Wind PRO

Chapter 8
OPTIMIZATION

8. WindPRO Optimize

8.0 OPTIMIZE – Intro, step-by-step guide

8.0.1 Introduction to Optimize

What is the optimal park layout?

The optimal park layout depends very much on the situation.

In short, maximizing the profit and at the same time giving the environmental aspects sufficient consideration would often be the best suggestion.

But this formulation already leads to several questions. What is a maximized profit? Here the time factor has to be considered. The highest rate of return, for example, does not necessarily give the highest net present value. Also, expectations to the development in power purchase prices, lifetime and operational costs are important. The size of the wind turbines can normally not be uniquely determined from given criteria - what is the available crane capacity, who can deliver - and when - are but a few of the many questions.

Are the environmental aspects considered in a sufficient way? Is it worth gaining a bit more on the economics side if the project thereby becomes problematic from a visual impact point of view ultimately resulting in a requirement to close the project long before the end of the calculated lifetime?

Then there are situations where landowner agreements include specific requirements like the distribution of WTGs on different land lots. Likewise, up front agreements might have been made with suppliers that define the type of WTG to be used.

Hence, many constraints that the park layout must respect will often be present.

The WindPRO optimization module is therefore structured so that it becomes a projecting tool that allows the user a high degree of control during the optimization process. Thus, a high priority has been given to secure a continuous interactivity between the program and the user during the layout optimization.

Currently in WindPRO the optimization combines the layout constraints in terms of spacing and land use with the wind resource available. As an alternative WindPRO can optimize the noise operation mode strategy of a fixed layout. However the strongest feature is the support it lends to manual manipulations with the layout.

Optimization in WindPRO consists of four elements:
- Site constraints in the form of a WTG Area object where available land, exclusion zones and spacing requirements are defined.
- A wind resource map, either imported or create with the RESOURCE module
- Optimization algorithms, which depending on requirements, will offer a suitable optimization result.
- A dedicated optimization window where results are updated and the history is tracked.

The optimization algorithms cover the following four situations:
- **Random pattern**. The choice when geometry is not a concern, but the terrain makes some locations distinctly windier than other.
- **Regular pattern**. For offshore wind farms or similar uncomplicated terrain where the wind farm must obey geometrical constraints.
- **Noise based on remove/noise reduce turbines**. Allows the user to reduce a wind farm with a given layout to comply with noise constraints and find the optimal noise operation mode strategy.
- **Random pattern including noise based on remove/noise reduce visible turbines**. This combines the first and third option by first finding the optimal layout for maximum energy and then reducing it to comply with the noise limits. It also allows a track on the production loss due to different noise reduction strategies.

8.0.2 Optimize Step-by-step guide

8.0.2.1 Random pattern (hilly/complex terrain)

- ❑ Establish a WTG-area object with the region(s) of interest, eventually with restrictions for the number of WTG's or MW (for each area) and for the minimum distance.
- ❑ Add exclusion zones to restrict the wind farm from unsuitable land. This can be used to enforce a setback from critical terrain elements, roads or dwellings.
- ❑ Calculate a wind resource map with module RESOURCE (see chapter 3) or find an .rsf file from a WAsP calculation for the area of interest.
- ❑ Establish the .rsf file in a Result layer object.
- ❑ Start from calculation menu "OPTIMIZE" and choose "Random pattern".
- ❑ Set conditions for the calculation setup.
- ❑ Start the calculation – if a layout proposal has already been established, you can start with a PARK-calculation for this layout. This is started from the optimize window.
- ❑ Run a fast layout. This will add turbines to your projects using a fast but crude algorithm.
- ❑ Run the Full optimize. This is more detailed but also rather slow.
- ❑ Refine your setup manually and test if it leads to any improvements by clicking on PARK.
- ❑ Restore the preferred layout from the list with a right click.
- ❑ Close with OK and Print reports.

8.0.2.2 Regular pattern (relative flat terrain or off-shore)

- ❑ Establish a WTG-area object with the region(s) of interest, eventually with restrictions for the number of WTG's or MW (for each area).
- ❑ Add exclusion zones to restrict the wind farm from unsuitable land. This can be used to enforce a setback from critical terrain elements, roads, dwellings or sailing routes.
- ❑ Calculate a wind resource map with module RESOURCE (se chapter 3) or find an .rsf file from a WAsP calculation for the area of interest OR use a meteo object to describe the wind resource.
- ❑ Establish eventually the .rsf file in a Result layer object.
- ❑ Establish a PARK design object and set up the starting properties.
- ❑ Start from calculation menu "Optimize".
- ❑ Choose "regular pattern" and fill out conditions on calculation setup.
- ❑ Start optimizer – start with a PARK-calculation from the optimize window on the Park-design layout (do not "realize") – then set up the parameters for variation and run "full optimize".
- ❑ Refine your PARK design object and/or parameter variations until the best layout is found. Realize the layout by right clicking on the Park-design object or the result of the preferred layout.
- ❑ Close with OK and Print reports.

8.0.2.3 Noise based on remove/noise reduce visible WTGs

- ❑ Establish a WTG-area object with the region(s) of interest, eventually with restrictions for the number of WTG's or MW (for each area).
- ❑ Add exclusion zones to restrict the wind farm from unsuitable land. This can be used to enforce a setback from critical terrain elements, roads or dwellings.
- ❑ Insert noise receptors (NSA, see chapter 4) and give them appropriate noise limits.
- ❑ Insert a layout of wind turbines and if necessary define the different noise settings of the turbines.
- ❑ Start from calculation menu "Optimize".
- ❑ Choose "Noise based on remove/noise reduce visible WTGs"
- ❑ Select a turbine type in case you want to add turbines to the layout and select a noise calculation model.
- ❑ Run the "Noise optimize".
- ❑ Alternatively run "Auto fill" to insert a default tightly compacted layout and run "Noise optimize" to remove and reduce turbines until the noise requirements are fulfilled.
- ❑ Close with OK and Print reports.

8.0.2.4 Random pattern including Noise based on remove/noise reduce visible WTGs

- ❑ Follow the steps of Random pattern and Noise based on remove/noise reduce visible WTGs.
- ❑ When the Optimize controller appears it is possible both to run fast and full optimization and afterwards run the Noise optimization to reduce the layout to comply with noise limits. In addition the Park calculation option becomes available making it possible to immediately assess the production cost of reducing the noise level.

8.1. OPTIMIZE – Energy and noise

8.1.1 Calculation methods

WindPRO OPTIMIZER for optimizing a park layout is using three fundamentally different methods.

Model A. Regular pattern, where strict geometrical requirements is met (straight parallel rows with constant distances between WTGs in rows or arc layout)
Here, the Park-design object is used. Both manual and automatic optimization is possible.
The manual way: With the park-design object the user can graphically move, rotate and change distances while the program keeps track of the number of WTGs or total capacity within the wind farm areas that can be defined with the WTG-area object. Once a reasonable layout has been found that meets the constraints for the project you can establish with the "realize" menu the WTGs that are within the specified WTG areas. New additional layout can be established - each time a layout is realized, a new layer is automatically created holding the realized WTGs. When the different layout alternatives have been created, the alternatives can be easily calculated and compared with regard to energy production, noise, visual impact etc.
The automatic way: After establishing of the Park design object, start the OPTIMIZE program from the main menu. Select "Regular pattern" and set up the calculation. Note you can set a minimum park efficiency (max. array losses) and thereby secure that configurations not fulfilling this minimum is excluded in the optimization. When the optimize window is started you can choose which parameters to vary and step size. Choosing "Full optimize" all combinations will be calculated and the one giving the highest energy production will come out as the result. If minimum park efficiency is set, this criterion will be added in the selection of the optimal layout, ignoring layouts that do not meet the minimum park efficiency.

Model B. Automatic optimization of the layout with regard to energy production within specified areas.
The optimization can include constraints on minimum distances to neighbors. All main assumptions for the calculations are specified under the WTG-area object where requirements to the number of WTGs or installed capacity can be defined together with minimum distances within one or more areas. The WTG area object also defines restriction zones and setbacks from these.

Before starting the Optimizer you will need to calculate a wind resource map (a WAsP .rsf file) at a reasonable high resolution (typically 10 - 25 m grid) for the area for all relevant hub heights.

You can choose whether Optimizer should move already defined WTGs inside the area to the best positions or let Optimizer create the new WTGs. The first option enables the use of different WTGs and/or hub heights while the latter option only allows one WTGs type and hub height. The program will create the number of WTGs or the total capacity required if there is sufficient space - otherwise as many as possible.

To place the turbines three options are available.

Auto fill. WindPRO will pack as many turbines as possible onto the WTG area available. It starts a corner and simply places the next turbine on the first available location keeping the distance constrain as defined in the area. to the right and below the last turbine placed.

Fast energy layout. WindPRO finds the available location with the highest energy resource according to the wind resource maps and place a turbine. The next turbine will be placed on the location with the highest energy resource now available. This method does not take into account the park efficiency when selecting where to place the turbines. Locations are defined by a grid which can either be the grid of the wind resource map or a custom defined grid.

Full energy optimize. As in the fast optimize WindPRO finds the location with the highest energy resource but also takes into account the wake loss caused by turbines already placed. After it has placed the second turbine the first turbine is replaced taking into account the wake of the second turbine. This is repeated every time new turbines are placed. The turbines previously placed are replaced according to best park efficiency.

Model C. Noise optimization.
The noise optimization requires a given layout of turbines with a range of operation settings. The operation settings of the turbines are defined in the properties of the wind turbine as level 0 (standard), level 1, level 2 etc. with progressively lower noise level and accordingly less producing power curves. Also a number of Noise Sensitive Areas (NSA) must be defined for the surrounding dwellings and other noise sensitive locations.

The noise optimization is set up by selecting the appropriate noise propagation model (see chapter 4) and is started from the optimizer controller. It follows the following algorithm:

All turbines are reduced to the lowest noise level and a noise calculation is made. If the noise calculation does not pass the noise limits at the receptors, the turbine that provides the highest noise contribution at the receptor where the noise limit is exceeded the most, is removed. The process is repeated until the wind farm at its lowest noise setting pass below the noise limits of the receptors.

The turbines left are then set to the highest noise level and the noise impact is calculated for the receptors. If the noise limits are exceeded the turbine contributing with most noise at the receptor where the noise limits are exceeded the most, is reduced one level to a lower noise emission. The process is repeated until the noise calculation complies with noise limits for all the receptors.

If the combination of noise and random pattern optimization is selected a park calculation can be made on the layout from the Optimizer controller before and after the noise optimization to assess the loss of production due to noise constraints.

8.1.2 The objects used in the optimization calculations

8.1.2.1 The WTG Area Object

The WTG Area Object is used to define the areas to use for siting the WTGs. This is often the very first task when a WindPRO project is made, to define what land is available and often just as important, what land is not available. The WTG area object defines both types of land.

The land may be a large swath of land or parceled out in many smaller elements but for a given project all the areas are handled by a single WTG area object.

A WTG area object is placed on the map by selecting it from the list of object types and a single left click on the map. The location of the object is not important. When an object is placed the properties of the WTG area object is immediately shown.
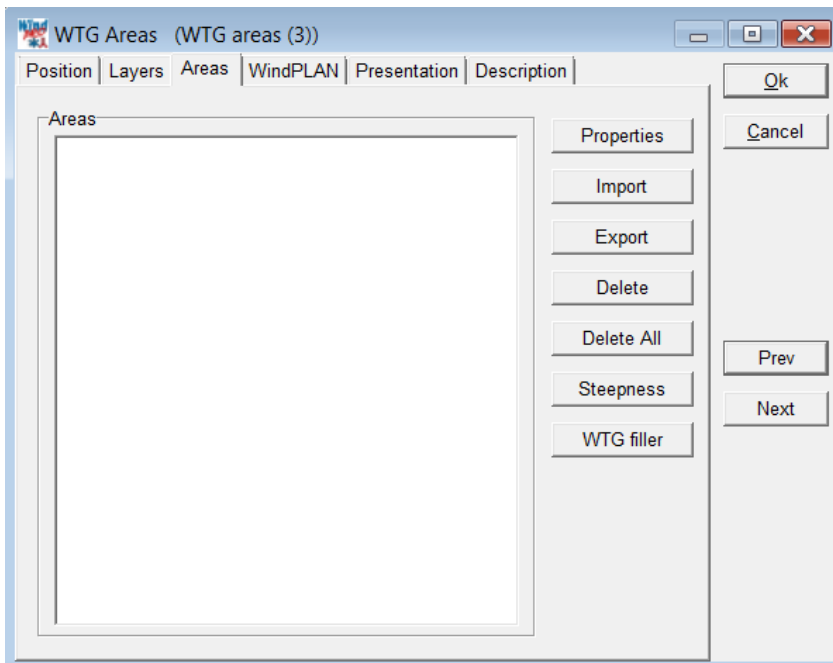

The limits of the areas can be digitized directly using an on-screen map (see below), but it is also possible to import coordinate files defining the limits. At present, files in the formats: **.dxf** (AutoCad/Autodesk) or **.shp** (Shape files from Arc View GIS files) can be imported.

Import of areas from file
From the WTG area object properties press the Import button to import a shape or .dxf file with area definitions. Please note that the dxf file must be in Autocad12 ASCII format.

In the file browser select the appropriate file. Beware that the coordinate system of your file has to be selected accordingly otherwise the areas will not be imported into their correct positions.
If the file is a .dxf file it is simply loaded. If however a shape file is selected an import window appears.
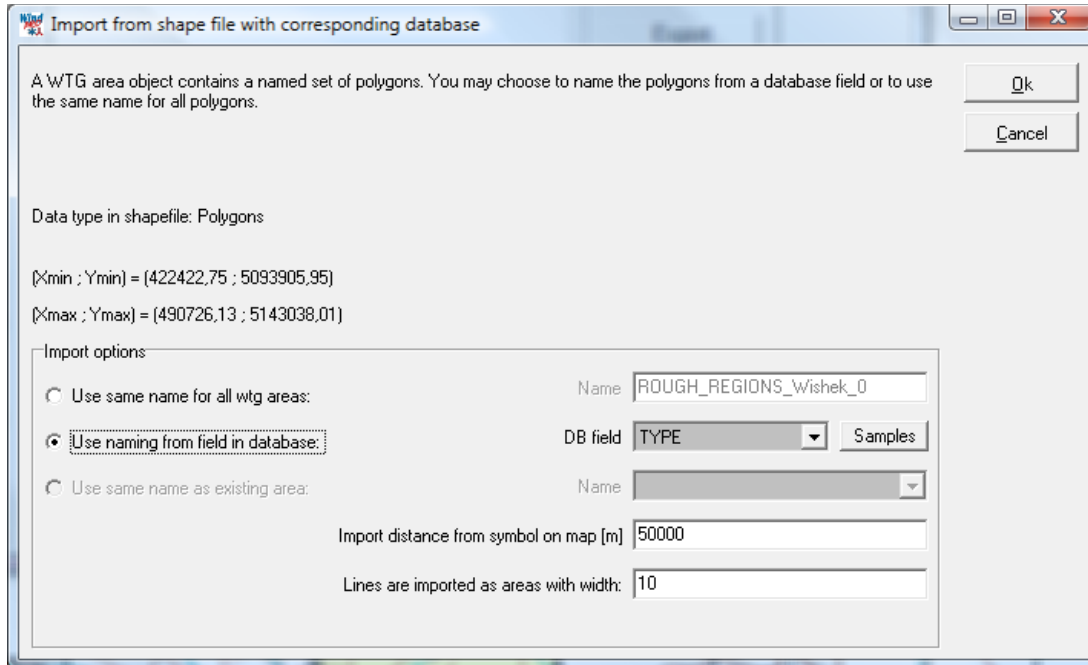
This window allows some options when loading an area file:

Use same name for all WTG area: this will label all the areas defined in the file with the same name. The name is written in the Name field to the right.

Use naming from field in database: you now get access to the DB field, where you can select which field in the database file defines the area type. To recognize the field, it is useful to press the Sample button to show the first few names in the list.

Use same name as existing areas: in this case, you can select in the Name field to the right one of the names already being used in the WTG area object. For example this is useful when you have already defined a few roads and now got a file with more roads to add to the existing ones.

Import distance from symbol on the map: this limits the import of areas within the given radius.

Lines are imported as areas with width: some shape files contain elements not defined as an area but as open lines. The WTG area object cannot operate with lines, but will convert the lines to areas with a width given by the number in meters in this field.

The file is now imported by pressing OK and the areas are labeled according to the choice made.

