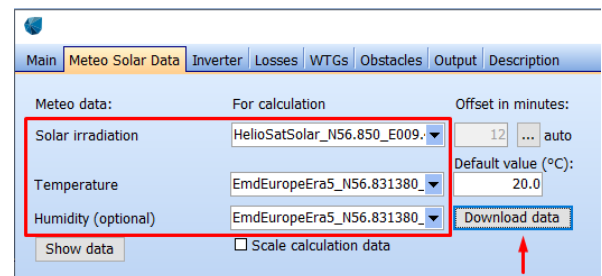


In any case, the Solar PV license allows access to download of select datasets from the Online Data Service for Solar PV purposes.

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



Here, the relevant data are 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.



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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.

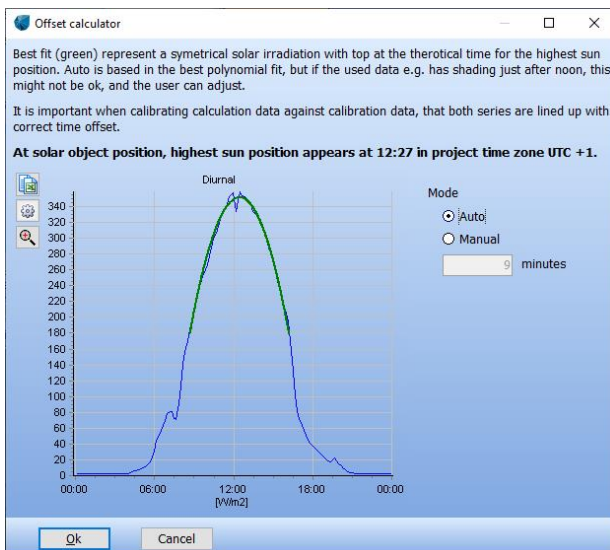
If no temperature data is available, a default value can be used. Humidity data are ONLY used for subdividing global irradiation into direct and diffuse, a simplified model will be used if no humidity is available:

*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/](http://emd.dk/data-services/mesoscale-time-series/)*

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”:

This opens a small time-alignment tool:



Based on the average of all data, the upper half of the irradiation data is fitted to a 2<sup>nd</sup> degree polynomial, and the top point identified as highest sun position, which is then matched to the time where theoretical maximum is at the specific site and the needed time alignment is found.

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.

### 5. SETUP – LOSSES AND INVERTERS

On the second tab in setup, the inverter setup is specified for each PV area:

Solar calculation setup						
Areas	AC/DC spec.	DC-power (kW)	Inv. Size (kW)	No. Of inverters	AC power (kW)	AC/DC realized
<b>Edit all</b>	<b>0.900</b>		<b>5.0</b>			
Area description 2	0.900	419	5.0	76	380	0.91
Area description 3	0.900	18	5.0	4	20	1.11

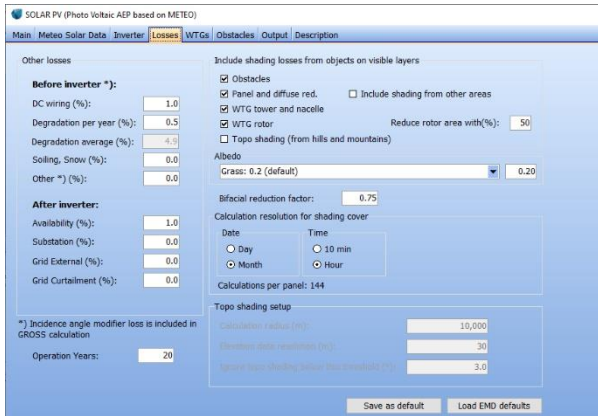
The required number of inverters per area are calculated so the specified AC/DC ratio at least will be fulfilled.

