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Introduction

SHADOW is the WindPRO calculation module that calculates how often and in which intervals a specific neighbor or area will be affected by shadows generated by one or more WTGs. These calculations are **worst-case scenarios** (astronomical maximum shadow) (i.e. calculations which are solely based on the positions of the sun relative to the WTG).

If the weather is overcast or calm, or if the wind direction forces the rotor plane of the WTG to stand parallel with the line between the sun and the neighbor, the WTG will not produce shadow impacts, but **the impact will still appear in the calculations**. In other words, the calculation is a worst-case scenario, which represents the maximum potential risk of shadow impact.

A calendar can be printed for any specific point of observation, which indicates the exact days, and time periods where shadow impact may occur.

Apart from calculating the potential shadow impact at a given neighbor, a map rendering the iso-lines of the shadow impact can be printed. This printout will render the amount of shadow impact for any spot within the project area.

At present, only Germany has detailed guidelines on limits and conditions for calculating shadow impact. These are found in "Hinweise zur Ermittlung und Beurteilung der optischen Immissionen von Windnergianlagen" (WEA-Shattenwurf-Hinweise).

According to the German guidelines, the limit of the shadow is set by two factors:

- The angle of the sun over the horizon must be at least 3 degrees
- The blade of the wind WTG must cover at least 20 % of the sun.

The maximum shadow impact for a neighbor to a wind farm according to the German guidelines is:

- Maximum 30 hours per year of astronomical maximum shadow (worst case)
- Maximum 30 minutes worst day of astronomical maximum shadow (worst case)
- If automatic regulation is used, the real shadow impact must be limited to 8 hours per year.

In Sweden and Denmark there are no official guidelines as yet on shadow flickering, but for practical purposes, 10 hours (Denmark) and 8 hours (Sweden) real case (weather dependent) shadow impact is used as the limit.

Finally, the actual amount of shadow impact as a fraction of the calculated potential risk will depend heavily on the geographic location in question. In areas with **high rates of overcast weather** the problem would obviously **decrease**, and during potential hours of shadow impact in the summer the WTG may often be stopped due to lack of wind. Statistics regarding the wind conditions and number of hours with clear sky can be taken into account.

The SHADOW calculation method

The position of the sun relative to the WTG rotor disk and the resulting shadow is calculated in steps of 1 minute throughout a complete year. If the shadow of the rotor disk (which in the calculation is assumed solid) at any time casts a shadow reflection on the window, which has been defined as a shadow receptor object, then this step will be registered as 1 minute of potential shadow impact.

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Shadow Receptors

Shadow Receptors are objects for which the potential risk of shadow impact is calculated.

The shadow receptors are described by the following information:

- The position of the “window” above ground level and its size (height and width).
- The tilt of the “window” relative to horizontal (you can choose between vertical, horizontal and roof window [45°]).
- The directional orientation of the window relative to south (in degrees, positive, westwards)
- The default parameters are good as a standard description of typical windows.

Alternatively “**Green house**” mode can be selected. Then the receptor will not face any particular direction, but instead will face all directions.

SHADOW - Calculation Setup

According to the German guidelines flickering is only an issue when at least 20% of the sun disk is covered by the blade. Checking this box lets WindPRO calculate the maximum distance from the turbine where flickering must be calculated. Beyond this distance, the turbine will not contribute to the flickering impact.

The minimum angle of the sun above the horizon can also be set (default is 3,0 degrees). When the sun angle gets very low, the light has to pass through more atmosphere and becomes too diffuse to form a coherent shadow.

You can choose either to calculate only the “**Astronomical maximum shadow**” (also called worst case shadow) or set up the statistical parameters for calculating the “**Meteorological probable shadow**” (also called **real** shadow). Note that when calculating the real shadow, the worst-case shadow calculation will automatically be included in the reports.

Two statistical parameters can be set.

1. Operational hours statistics. This is the period that the WTG will be in operation from the different wind directions during the year.
2. Sunshine probability statistics. This is the percentage of sunshine hours in daytime (from sunrise until sunset).

Area objects defining blocking elements like forests or villages and obstacles can also be included.

SHADOW supports the following six report types:

1. Main result: This shows the hours of astronomical maximum shadow (Worst case) or statistical real shadow impact at each shadow receptor (and the number of minutes on the “worst day”). Also results are generated for each turbine indicating how many hours per day that each of the turbines are causing shadows, both for the real and worst cases.
2. Calendar: This presents a calendar for each shadow receptor which contains the following information:
 - Timetable for sunrise and sunset for each day of the year in local time (i.e. corrected for time zone and daylight saving time)



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- Table for when shadow impact may occur for each day of the year, the total amount of hours of impact for the day in question and moment of commencement and termination of the shadow impact.
 - The number of the WTGs, which cause the shadow impact at the moment of commencement and termination respectively.
 - The total amount of hours of potential impact month by month.
 - Reductions due to sunshine statistics and statistics of operational hours.
3. Graphic calendar: Showing when (hours and months) and from which WTGs flickering problems CAN occur (worst case).
 4. Calendar per WTG: This is similar to the regular calendar, but is instead for the individual turbines, telling when the flickering it causes begins and ends. The purpose of this calendar is to help set up stop periods for the turbines to avoid flickering problems.
 5. Calendar per WTG, Graphical: Like the graphical calendar for the receptors, this shows when the turbines will cause flickering.
 6. Map: A map which renders the WTGs, the shadow receptors AND, if the calculation has been set up for it, a map rendering the iso-lines of the shadow impact for the area in question. It is possible to freely define the following features of the iso-lines: amount of lines, values, colors and line widths.

Finally data from the calculation can be printed, the calendar results as .txt files for other presentation or further calculations (imported into a spreadsheet), the shadow map iso-lines as .shp (shape) files for use in GIS systems.