Digitizing your own WTG areas
If you have just placed a WTG area object on the map and want to digitize your own WTG areas you need to close the properties window by pressing OK.

You will notice that the WTG area object is surrounded by a red dashed square. This means that it is in edit mode and you can now start digitizing. Find the boundary of your area and right click in the mouse at the starting position. You now get the following options:
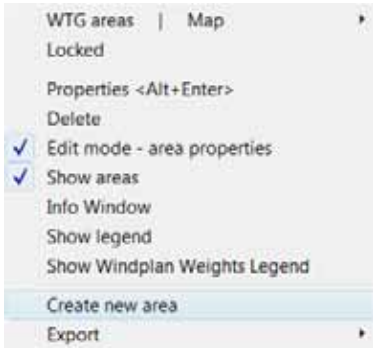
Select "Create new area". Now appears the properties for this particular area you have started to digitize.
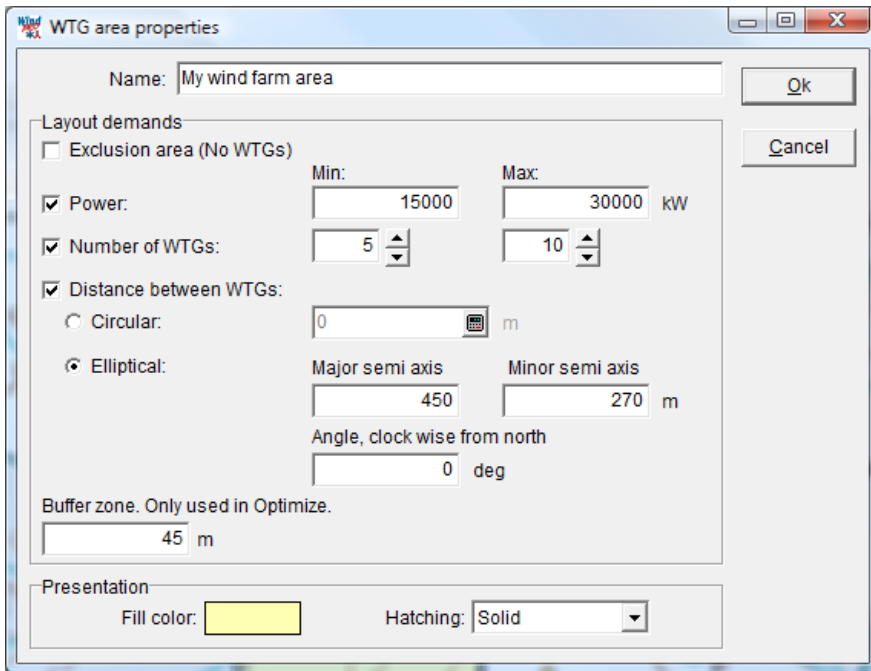
Give the area a name and set appropriate properties for the area.

Power: Hatching this allows you to set a minimum and maximum amount of installed power for this area. The optimizer must if it is possible at least place the amount of installed power indicated but no more than the maximum amount.

Number of WTGs: Same as for power but by count of wind turbines.

Distance between WTGs: Circular means than the required minimum spacing between turbines in this area is omnidirectional and the spacing can be typed in or calculated with the little calculator. If elliptical is chosen there is a main direction (typical the prevalent wind direction) defined by the Angle and a spacing given as the Major semi axis. Perpendicular to this is the spacing along the Minor semi axis. In the example below an elliptical spacing is selected with the major axis pointing north-south, 450 m spacing along this axis and 270 m across.

Buffer zone: This creates a setback from the area boundary to keep the turbines away from the edge of the area;this could be used to avoid the blade tips to cross into the neighboring piece of land.

Fill color and Hatching: The area will be filled or hatched with the color and hatching shown. The color is transparent so it is possible to see what happens underneath.

Click Ok and start digitizing (see chapter 2 for detail on digitizing areas). Be sure to close the area (right click, End) before proceeding.
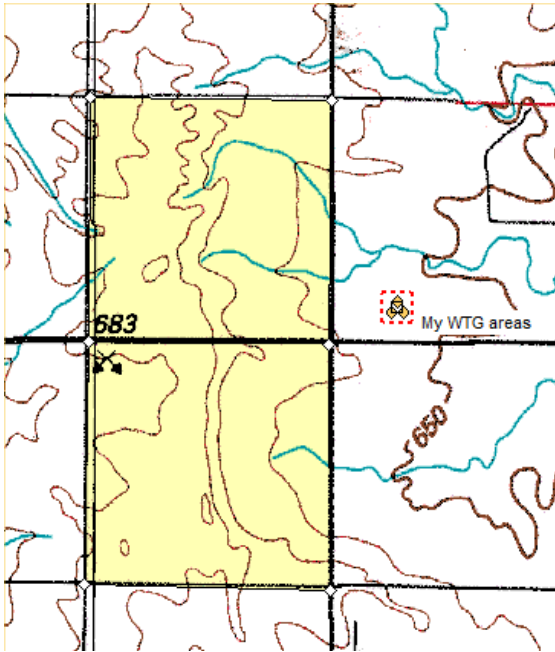
If you select the area (by clicking on it) you can see the points it is made of. This white diamonds can be moved manually from the map. If you right click on the boundary you have a few more options:
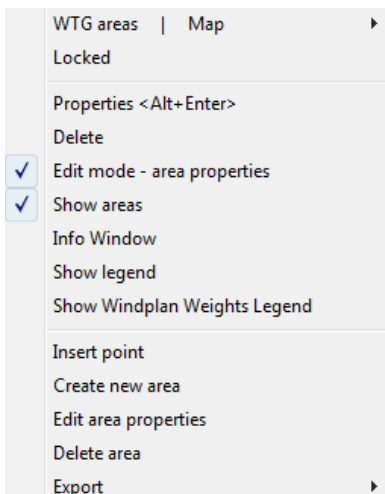
Insert and Remove point will add or remove node points along the sides of the area.
Delete area will simply remove the area. Be careful not to select Delete as this will remove the entire area object.
Edit area properties takes you back to define the properties of this particular area.
Create new area allows you to digitize another area.

Info Window gives information of the individual defined areas like size (m^2), color representation and demands see example below:

**Properties of the WTG area object**

Right click on the WTG area object to assess the properties of the WTG area object. Here the digitized or loaded areas are listed and a number of options are given on the right side of the list. There are a number of tabs, but only the "Areas" is relevant for the Optimize functions.
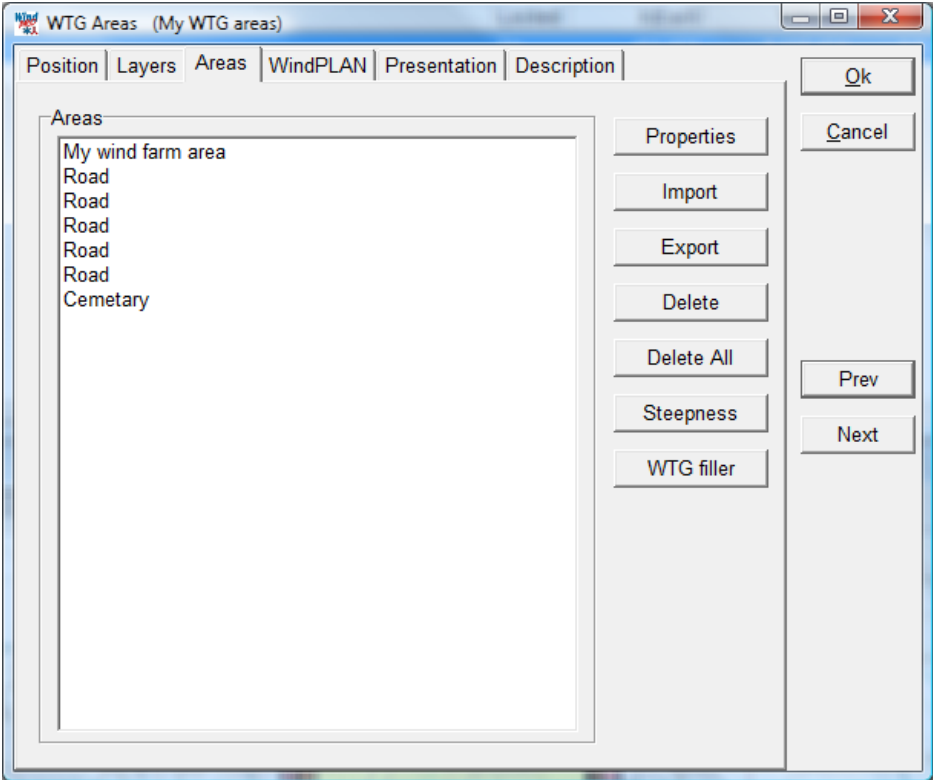
Properties: Highlight an area and select Properties to access the properties of the particular area. Double clicking on an area will also access the properties of the area.

Import: See above

Export: Pressing the Export button allows you to save the area definitions as a shape file. A specific coordinate system and file path can be selected.
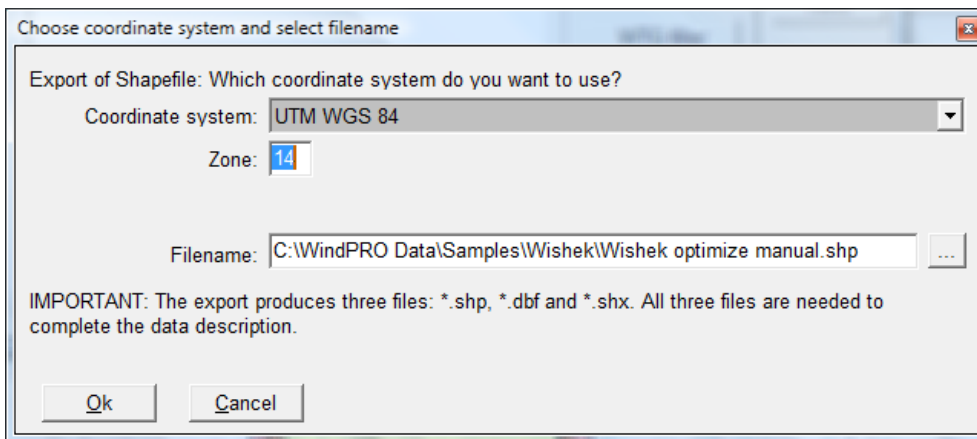

Delete: Highlight an area and press Delete to remove it. WindPRO will first ask if you are sure and then ask if you want to remove all areas with this name. In this way it is possible to easily get rid of for example 50000 imported wetland areas.

Delete All: This removes all areas.

Steepness
Press the steepness button to open the steepness tool. The steepness tool is used to find all locations within a defined area where the steepness of the terrain exceeds a given limit and declare them exclusion zones.
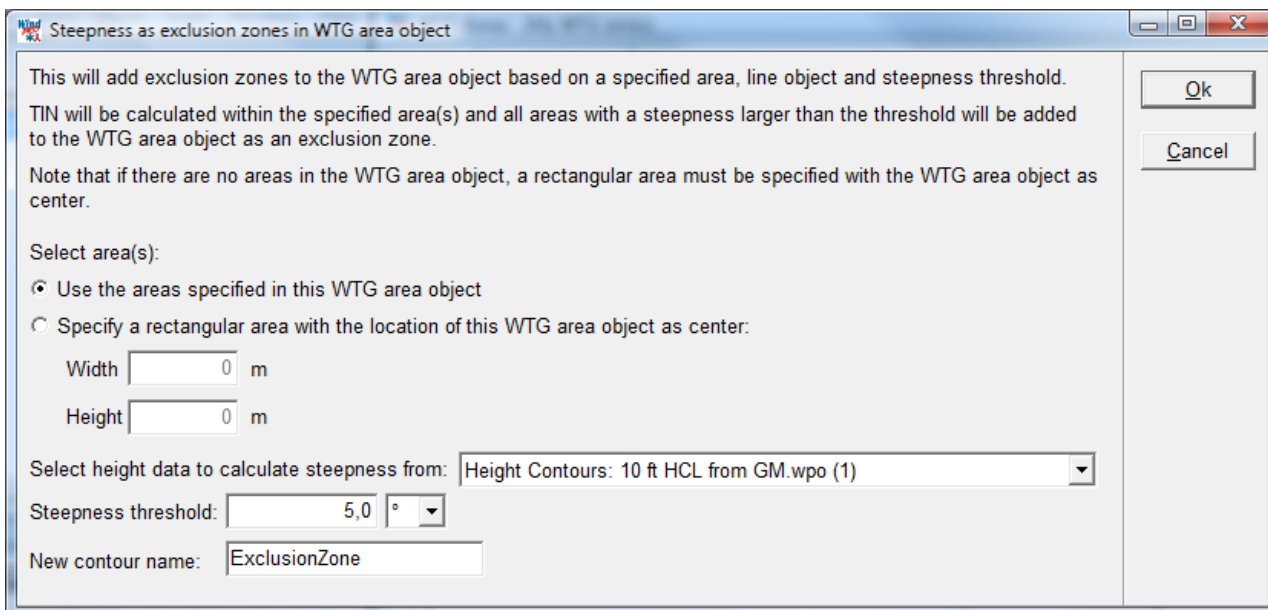

The extent of the steepness analysis can either be given by the WTG areas defined in the WTG area object (recommended) or by giving a width and height of a rectangle centered on the WTG area object.

The steepness is based on a line object with height data. This can be in the form of height contours or point elevation data (XYZ data). The line object that is to be used can thus be selected.

The steepness threshold is the steepness beyond which should be classed as exclusion zone. The steepness can be given in both degrees and percentage.

When the calculation is run WindPRO will create an exclusion zone for every TIN triangle where at least one altitude exceeds the steepness threshold. Neighboring triangles that exceed the threshold are merged to a larger area to reduce the total number of steepness areas.
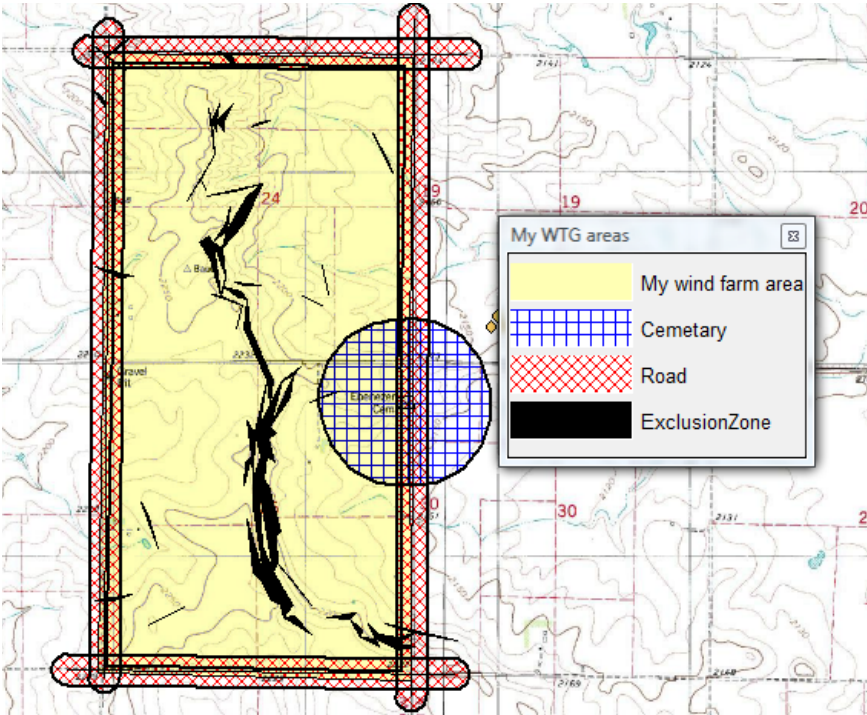
WTG filler

The WTG filler button fills up the available area with turbines.A turbine type and hub height is selected using the usual WTG browser. Then WindPRO fills up the available land defined by the WTG area object, but excluding areas defined as exclusion zone. The filler ignores the minimum and maximum number of turbines or MW of the areas but uses the spacing information to place as tight a formation of turbines as possible. This function is identical to the Auto fill function in the Optimize controller and is described in section 8.1.1.
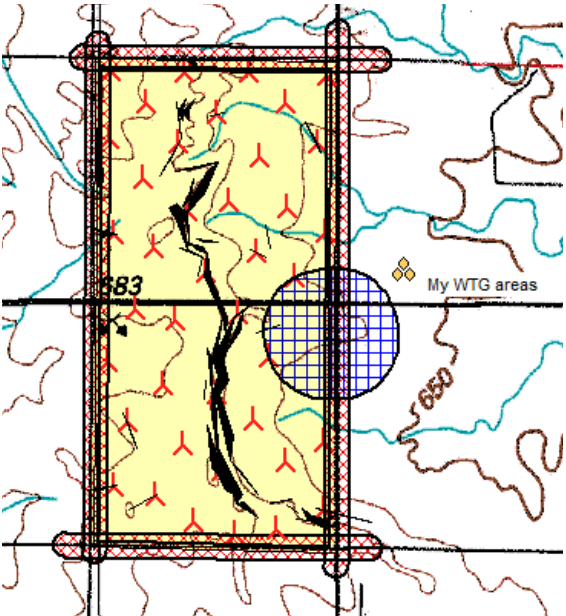
8.1.2.2 The Park Design object

The Park Design object creates regular pattern layouts. Instead of placing individual turbines or rows of turbines on the map, the Park design object can place a geometrical layout consisting of rows and columns on the map. The following regular patterns are available in present version:
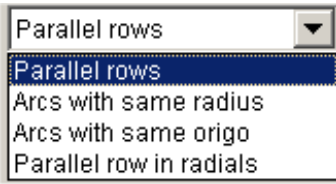
With the park design object it is possible to create a layout template which can be realized within the available land boundaries defined by the WTG area object.