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:

power (kW)	AC/DC realized	
		<b>Edit inv.</b>
380	0.91	<b>Edit inv.</b>
20	1.11	<b>Edit inv.</b>

Staying with the default settings, go to the Losses tab:

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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.

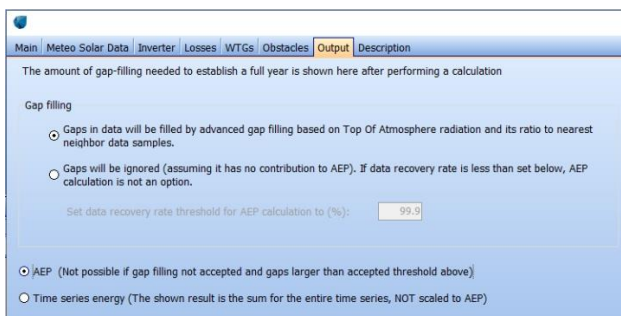
For the WTG rotor, the rotor swept disc can be reduced in the calculation to compensate for the swept rotor disc not being a solid structure. Experimentally a reduction of round 50% (default) seem to reproduce the rotor shading well.

In addition to shading losses, losses due to DC wiring, degradation, soiling/snow etc. is “before inverter” loss and subtracted before the DC input to inverters are found.

After inverter loss are availability, substation loss etc.

### 6. CALCULATING AEP OR PERIOD ENERGY

On the “Output” tab you can specify if gap filled data are accepted and how to calculate if not.



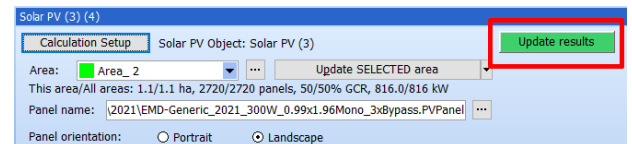
The simple solution is to accept gap filling, which based on the advanced method is a quite safe choice. It is informed how many percent is gap filled. Even with Heliosat data, some gap filling does occur. For this dataset the gap filling is although very precise, as the gaps are no larger than ½-1 hour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



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

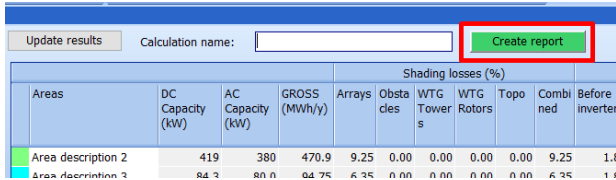
This can be copied to e.g. Excel by right-clicking on the table.

Area	DC Capacity (kW)	AC Capacity (kW)	GROSS (MWh/y)	WTG Array's (MW)	WTG's (MW)	Before inverter (MWh/y)	DC/AC conversion (MWh/y)	After inverter (MWh/y)	All losses (MWh/y)	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	2	8	27,4	269,28	10,4
Below percent losses as percent of gross, above as percent of "input".																	
Area 04	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 04	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.

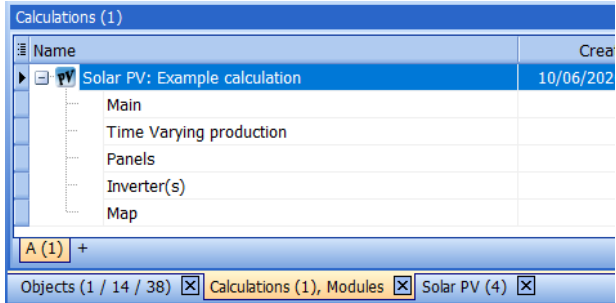
A report can be generated by clicking “Create report”:

## QUICK GUIDE – Solar PV Energy Calculation



Areas	DC Capacity (kW)	AC Capacity (kW)	GROSS (MWh/y)	Shading losses (%)					Combin	Before inverter
				Arrays	Obsta	WTG Tower	WTG Rotors	Topo		
Area description 2	419	380	470.9	9.25	0.00	0.00	0.00	0.00	9.25	1.8
Area description 3	84.3	80.0	84.75	6.35	0.00	0.00	0.00	0.00	6.35	1.8