The park design object is created by selecting the object from the object type list and left-clicking on the map. This opens the properties window of the Park design object.

On the WTG type tab the appropriate turbine type and hub height is selected using the usual WTG browser.

The grid tab defines the WTG grid:
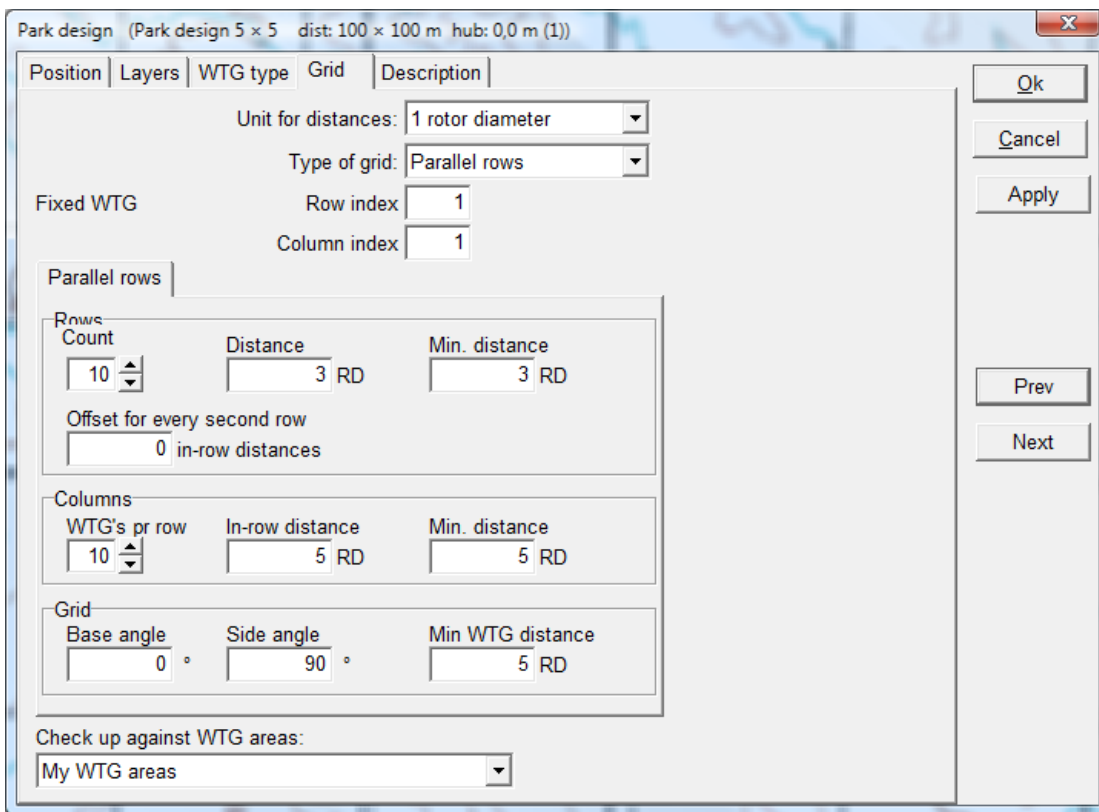
Unit for distances: The distances in the grid can be given both in meters and in multiples of rotor diameters.

Type of grid: The available grid types are described above.

Fixed WTG: it is like an anchor around which the grid can rotate or be shifted. It is marked on the map with a circle. For further description see below.

The parameters options of the grid depend on the grid type selected. Here are described the grid types for the parallel grid.

Rows
Count: This is the number of turbines in a row.

Distance: This gives the initial distance between turbines in the rows.

Min. distance: The minimum distance between turbines in a row. The grid cannot be manipulated to a lower spacing than this in the rows. The value must be similar or less than the initial distance.

Offset for every second row: This is a value between 0 and 1 giving the multiples of the in-row spacing that every second row will be offset.

Columns
WTG's per row, in-row distance and Min. distance: These are column equivalents of the parameters for the rows.

Grid
Base angle: The angle (direction) of the base line in the grid.

Side angle: The perpendicular angle. 90 degrees gives a right angle on the base angle.

Min. WTG distance: This is the overall spacing requirement of the entire grid.

Check up against WTG areas: Here a WTG area object must be selected. The WTG area object will give the boundaries of the wind farm and thus define which turbines in the grid will be allowed to be realized.
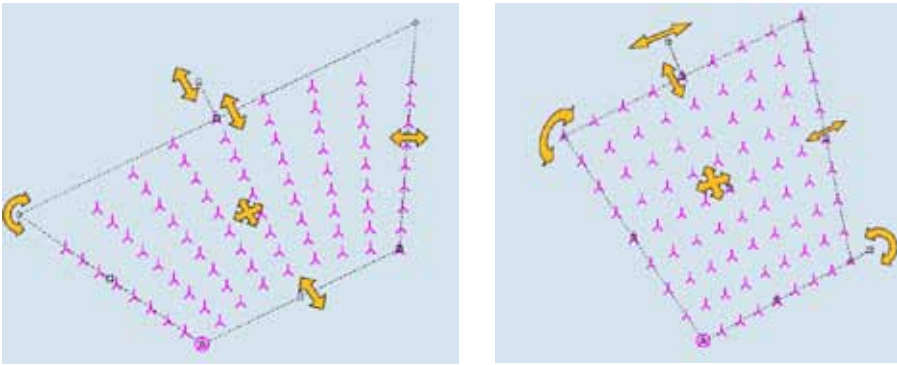
Press OK to close the properties window and the Park design object now appears as a grid of turbines.
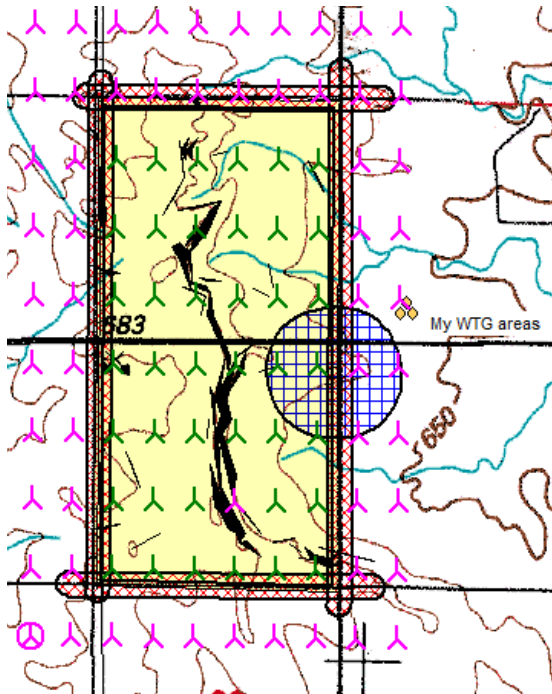
Manipulation of the layout with the Park design object.
Below the four different regular patterns (Parallel row, Arcs with same radius, Arcs with same origo and Parallel row in radials) are illustrated:
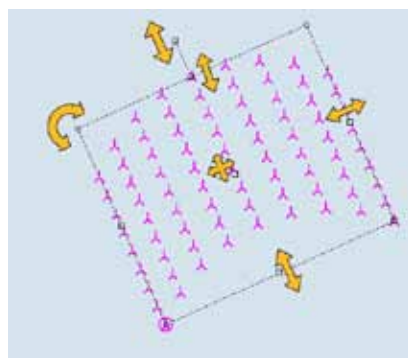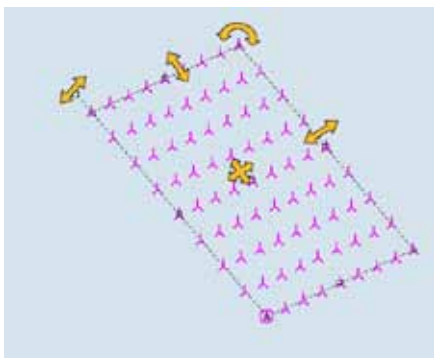
There are handles, which makes it possible with mouse drags to change all figures defining the rotation, distances, position and specific angles/radius depending of type of pattern.

The fixed WTG, marked with a circle around the turbine. This is the WTG in the pattern that always stay at the same position except if the middle point is moved, which in that case makes a parallel move of the complete pattern. The fixed WTG can be changed to another WTG in the pattern simply by right clicking at a WTG symbol and choosing "Mark as fixed WTG".

The only parameter that cannot be changed graphically is the row offset, illustrated below.
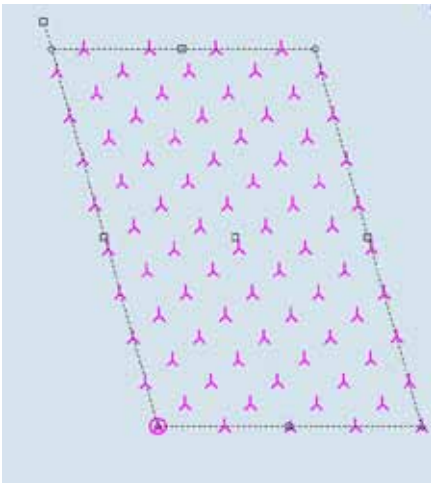
The row offset in the parallel row layout makes it possible to shift every second row from 0 to 1 in row distances. Here illustrated by the value 0.5.
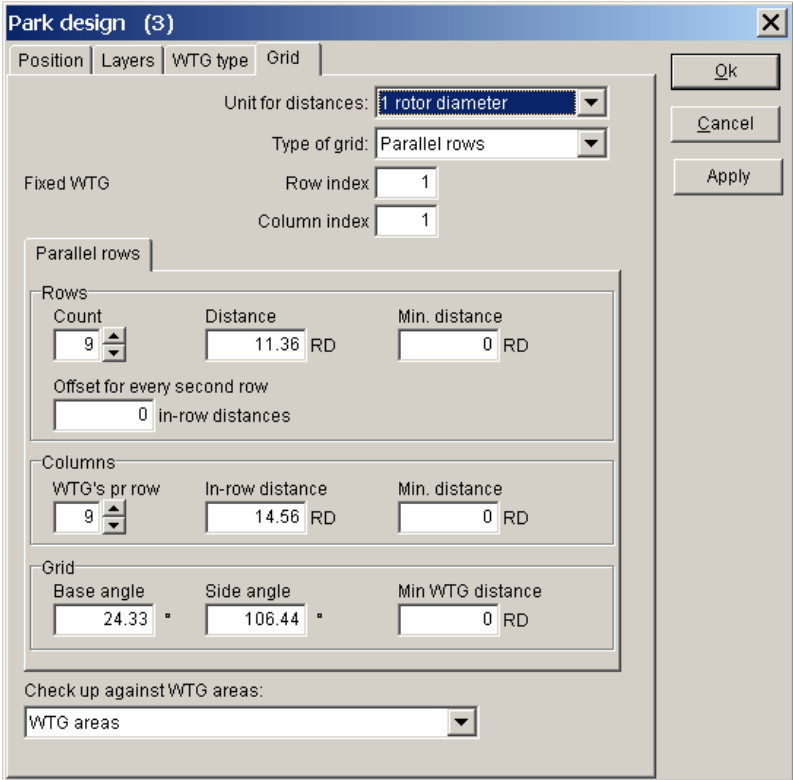
It is possible to keep a continuous control of the number of WTGs or total installed capacity within the area specified by the WTG-area object (see next graphic, right click on the object and select "Info window") when the specific WTG area object is selected in the drop down menu in the bottom.

Area name	▲	Insid...	Min c...	Max c...	Diff c...	
North		8	8	10	0	
South		3	3	3	0	
		11			0	
Count	▼					
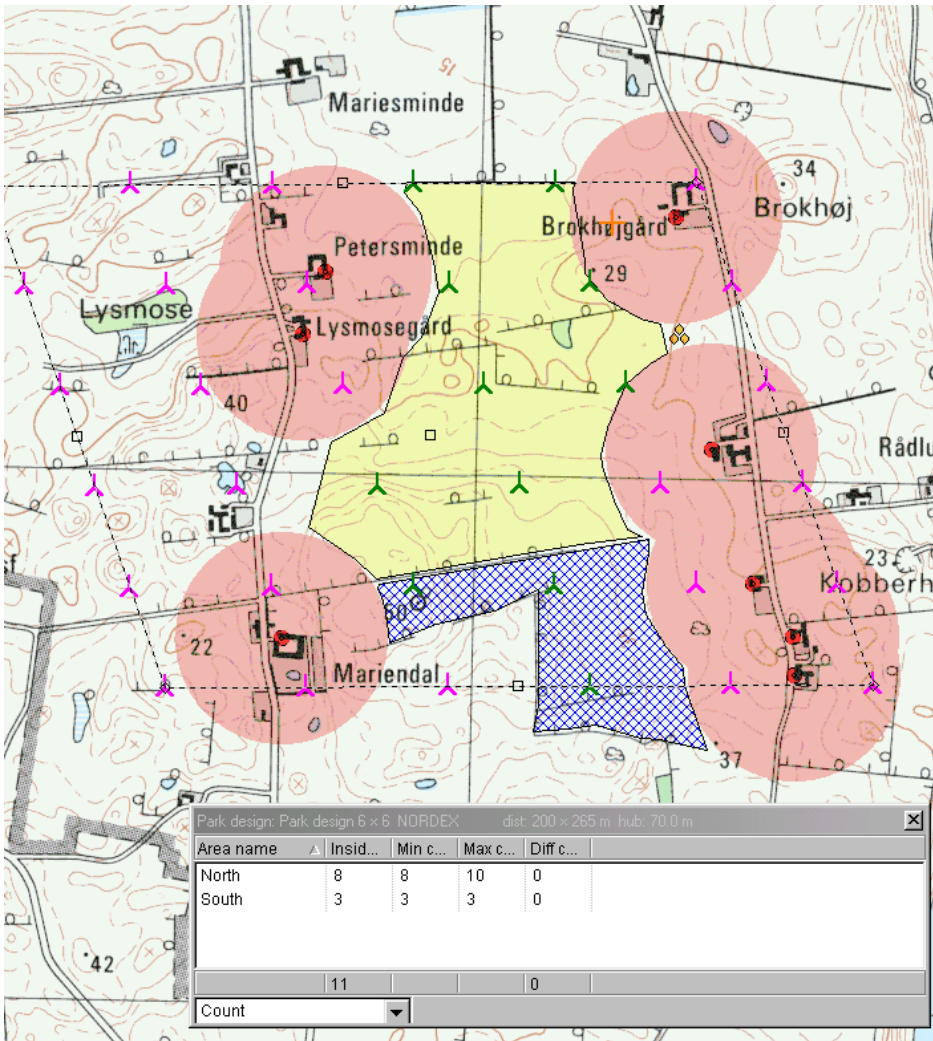
WTG symbols inside the WTG areas are shown in green while those outside the areas are shown in pink. Note the info window that informs you that there are 8 WTGs in the northern area and 7 in the southern. The deviation between actual and required values is shown in the rightmost column - in this case "0" in both areas indicating that the actual values are within the requirements.

8.1.2.3 Realizing the WTGs placed inside the areas (model A manual)

When a suitable layout has been made with the Park design object, right click on it and select "realize". The green WTGs will now turn red, as they become WTG objects. These can then be treated as normal WTG objects. The WTGs are automatically created in a new layer. You can then modify the park-design object (move, rotate, change WTG type or hub height) and realize a new layout. When all the proposals you want to test have been realized, you can get to the calculation menu and carry out the required calculations.
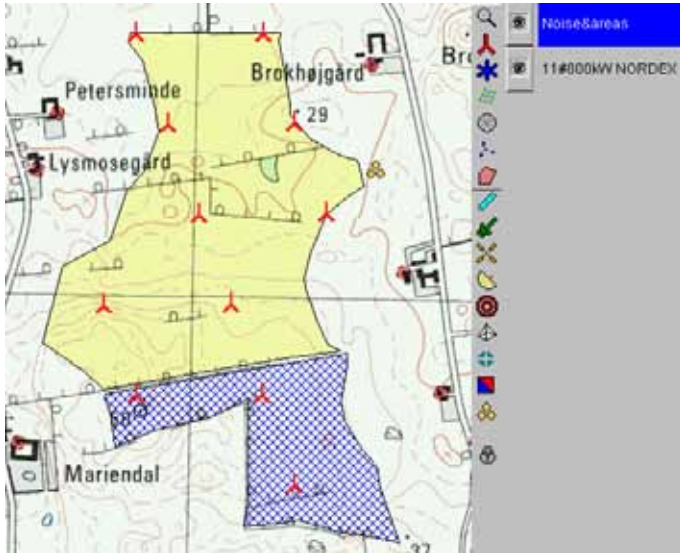
## 8.1.3 OPTIMIZE – Energy, Regular pattern, model A automatic

The optimization of a regular pattern layout is simply a calculation of all layout combinations possible with the chosen set of parameters for the project.

This is here illustrated for an off-shore project.
First the area of interest has to be defined. Below a map from UK, DTI report showing "potential areas" give an example of a region that could be chosen.
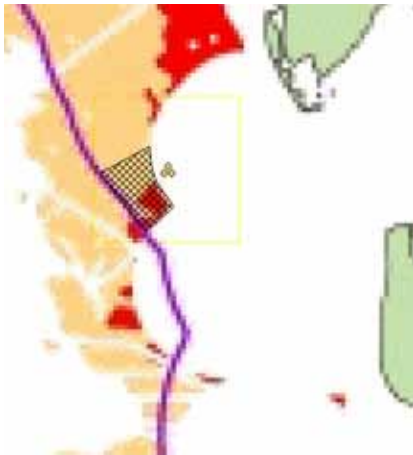
A WTG area is defined with the WTG area object around the area of interest by digitizing on top of the background map. On below map a wind resource map has been calculated and placed as a background on top of the map (with a Result layer object). As can be seen in the example the wind resource is often uniformly distributed and thus a METEO object can be used as an alternative to the wind resource map. A PARK design object giving the first draft layout is placed on top of the WTG area.
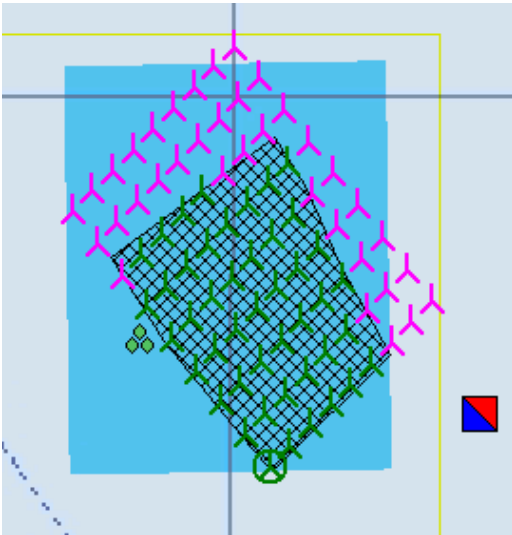
The WTGs inside the area are green, the ones outside are purple. Now it has to be decided which criteria should be met and which parameters to vary. The calculation module OPTIMIZE is started.
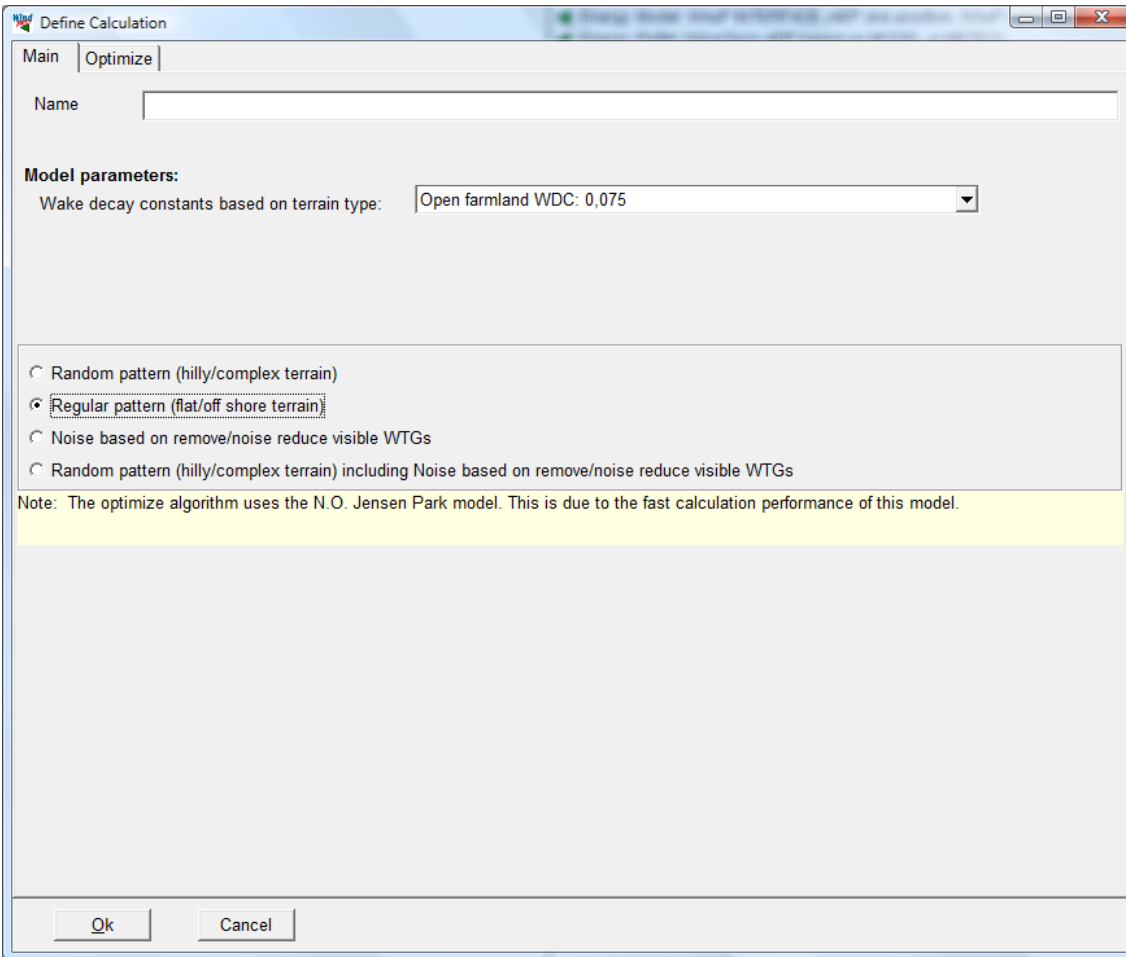

While the general recommendation is to set the Wake decay constant to 0.075, the consensus is that 0.04 is a better choice for off-shore wind farms.

For a regular pattern optimization select the Regular pattern option.

On the Optimize tab sheet the Park design object and the .RSF file already established appear as default. If more than one of these are established in the project, the right one can be chosen here. Alternatively a Meteo object can be selected. The measured wind speed scaled to hub height with the shear factors in the Meteo

object will then be used for all turbines in the layout. A minimum park efficiency can be set (here 95%). Layouts with a poorer performance than this will be ignored in the optimization.
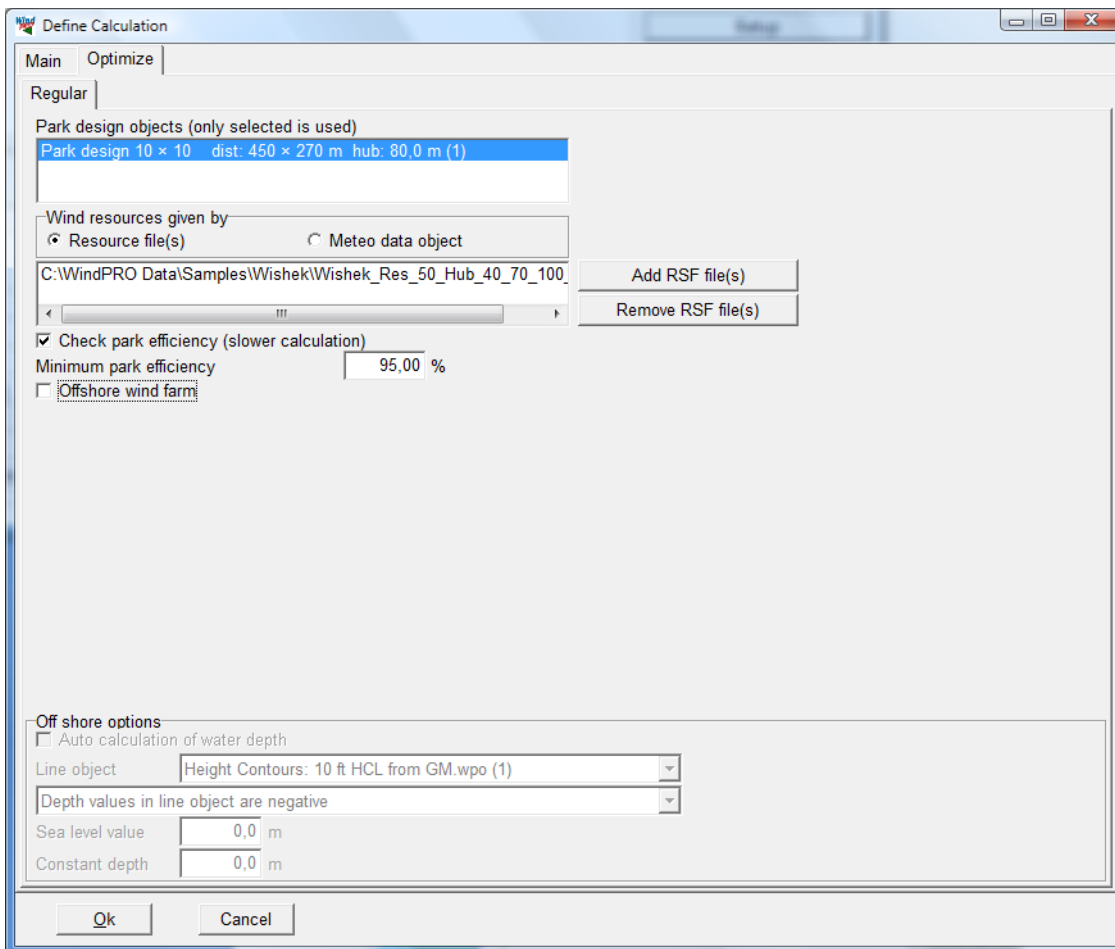
It is possible to hatch a box called Offshore wind farm. This makes the bottom part active. WindPRO can then use a line object with height contours as water depth (Auto calculation of water depth) or assume a fixed water depth (with Constant depth). These values are used later when dumping results to file (see below).

Sea level value: This is the water level that can be changed in the case of an offshore project in a lake.

Press OK to start the optimization. This opens the Optimizer controller for regular pattern optimization.
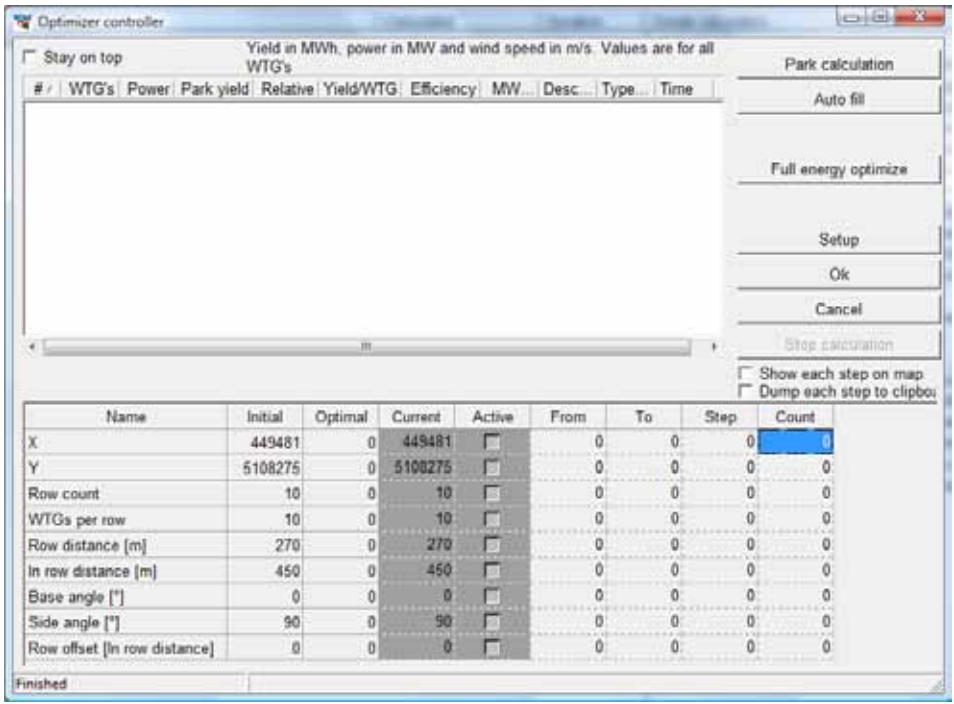
The Optimizer controller is one of the few windows in WindPRO which are allowed to stay open while you work on the map. The box "Stay on top" forces the controller always to remain on top of the map. Unfortunately this may block access to error messages so it should be used with care.

A PARK calculation can be performed in order to have a reference production based on the manual first layout. The result is displayed in the white result window.

Auto fill fills up the area according to the algorithms described in section 8.1.1.

Now the task is to find the layout that maximizes the energy production within the WTG area without going below the minimum Park efficiency.

The pattern of WTG's is fixed in the lower left corner. The parameters that can be varied are:

- · Starting point X of the fixed WTG
- · Starting point Y of the fixed WTG
- · Number of rows
- · Number of turbines in the row
- · Row distance
- · In row distance
- · Base angle
- · Side angle
- · Row off set

The parameters, which should be varied, are checked and reasonable intervals and step values are set.

Start the calculation with "Full energy optimize".

Below the calculation result and the optimization set-up is seen. 1944 calculations are performed (around 10 minutes on 1 GHz PC). The result is 64 WTGs and a total production of 965 GWh – this is 36.9% more than the reference layout and the Park efficiency is the 95% that was set as the minimum limit for an acceptable result.
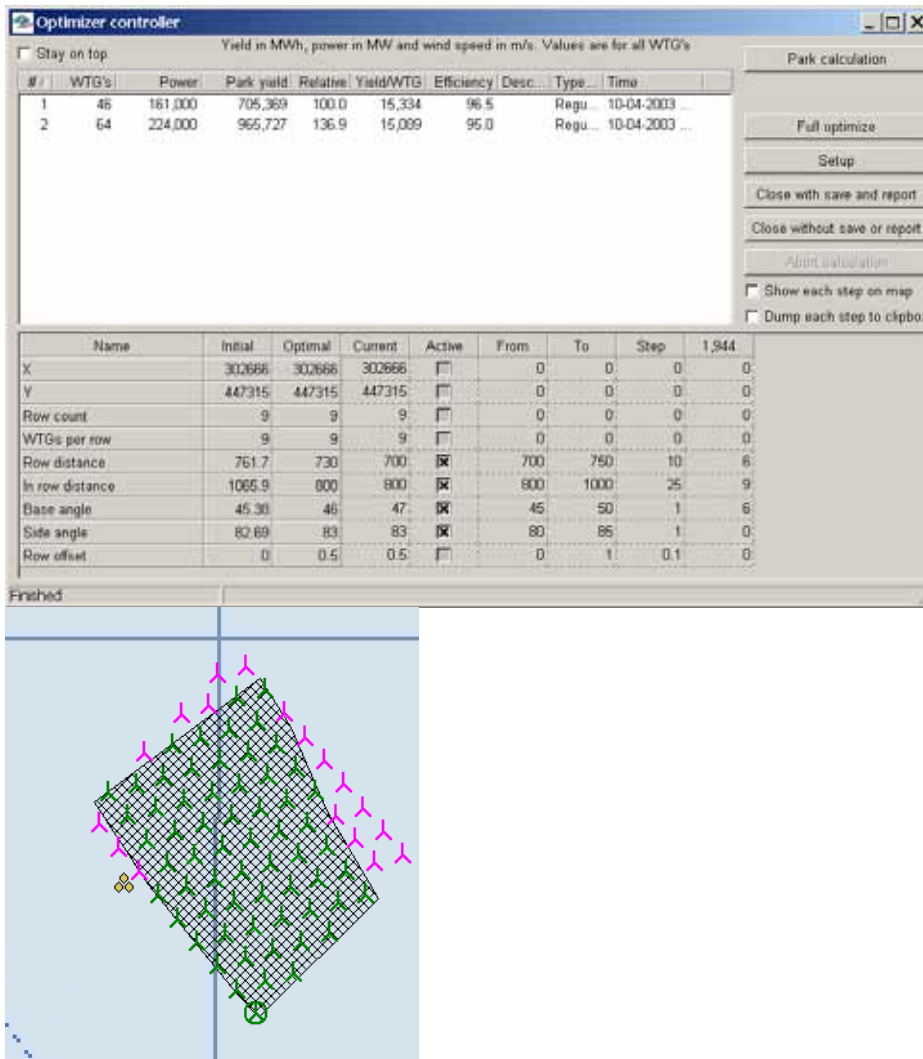
The optimized layout based on first run.