This report can then be viewed from the Calculation list:



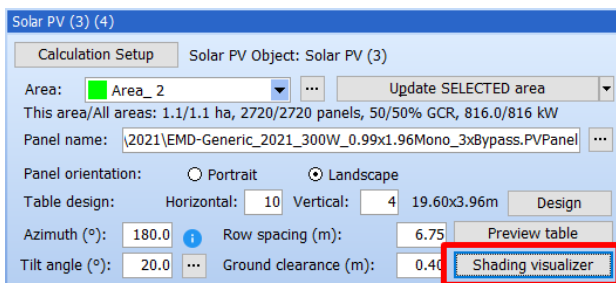
Name	Created
Solar PV: Example calculation	10/06/202
Main	
Time Varying production	
Panels	
Inverter(s)	
Map	

### 7. 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, click “Shading visualizer”:



Calculation Setup Solar PV Object: Solar PV (3)

Area: Area\_2 Update SELECTED area

This area/All areas: 1.1/1.1 ha, 2720/2720 panels, 50/50% GCR, 816.0/816 kW

Panel name: \2021\EMD-Generic\_2021\_300W\_0.99x1.96Mono\_3xBypass.PVPanel

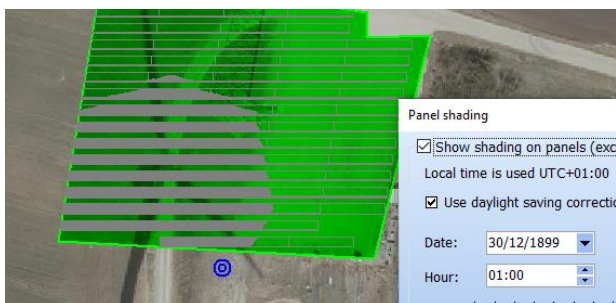
Panel orientation:  Portrait  Landscape

Table design: Horizontal: 10 Vertical: 4 19.60x3.96m Design

Azimuth (°): 180.0 Row spacing (m): 6.75 Preview table

Tilt angle (°): 20.0 Ground clearance (m): 0.40 Shading visualizer

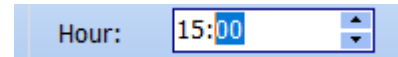
Here you can control the date and time you want to simulate on the map:



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 seen 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:



Hour: 15:00

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

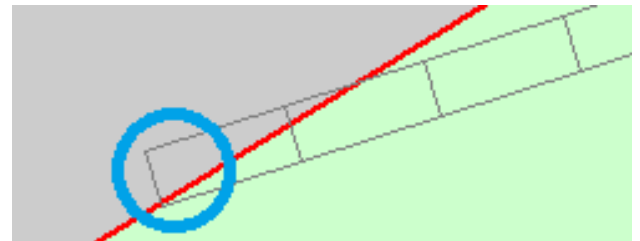
### 8. MISCELLANEOUS

#### 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:

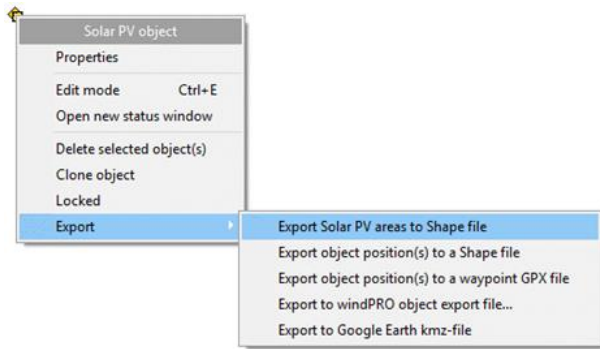


The only option is to move the boundary of the PV area or to insert an exclusion area. The panel designer is made so the lower left corner of the panels seeks to match lower left area corner, then filling from there. When filling it just check if the lower corners of the panels are inside areas, to speed up the area filling process.