Now the first layout has been made and it is possible to continue with further optimization by varying the parameters in smaller steps around the first optimum and include more parameters. Or we could test other WTG types or other patterns. If we later want to return to a previous result, the result is highlighted and a right-click allows "Restore layout". This resets the PARK-design object to that particular configuration. In this way the optimization is an interactive process where the user gives the specifications and the software helps optimize the parameter values.
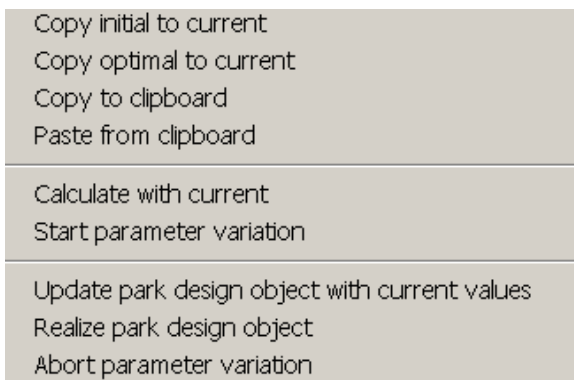
A right click in the parameter variation area access the above list of possibilities. They have the following functions:

Copy initial to current: Copies the content of the "initial" column to the "Current" column. The "current" column being the set of parameters generally used in the calculation.

Copy optimal to current: Copies the parameter setting from the so far most optimal layout and pastes it into the "current" column.
Copy to clipboard: Allows for transfer of settings to spreadsheet and other applications.
Paste from clipboard: Allows for transfer of settings from spreadsheet and other applications.
Calculate with current: Performs a PARK calculation with the settings in the "current" column. The result is displayed in the Optimize window as a separate layout result.
Start parameter variation: Starts the optimization run through the parameter intervals searching for the optimal layout.
Update park design object with current values: Modifies the active Park design object to reflect the parameter settings in the "current" column.
Realize park design object: Converts the draft WTG layout (green and purple symbols) to actual WTGs (red symbols) that can be used by other calculations.
Abort the parameter variation: Aborts the optimization run before it is through.

8.1.4 OPTIMIZE – Energy, Random pattern, model B

An automatic calculation of WTG positions requires the following input:

At least one WTG area defining the land available. Here you can also specify requirements to maximum number of WTGs or installed capacity as well as minimum distances (see description of the WTG-area object).

A wind resource map (a WAsP .rsf file) in a sufficient resolution - typically a 25 m grid. With the WindPRO resource module this can be calculated for a number heights in one process (and the results saved in a single .rsf file). This can be helpful in cases where you want to optimize for more heights or to use WTGs with different hub heights in one project. Please note that it is possible to link the WTG area object to the Resource calculation so that only the area where turbines are allowed will be calculated.

EXEMPTION: In cases where the wind conditions are constant over the whole area, e.g. for offshore projects or for large open flat plains, you can enter the wind distribution in a Meteo-object instead of using a wind resource map file. However, such projects typically require a geometrical pattern in which case it may be preferable to use the regular pattern optimization, model A described in section 8.1..3


You can with advantage present the calculated .rsf file via the Result layer object before starting OPTIMIZER. The .rsf file will then automatically be transferred to this object where it can be checked that the .rsf file looks plausible.

Click on OPTIMIZE in the calculation menu (double-click on the name or single-click the green arrow beside it - if the arrow is yellow instead of green you do not have a license to the module).

8.1.4.1 Optimization properties

On the Main tab select Random pattern and the appropriate wake decay constant. Note that in the optimization a simplified version of the N.O. Jensen method is used.
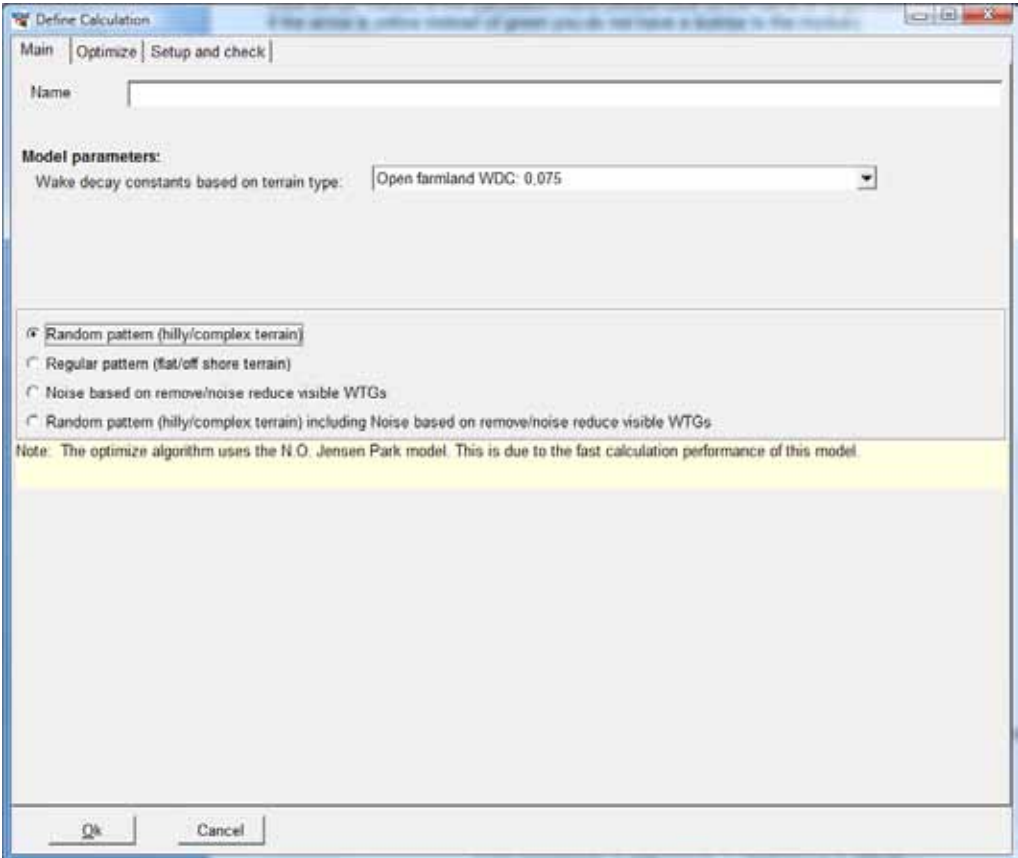
Continue to the Optimize tab.
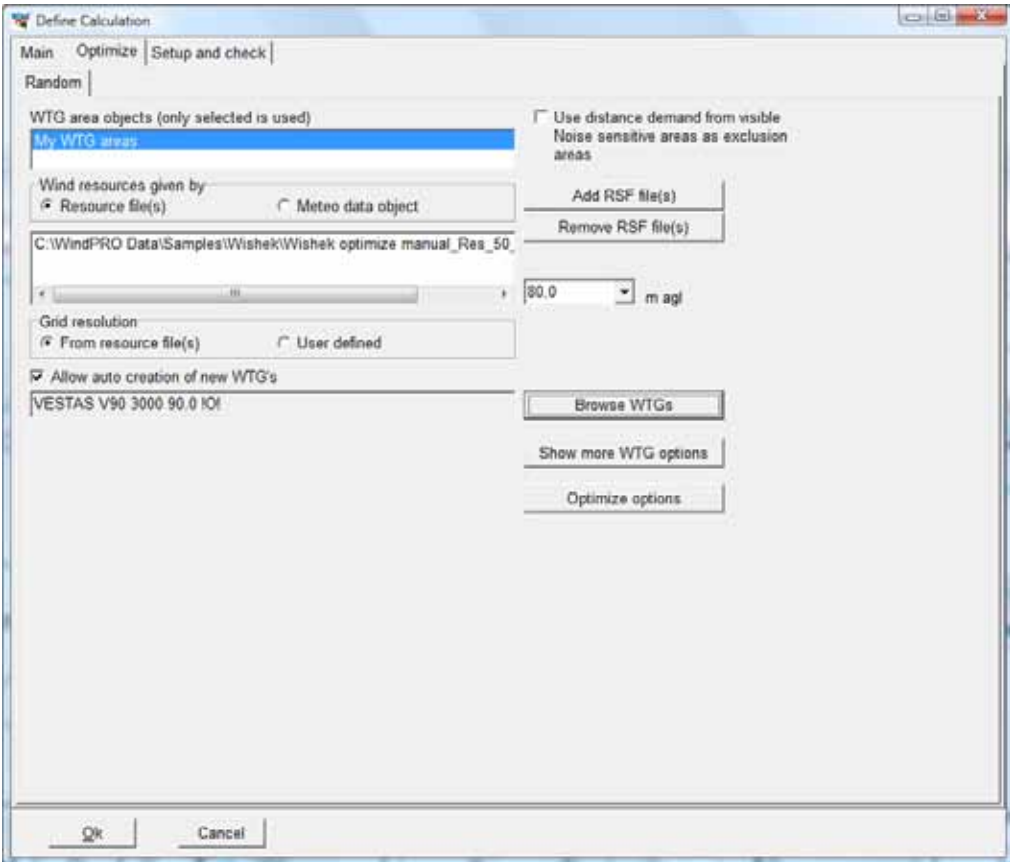
The window shown above is used to define the data you want to use and to perform different choices in case the Random pattern method is chosen.

The following settings are available:

- **Ø** The WTG-area objects to be used in the calculation. This tells WindPRO where (and where not) to place the turbines, how many and with what spacing.
- **Ø** Use distance demand from visible Noise sensitive areas as exclusion zones. This reads the distance demand of visible NSA and ensures a minimum setback to the neighbors of the wind farm.
- **Ø** The .rsf file(s) to be used in the calculation. Alternatively a Meteo object can be used. In that case all turbines will use the measured wind climate scaled up to hub height using the shear coefficient of the Meteo object.
- **Ø** The hub height to be used from the .rsf file.
- **Ø** The required grid resolution. OPTIMIZE will only place WTGs in the grid node points. Thus, if the resolution is 100m, only positions in a grid with 100m distances will be tested which will probably not lead to an optimal result. It is not recommended to use a lower resolution that 10 m and 25 m will normally be the best compromise between calculation time and accuracy. You can choose to use the resolution of the .rsf file as default or to specify a given resolution in which case an interpolated .rsf file is generated and used in the calculations.
- **Ø** Allow auto creation of new WTGs - must be activated unless the WTGs are already in the project and you "only" want to move these to optimized positions.
- **Ø** In case auto creation is chosen WTG type must be selected via the Browse WTGs button.

More WTG options - New WTGs can be created
If you have already created WTGs (and these are present in visible layers) you can decide how already created NEW WTGs on the map shall be treated:

- **Ø** Let the program delete them and create new WTGs from scratch
- **Ø** Keep them and lock them to their present positions (to be used in cases where some WTGs are required at fixed positions while new are inserted at their optimal positions).
- **Ø** Keep them, but move them to their optimized positions (this is the way to optimize a project with different WTGs types and sizes).

More WTG options - No new WTGs can be created
Here you have to create each WTG to be used in the project and the optimization manually. The options for these NEW WTGs you have created or are going to create are:

- **Ø** Allow WTGs to be moved between the WTG areas during the optimization. Typically used when the number of each different type of WTG is given but they can be optimized freely over the different areas.
- **Ø** Keep the WTGs within their original areas. Useful when you require different WTG types (or hub heights) in different area.

Finally you can decide how to handle already defined WTGs that fall outside the calculation area (the grid span of the .rsf file). You can choose to include them in the optimization by moving them inside the .rsf definition area or to delete them. The problem is that it is not possible for the program to include WTGs outside the .rsf definition area since there would then be no wind data to work on. Therefore you have to choose between the two options mentioned above.

Existing WTGs (blue symbols) will always stay at their positions but are only included in the calculation if they are within the .rsf definition area. If they are outside, the program will simply disregard them in the park/optimization calculations. When generating reports you can choose whether or not to include these WTGs in the printout. This choice is made in the properties for existing WTGs (see screen dump below).
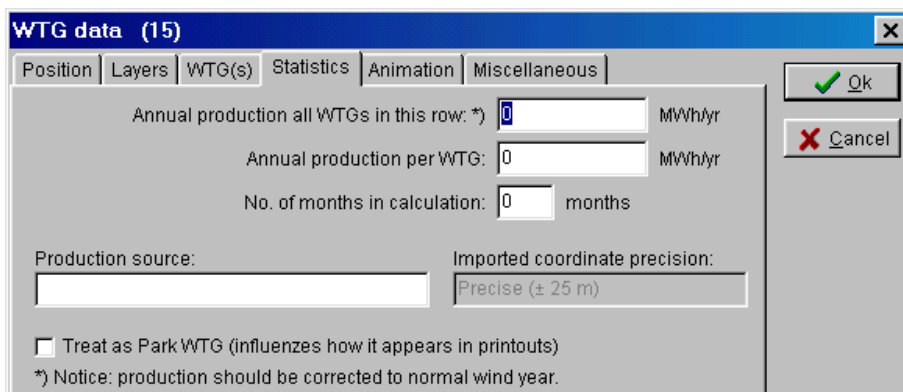
If the bottom check box is marked, the WTG will be included in the energy production calculation and in the report as a member of the wind farm. Otherwise it will only contribute to the array loss calculation while the energy production will not be included.

Optimize options
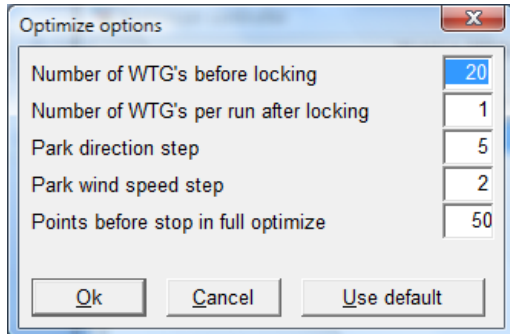
Number of WTGs to lock. For very large wind farms the calculation time would be almost endless if all possible layout patterns were to be tested. Therefore, the layout is locked at a certain stage for a number of WTGs. So, when the number of locked WTGs (here 20) has been selected, the free optimization stops and the first 20 WTGs are locked to their positions.

Number of WTGs per run after locking the first ones. After locking, WTG no. 21 will be inserted on the best remaining position with regard to the total wind farm production. You can also increase the number of WTGs per run after locking, e.g. to 5 WTGs - this speeds up the calculation but at the possible cost of a less optimized layout.

Park direction and wind speed step. Each optimization requires a very large number of calculations - therefore, the level of precision has a crucial impact on the calculation time. The last park calculation, however, is always carried out at the highest precision, e.g. in step of 1 degree and 1 m/s.

Layouts tested before stop in full optimization. Here you enter the number of layout variations to be tested for each new WTG to be included. Before each optimization run the program determines the specified number of layouts in the .rsf file that give the highest total productions considering a simple array loss model (outside the areas already occupied by the locked WTGs). Each of these layouts are then used in a full park calculation and the best total result is chosen. By reducing the number of layouts the calculations will of course run faster while an increase will be more accurate but slow down the process.

8.1.4.2 The Setup and check sheet

Here you can view the various optimization parameters entered into the program. The program checks the requirements from the WTG-area object and the optimize sheet. It informs you about the optimization to be started so that changes can be made before a time consuming calculation is performed.
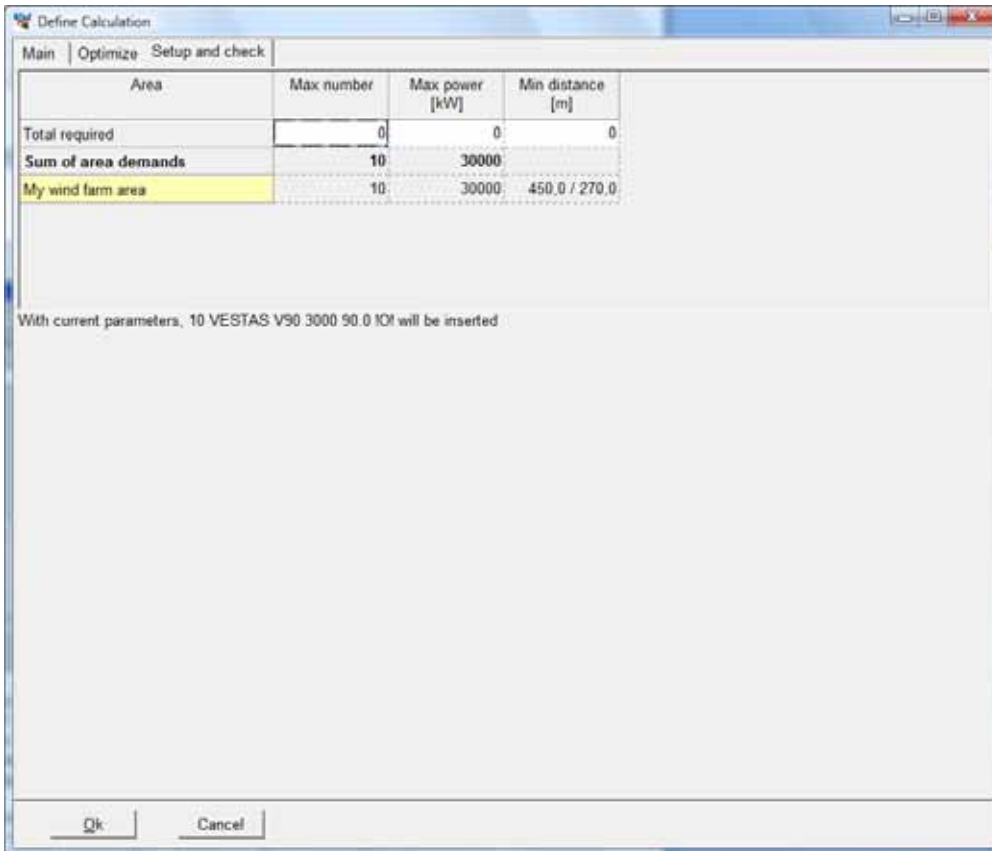
In the above example there is one area in the WTG-area object with a total maximum of 10 WTGs and 30000 kW. Since a 3 MW WTG has been chosen, the requirements will lead to a maximum of 10 WTGs. NOTE: Only the requirements to the total will be checked - not the requirements for the individual areas. Therefore the check will not necessarily give the precise prognosis. Furthermore, it might not be possible to include all the WTGs due to requirements to minimum distances and project area limitations.

Beside the check it is also possible to print the requirements entered for the WTG-area objects. In the line "total demands" you can enter requirements for the total. For example, if you have 3 areas with a maximum of 10 WTGs in each but need to limit the total number of WTGs to 25 because of the electrical grid, you can enter a maximum of 10 WTGs per area but limited to a total of 25. You can only reduce the overall limitations - not increase them. Finally, you can enter an overall minimum distance requirement for all areas, which will apply for each area and overrule any local requirements.

8.1.4.3 Start and use of the OPTIMIZE window
By clicking the OK button for "Define calculation" the Optimizer controller window appears.
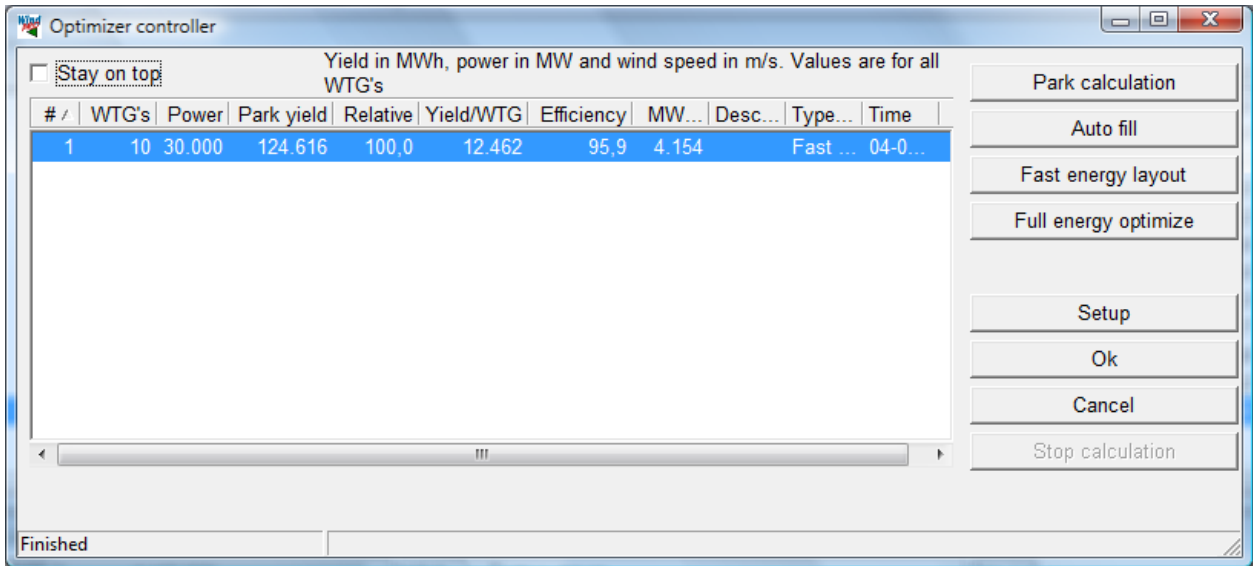
You can now click on the map and have both the map + the object list + the optimize window opened at the same time. The Optimizer controller is one of the few windows in WindPRO which are allowed to stay open while you work on the map. The box "Stay on top" forces the controller always to remain on top of the map. Unfortunately this may block access to error messages so it should be used with care.

It is always the visible WTGs (controlled by the layer structure) and the WTGs created automatically by the optimizer that are included in the calculations.

Here are four options:
Park calculation
This park calculation differs from the traditional park calculation by reading wind data directly from the .rsf file, which makes the calculation much faster. You can check the performance for a number of different layouts by making the layers in which they reside (possibly created via the WTG-design object) visible one at a time. Or you can move the WTGs around on the map and thereby test different layouts.

For each calculation a new line is created in the optimize window. You can always re-establish a given layout by right-clicking the corresponding line in the optimizer controller and select "Restore layout".

If a calculation is started based on WTGs with other hub heights than those included in the .rsf file, the window below will appear:
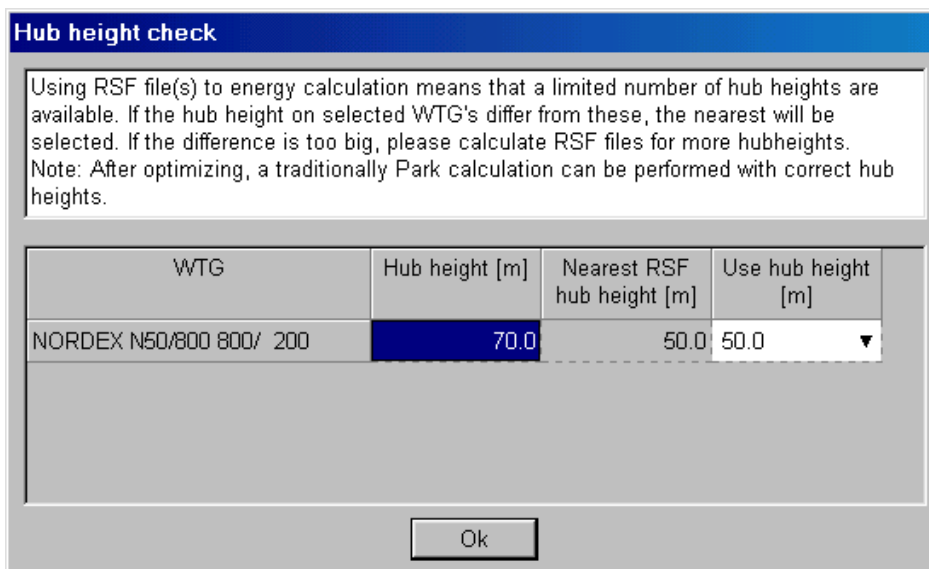
Here, you select which hub heights to use from the .rsf file. Of course using the wind speed from the wrong height results in the wrong wind speed and thus wrong production. However the relative differences will usually be correct if the height difference is small.

Auto fill
This option fill the WTG area with as many WTGs as possible can fit in based on minimum distance requirements. This is not really an optimization, just a way to find the maximum possible number of WTGs within the area. The algorithm used is described in section 8.1.1

Fast energy layout
This option makes an optimization based on the .rsf file and spacing requirements. This can be used with advantage to get a quick estimate of how the optimizer will place the WTGs without necessarily giving the optimal result. However, it gives you a general picture of the situation that can be used to assess and modify the input data if necessary before starting a time consuming calculation. The algorithm used is described in section 8.1.1

Full energy optimization
Here, the array losses are continuously calculated for each attempt to find the optimal layout. For large wind farms this calculation therefore can become very time consuming.

First, a WTG is inserted at the best node point of the .rsf file. Next, the second best position considering the park efficiency is found. Now, moving the first WTG in order to allow for two equally good positions rather than one superb it searches for a better total result. This process continues until all WTGs have been placed. The algorithm used is described in section 8.1.1

The program has been structured in a way that allows a compromise between the level of optimization and the computational time. You can choose yourself a weighting between calculation time and precision. In actuality this option only gives significant changes for wind farms with more than 10 WTGs. The option is found in the calculation setup under the "Optimize options" button.

8.1.4.4 An example of an optimization process

Below is shown an example of how an optimization process could look like - but there is of course more than one solution. The idea is more to show how some of the facilities can be used.

- Ø First, a fast optimization is run
- Ø Then a full optimization
- Ø A couple of WTGs are moved to improve the visual layout and a park calculation is run
- Ø This step is repeated

Below is shown the achieved production results for the two different calculations.

The gain from the fast optimization to the full optimization is 0.9% or 1.2 MWh/yr.
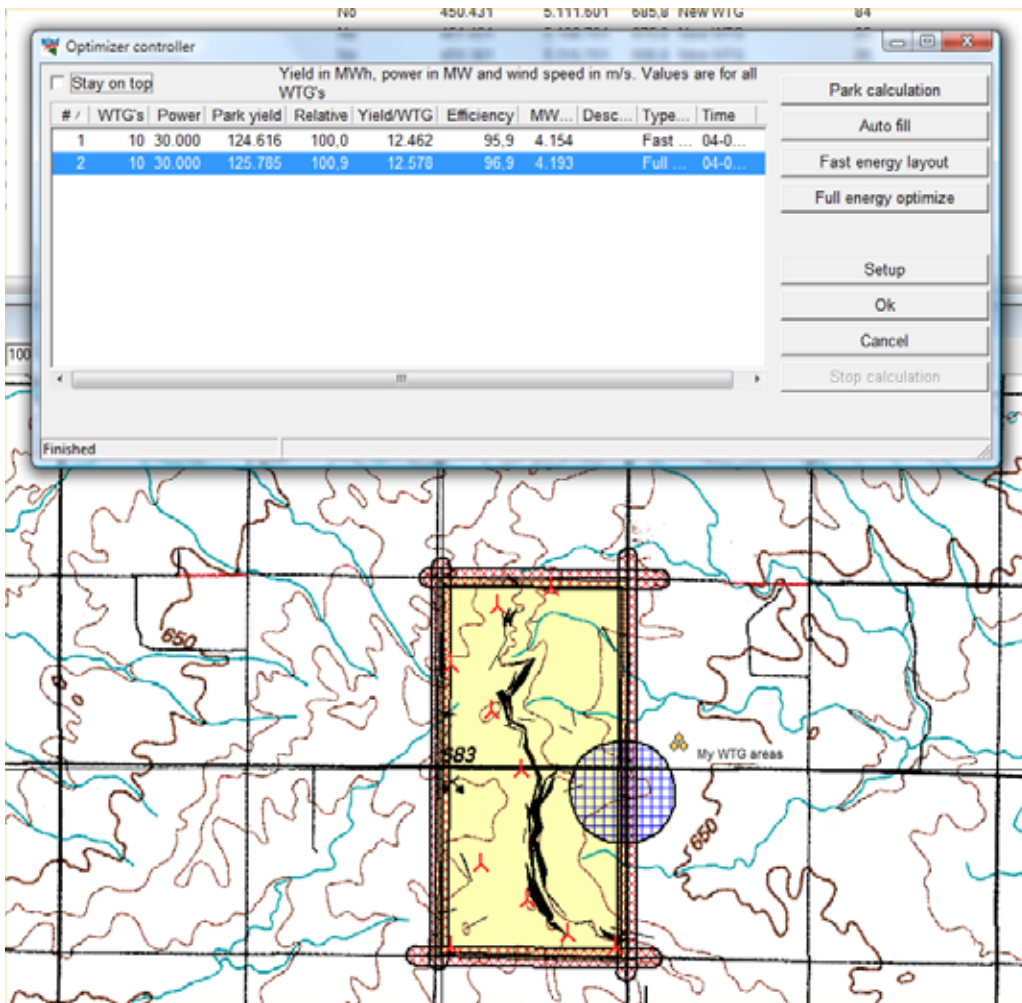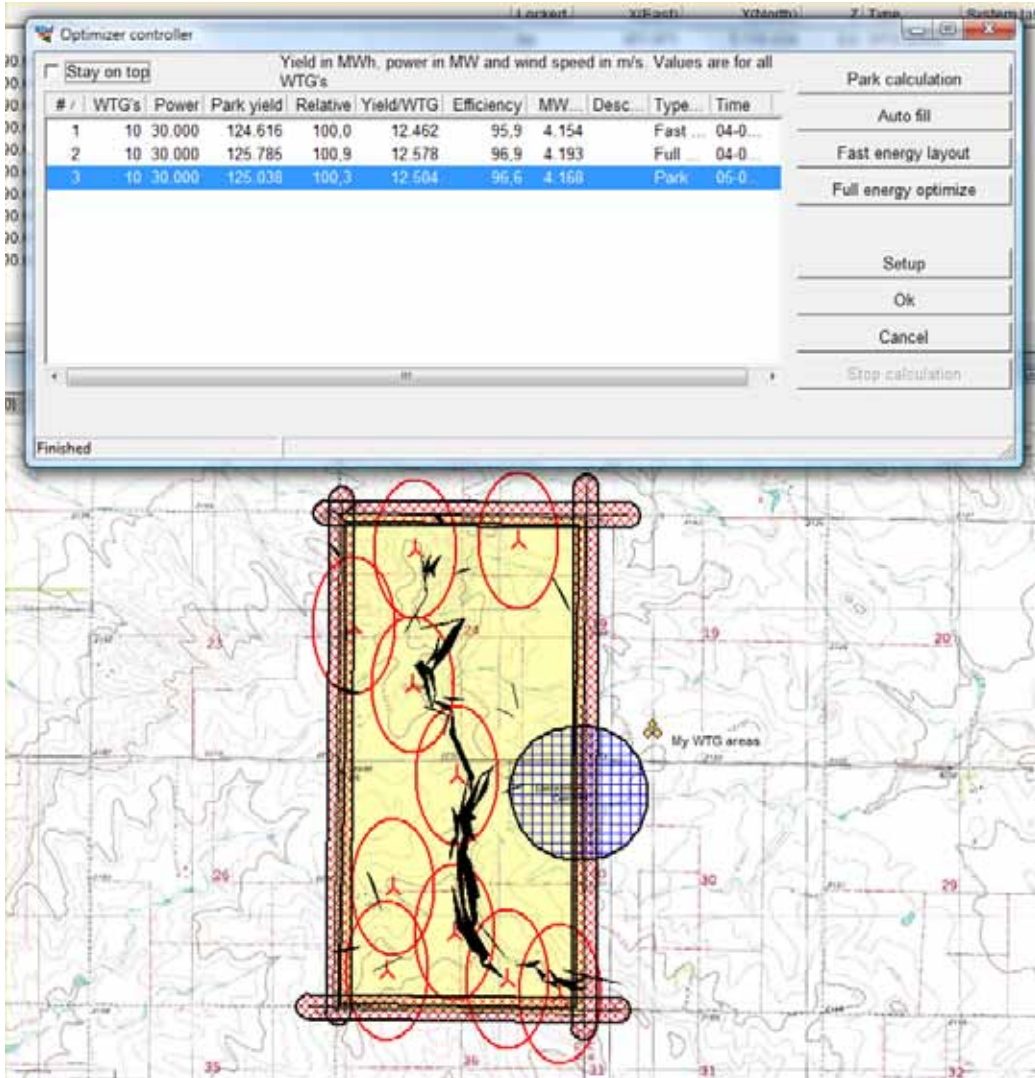
Right click on a turbine and select "Show distance circle". Distance circles or ellipses now become visible. The spacing is defined in the WTG area object and in this case it is defined as an ellipse with 5 times rotor diameter in the main (north) direction and 3 times rotor diameter across the main direction.
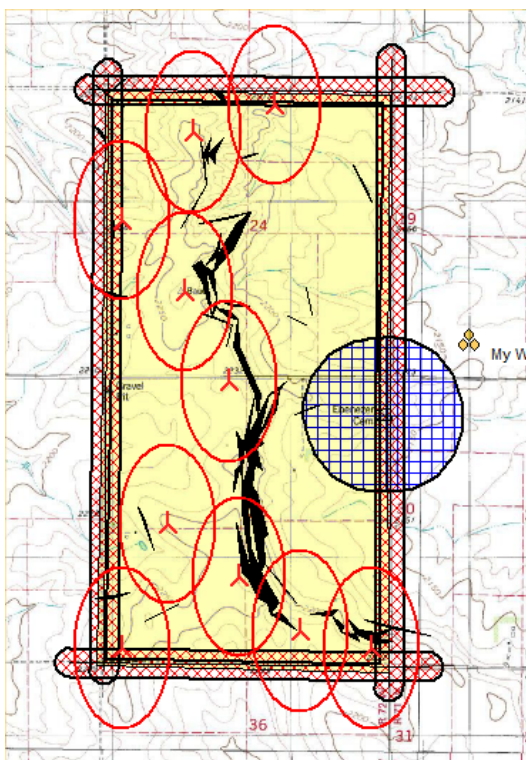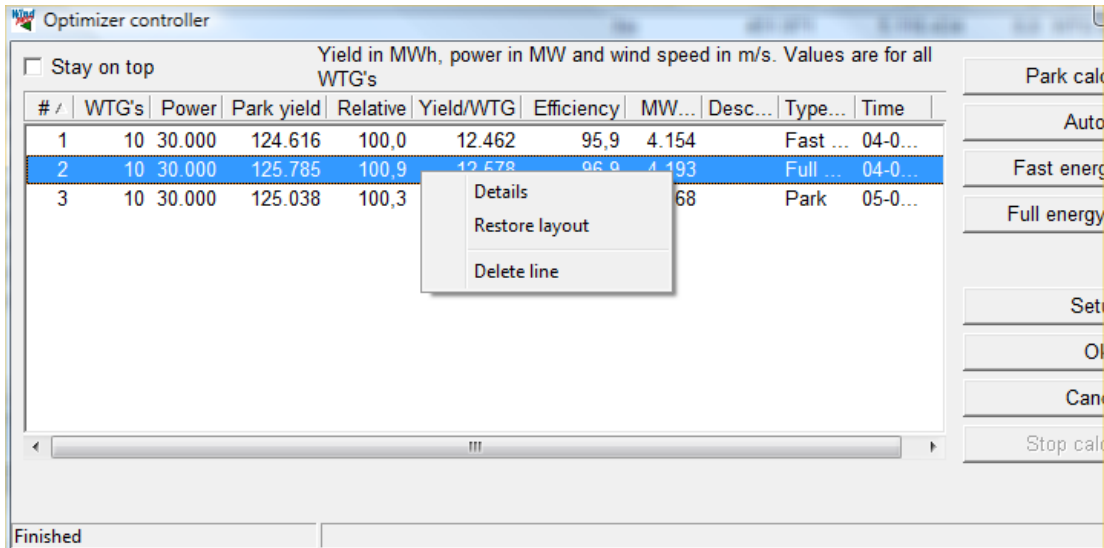
We try to move a few of the turbines that may be located inconveniently to more appropriate positions. In this way it may be possible to outsmart the optimizer and get a slightly better production. Remember that the optimizer only test locations defined by the grid size.