#### How do I export my layout?

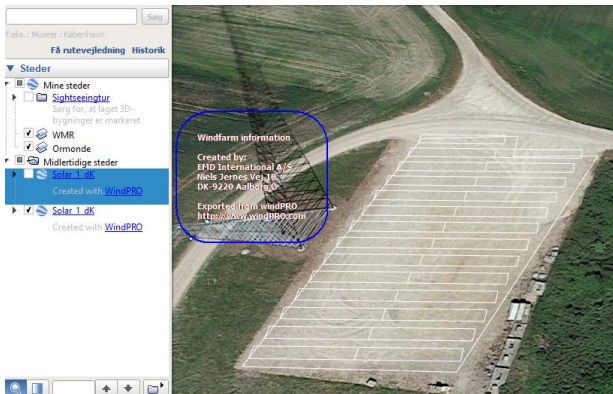
Right-click on the Solar PV object and select Export and Export Solar PV areas to Shape file:

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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:



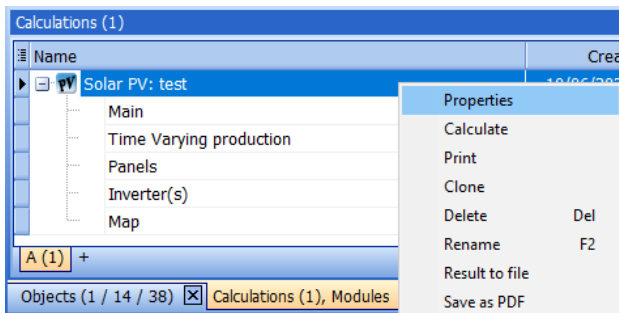
Note that both panels and design areas are shown on e.g. Google Earth. But these are in separate layers, and it is possible to switch off one or them to get a nicer view.

### How do I visualize my Solar PV farm?

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

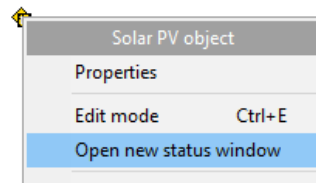
### How do I revisit the calculation setup of a previous PV calculation?

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



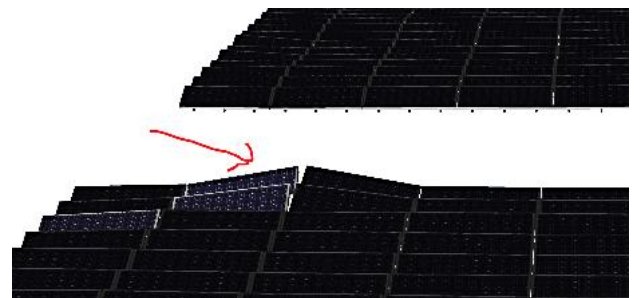
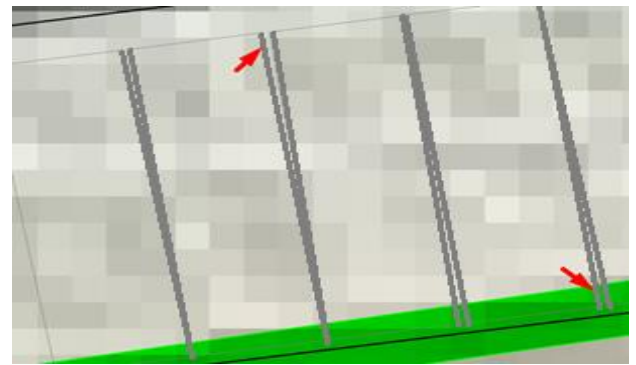
Then the object data and as the saved calculation setup will reappear.

When opening the Solar PV status window from the right-click menu of the Solar PV object, no 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.