Press the "Park calculation" button to update the calculation result.

In this case we can see that we actually lost 0.6% of production by moving the turbines around.

If we regret the layout change we did we can right click on a calculation result line and select "Restore". This restores the layout used for this calculation. In this way the Optimizer controller creates a library of the layouts you have tested. If you restore a layout in this way you will need to run a new Park calculation in order to make a report.

Delete line removes an unwanted layout from the list.

Under "Details" you get the following window:

Here, the calculated production and position of each WTG is shown. All data can be copied to the clipboard and transferred to a spreadsheet. You can sort any column by simply clicking the first line.

The results can be viewed graphically:
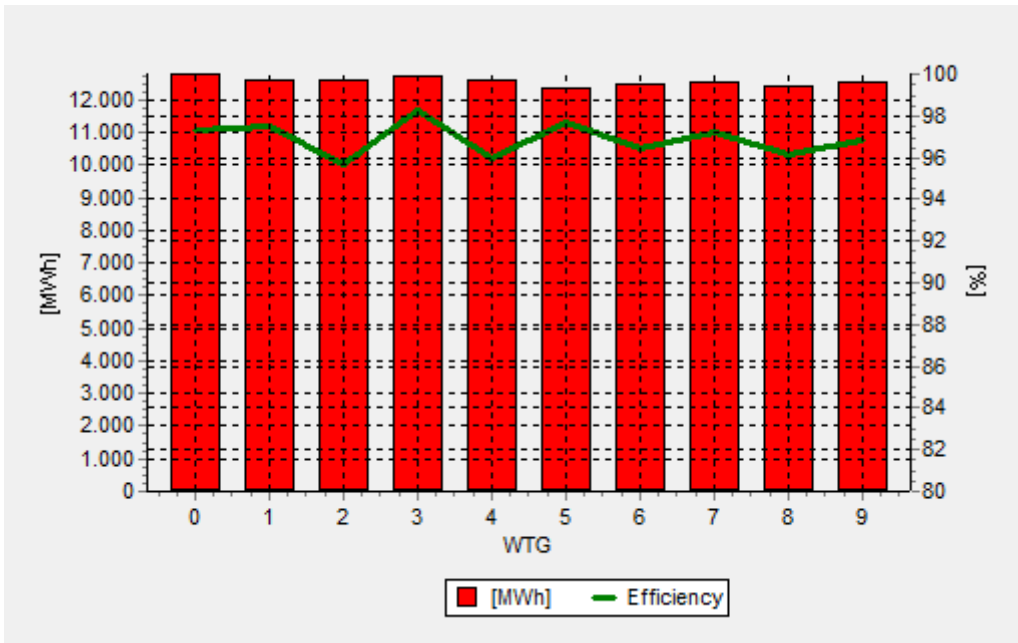
Here, both the energy production and the park efficiency are shown for each WTG. This graph too can be copied to the clipboard and imported into a text document or other Windows documents. In this view there is an "Edit", which allows you to modify the view of this diagram.

8.1.4.5 Calculation report

Once the optimization is completed and the layout is to your satisfaction a report can be generated by selecting "OK" in the Optimize controller.

The report can now be printed.
Note, however, that the calculation is based on an .rsf file which might not exactly give the same result as a PARK calculation based on a calculation at the exact position for each WTG. The hub height in the .rsf file might also differ slightly from the "real" hub height, which will give a "false" calculation from the Optimize module. So it is strongly recommended to perform a "normal" PARK calculation on the optimized layout to ensure the most direct link between assumptions and result.

An advantage by a direct printout from the optimization calculation is that you can get a map showing the used WTG areas as well as the underlying wind resource map, which can be quite informative.

In case you want to continue working on a saved optimization calculation (further optimization, e.g. with a new WTG type), you can right-click on the header of the calculation report and choose properties - the optimizer window will then be opened with the data last saved.

8.1.5 OPTIMIZE - Noise, model C

The above optimization methods only optimize in respect to production output, taking into account turbine spacing and setbacks as simple distance requirements.

A common limitation to a layout is the maximum noise impact that noise sensitive locations around the site is allowed to suffer. Indeed in many cases production optimization is entirely irrelevant compared to the optimal dealing with noise. Noise impact in general is described in section 4 of the manual.

Unfortunately it is not possible to test noise impact every time a turbine position is tested in the fast of full optimization. Even with fast noise calculation it would make an already slow optimization routine unacceptably slow.

Instead a number of partial solutions are made in WindPRO.

A very useful method is to use the interactive noise iso-lines directly on the map described in section 4.1.3.4. Together with the optimizer controller the turbines can be moved around while immediately testing the noise

impact and tracking the production with Park calculations in the Optimize controller. Such a procedure could follow a full optimize or Auto fill optimization to give an initial layout.

A second option, which will be explained below is to find the optimal operation strategy given a fixed layout. Since many turbine types can be reduced in noise output at the cost of production it may be possible to allow a layout which would otherwise not comply with noise restrictions. The noise optimization in WindPRO finds the optimal way to reduce the turbine output at the minimal production loss.

8.1.5.1 Noise reduced WTG's

WTG's can often be reduced in noise at the expense of production output. These reduced states are referred to as operation modes. The standard operation mode is labeled Level 0 and will usually be the default setting for the turbine type in WindPRO.

There are two typical strategies for reducing noise.

One method is to reduce the noise emission at specific wind speeds and then let it resume full power above the critical wind speeds. This is sometimes referred to as the Danish model, and would be the preferred choice when noise impact is restricted at specific wind speeds.

Another method is to cap the production output and thus reduce the noise. This is sometimes referred to as the German model and is used when the noise codes require noise to be calculated for the maximum noise level.

The two strategies are illustrated below.
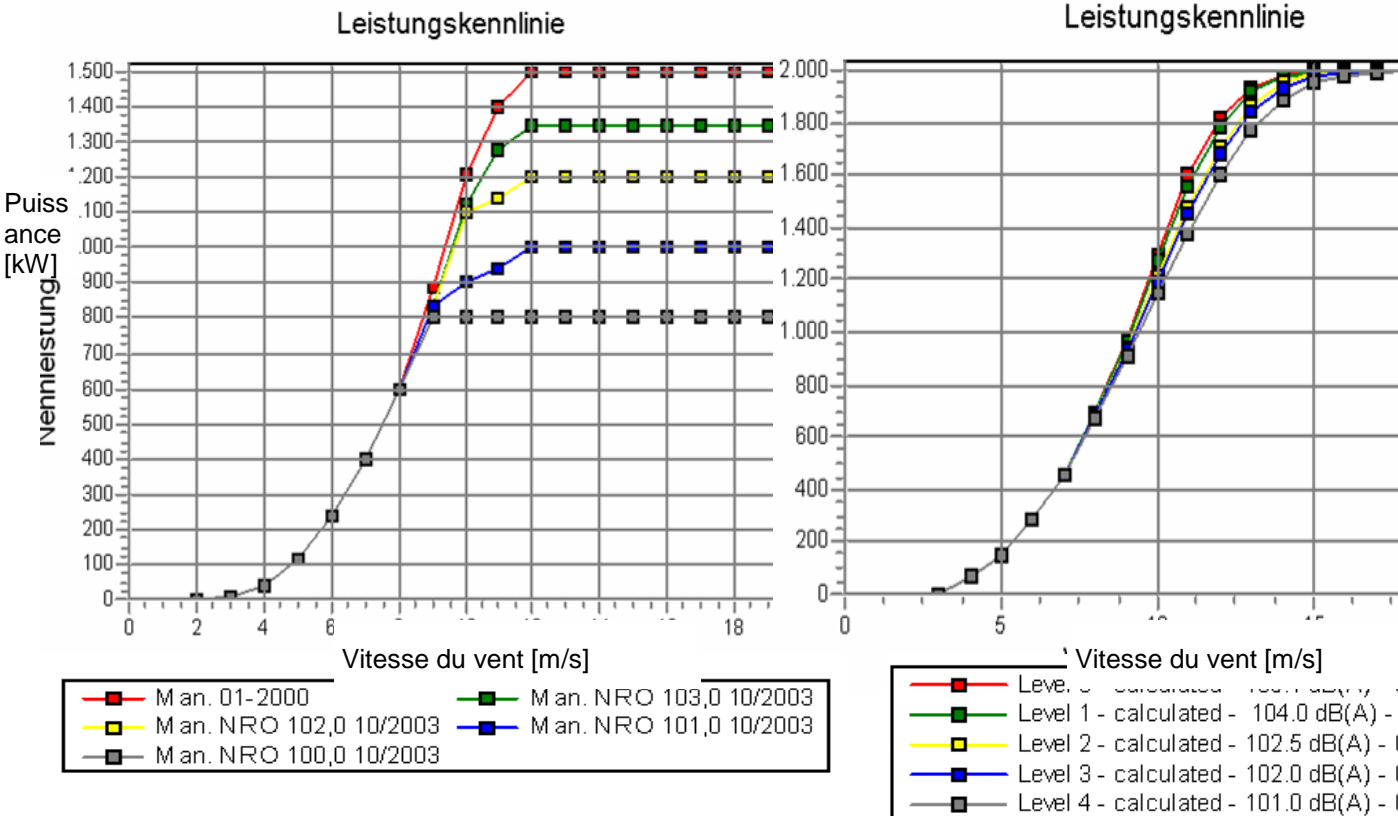
In the Basis section of the manual it is described how to select specific noise data and power curves for the WTG object. For the Optimize functions this feature is expanded.

If the hatch is removed from the "Always use default values" box on the WTG(s) tab in WTG properties the individual settings becomes available. Hatch the "Adv." box to enter the advanced mode.
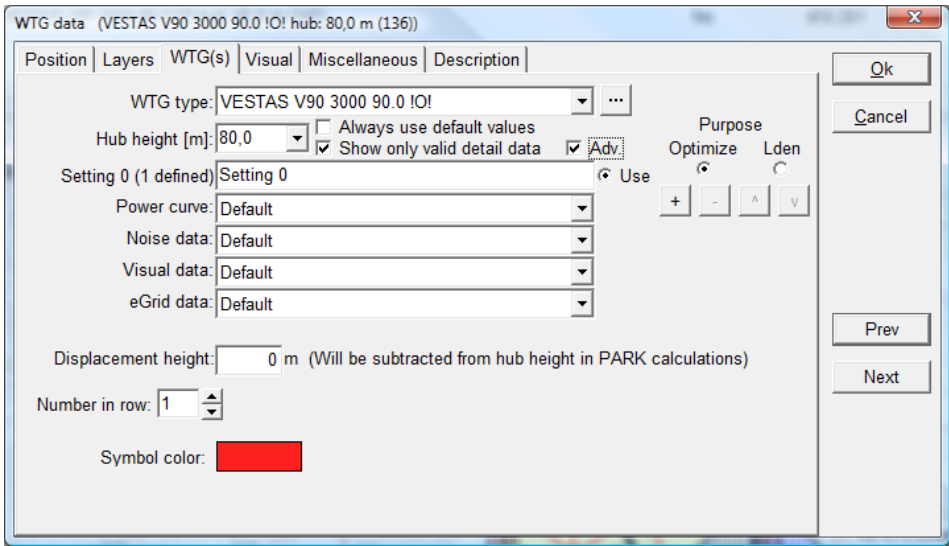
There are two purposes for the advanced mode. Optimize and Lden. The Lden purpose is covered in the Decibel section of the manual. Unfortunately it is not possible to use the optimize functions if the turbine is setup with Lden definitions.

Select the Optimize purpose. Setting 0 is automatically defined with default power curve and noise data. Select a level 0 power curve and a level 0 noise record for the turbine. Be sure the same level is chosen for both power curve and noise record.
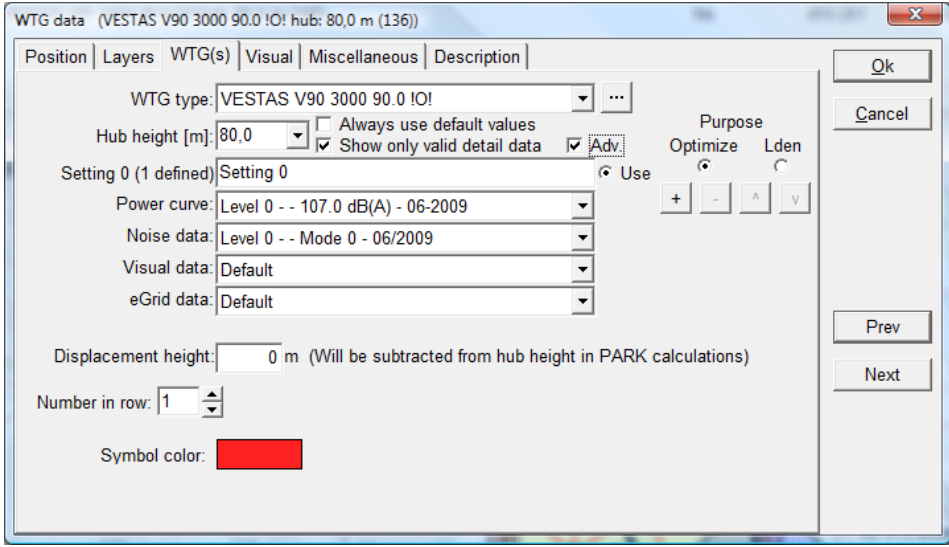
Press the "+" button to create the next setting and fill in level 1 power curve and noise data. The three other buttons now become active. The "-" button remove a setting, while the arrow up and down buttons move between the different settings.

The "Use" button indicates which setting is currently used for this turbine.

Press OK to leave the turbine.

If there are many turbines in the project it is useful to highlight objects in the object list and choose "Edit selected objects" and there set the advanced settings.

8.1.5.2 Noise sensitive areas.

The noise sensitive areas to be used for the optimization must be defined on the map. Section 4.1.2.2 explains how to insert and the function of noise sensitive points.

The optimizer uses NSA objects in visible layers, so it can be a good idea to organize NSA objects in appropriate layers. If for example on operation strategy is needed for day operation and another for night operation, two sets of otherwise identical NSA's can be grouped in a Day and Night layer respectively, each with appropriate noise limit settings for day and night. Make the Day layer visible for the day optimization and the Night layer visible for the night optimization.

In the below example three NSA are created at two dwellings and a cemetery. The given layout is the optimized layout from the full optimization. Note that this layout was created without setbacks from dwellings so the layout is at a disadvantage from the outset.
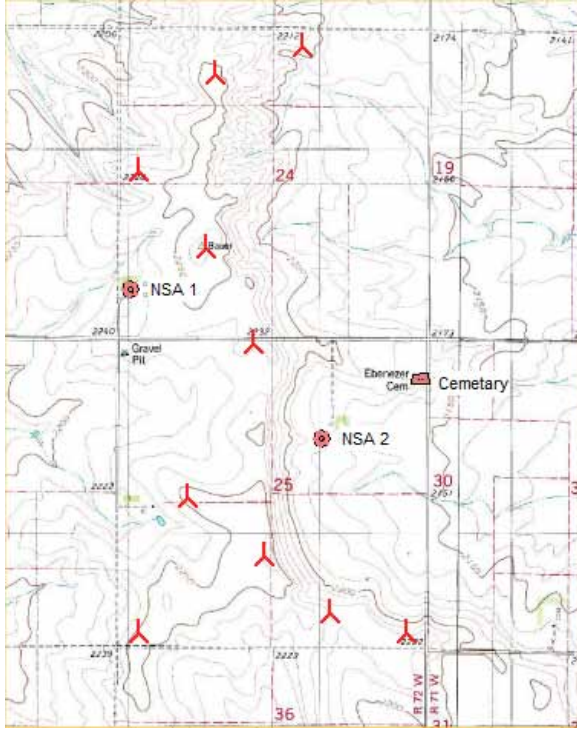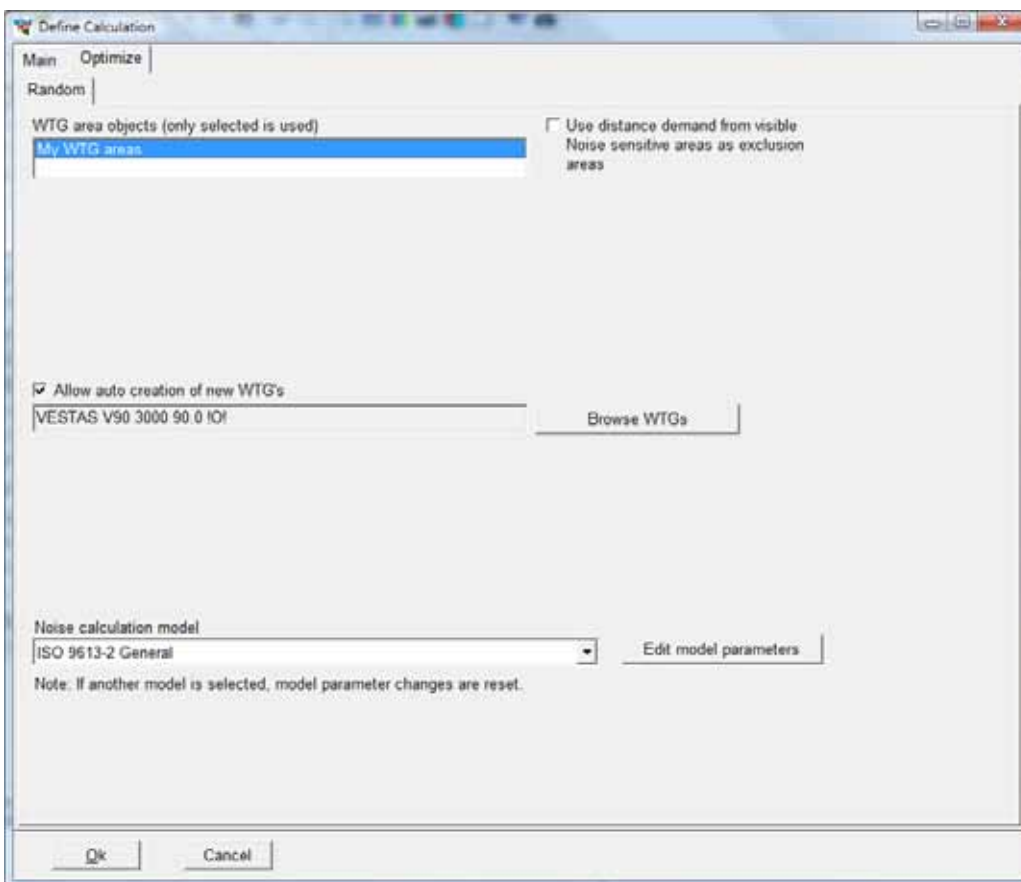

8.1.5.3 Noise optimization setup

Start the OPTIMIZE calculation from the Main menu by double clicking on the OPTIMIZE label or single click on the green arrow next to the OPTIMIZE label.

Select as optimization type "Noise based on remove/noise reduce visible WTGs".
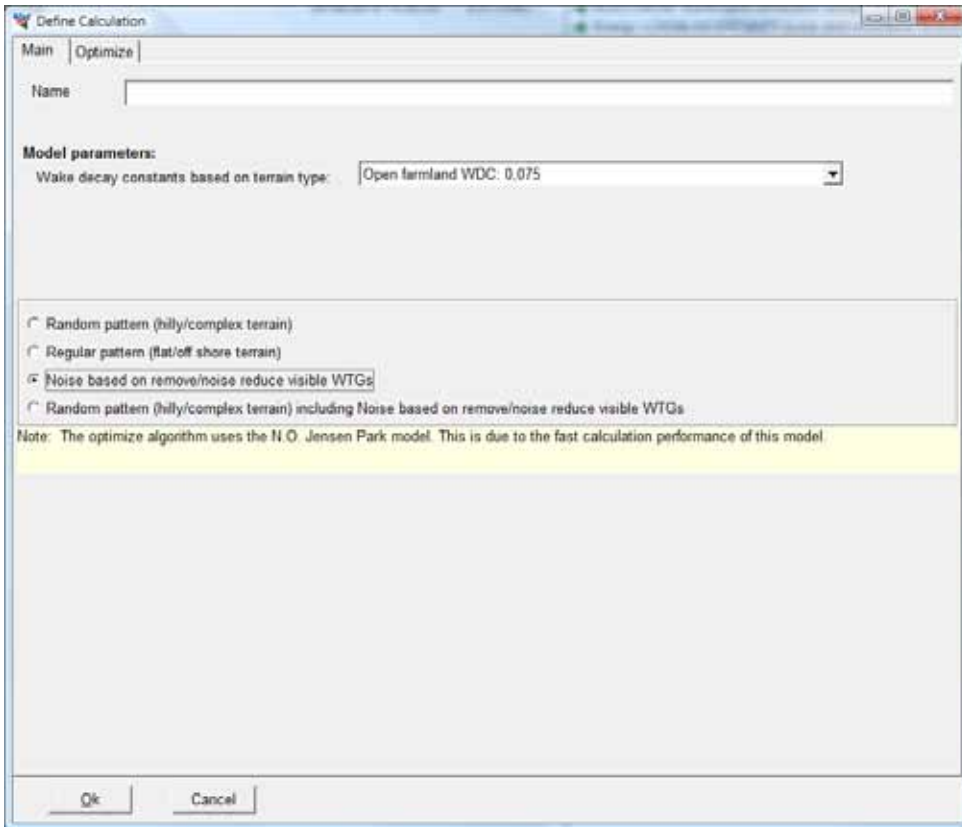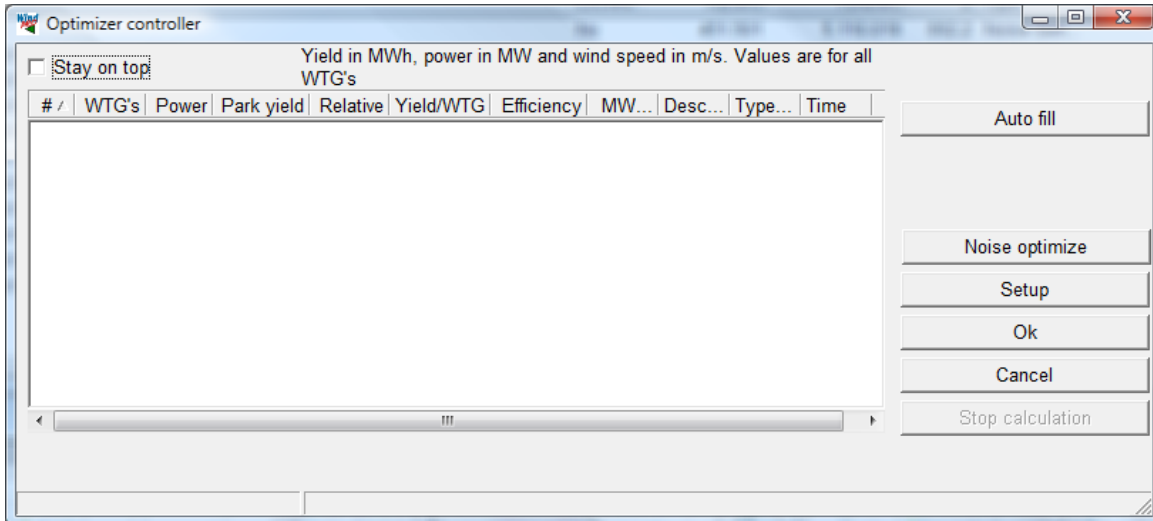
Go to the Optimize tab.

Select the WTG area object for the area definition.

For the noise optimization it is not possible to add turbines. However WindPRO requires the selection of a turbine. The actual choice is not important as the information is not used.

Select the appropriate noise model. Consult section 4 for information on noise models.

Press OK to start the Optimize controller.

If noise optimization has been selected there are two options in the Optimize controller: Auto fill and Noise optimize.

Auto fill fills up the WTG area with turbines according to the algorithm described in section 8.1.1.

Noise optimize start the noise optimization. The algorithm is described in section 8.1.1

The noise optimization reduces the wind farm down to a size where it is possible to comply with noise limits and reduce the remaining turbines to operation modes that will allow maximum output (by reducing as few turbines as little as possible).

A line with a result appears in the Optimizer controller, but this will only inform about the resulting number of turbines.

The turbines that need reduction are now reduced to a more noise reduced mode.

8.1.6 OPTIMIZE, Noise and energy

The noise and energy optimization is a combination of the B and C calculation option. It does not mean that in one run you optimize for both energy and noise, but that you from the Optimize controller are able to run both types of calculations.

The setup is a combination of the two.
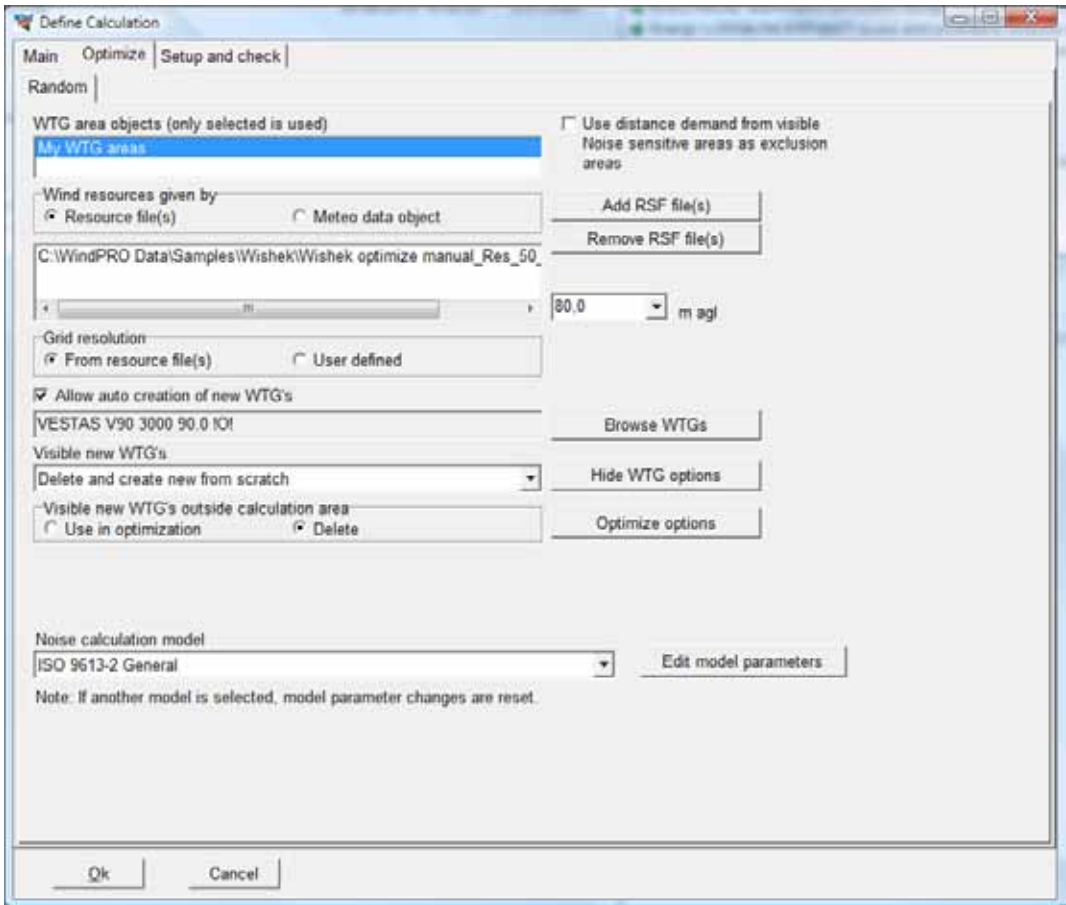
All the parameters are described in previous sections.

The advantage of running the options is that you immediately can see the consequence of running noise optimization.

In the below example a layout was found with a full optimization (the fist line). The noise optimization have then reduced the layout to 9 turbines and reduced the operation mode of some of the turbines. The consequence is a loss of 10.7% of production.