Wind PRO

Chapter 4
ENVIRONMENT

4. WindPRO Environment

4.0 ENVIRONMENT – Introduction and step-by-step guide

4.0.1 Introduction to Environmental Calculations

Environmental impact plays an increasing role in wind energy projects. With the continuing increase in project size, the environmental impact becomes a more and more decisive factor with regards to the siting of projects.

It is our intension to make it possible to calculate and document all the environmental requirements of a project using WindPRO, so that WindPRO can print the necessary documentation that the environmental authorities and neighbors might require.

Visual impact is described in a separate chapter.

4.0.2 Step-by-step guide to Environmental Calculations

- Establish a map and a proposed project (see Basis 2.0.5)
- Establish relevant objects; for DECIBEL: Noise-sensitive areas, for SHADOW: Shadow Receptors, for ZVI: Line Objects with height contour lines and eventually Area Objects and WAsP obstacles objects.
- From the calculation menu, run DECIBEL, SHADOW or ZVI
- Print reports.

4.1. DECIBEL - Noise Calculations

4.1.0 Introduction to DECIBEL

DECIBEL is the name of the WindPRO program module, which calculates the noise emission and checks if the noise requirements are met at neighbors and noise-sensitive areas. It also checks if the required minimum distances from the nearest WTG to these areas are met (if this is a relevant design issue).

Furthermore, DECIBEL can calculate and plot noise level curves for the project to enable an assessment of which areas will be prevented from being used for noise-sensitive activities in the future.

One of the major advantages of WindPRO is, however, the possibility for graphic input of data concerning WTGs and noise-sensitive areas/points on a digital map directly on the screen.

Immission: Disturbing effect on the environment of emission; the arrival of pollution from a remote source of polluting substances, arriving at a target
The immission point in this text is typically called the receptor, the neighbor or the Noise-sensitive Area (NSA).

Emission: The release of substances or energy (e.g. noise, vibration, radiation, heat) into the environment from a source
The source in this text is typically the WTG.

4.1.1 The DECIBEL calculation methods

The calculation of the noise impact generated by one or more WTGs at a specific location (e.g. a neighbor) requires the following information:

- The positions of the WTGs (x, y, z coordinates).
- WTG hub height and noise emission ($L_{WA,ref}$) at one or more wind speeds, possibly at different frequencies.
- Any pure tone contents in the WTG noise.
- The coordinates for the noise-sensitive locations/areas.
- Maximum noise level accepted inside the noise-sensitive areas. Possibly with information about the ambient background noise.
- The required calculation model.

A number of different calculation models have been implemented in WindPRO. These models typically relate to the requirement in certain countries or regions and we advise that the user finds out which methods and requirements has to be met in the region of the site.

If none of the country-specific methods apply, it is possible that the general implementation of the ISO 9613-2 calculation standard can be set up to fit the requirements.

The choice of method decides what kind of input data is required.

4.1.1.1 The International standard DIN ISO 9613-2, general

The ISO 9613-2 "Attenuation of sound during propagation outdoors, Part 2. A general method of calculation" describes the calculation of damping of the noise during propagation outdoors. The theoretical background for the calculations can be found in the Appendix: Theoretical background for noise propagation models.

By choosing the general version of ISO 9613-2 the user has access to all the parameters available in WindPRO. Specific national codes available in WindPRO will restrict the choices to those relevant for the specific country as described in following chapters.

Options for the calculation

The general setup makes it possible to choose settings for a range of parameters. This makes it possible to fit it to local recommendations.

The options available are shown in the figure below.

Wind speed

Fixed wind speed: The calculation will be made for only one wind speed, selected in the field to the right.

Wind speed range: The calculation will be made for a range of wind speeds with start, end and increment selected in the fields to the right. WindPRO will require source noise data for the wind speeds selected, but can also assume values based on what is available for the turbine types selected for the calculation.

95% rated power: The calculation will be made with the noise value for the turbine for 95% of the rated power. If no such value is available the user will be prompted to input this.

95% rated power else fixed wind speed: As above, but WindPRO will itself choose a substitute noise value if no data for the 95% rated power is available. The wind speed for the substitute is selected in the field to the right. If there is no value for this wind speed either the user will be prompted for noise data.

Loudest up to 95% rated power: WindPRO will choose the highest noise level no matter the wind speed or the 95% rated power level.

Octave data required

Checking this box forces the calculation to use octave band distributions instead of the total noise value. Default is off.

Spectral distribution

This allows a calculation result for each spectral band. The interval of frequencies will then have to be selected. This is used where critical noise limits are given specifically for each frequency. Default is off.

Ground Attenuation

None: No damping due to ground attenuation is used for the calculation. This approximates the very smooth surface offshore.

General: The damping of noise due to ground attenuation follows the general case described by the ISO 9613-2 code. The user is asked to select the general porosity of the ground with 0 being a hard surface and 1 being a porous surface. The default value is 1 but recent works suggest that 0 is a more appropriate value. However an individual assessment from site to site is normally needed. Octave-band source data for the turbines are required. If these data are not available WindPRO may suggest generic octave band distributions.
This method can only be used for flat terrain or terrain with a constant slope. If these conditions are not met, you are advised to use the Alternative method (see below) instead.
An interesting consequence of this method is that the ground attenuation becomes very sensitive to receiver height (height of immission point).

Alternative: The damping of noise due to ground attenuation follows the alternative case described by the ISO 9613-2 code. This method uses the orographic shape of the terrain to assess the ground attenuation by calculating the average vertical distance between line-of-sight between receptor and hub of the turbine and the terrain between the two points. A valley between the two points will cause a low attenuation whereas a hill will cause a high attenuation. If no orographic model (height contours) is given, the model assumes a terrain with a constant slope between the WTG and the NSA.
The model is valid for the case where:

· Only the A-weighted total noise level is required
· The sound predominantly spreads above porous ground
· The sound is not a pure tone

Both methods are described further in the theoretical appendix.

Meteorological coefficient, C_0
A value for the meteorological coefficient between 0 and 5 can be selected. The meteorological coefficient is supposed to reflect damping due to special meteorological conditions. EMD recommends setting this to 0 for most situations.

Type of demand in calculation
WTG noise is compared to demand: The noise due to wind turbine noise only is compared to the critical demand assigned for each noise receptor. If the calculation covers several wind speeds the critical demand is either the fixed demand or a wind speed specific demand. This is the normal procedure in countries like Denmark, Germany, Sweden and The Netherlands.

WTG plus ambient noise is compared to ambient noise plus margin: This is the scenario where the noise level at the receptors is the background noise plus the noise contribution from the turbines. This sum is compared to a noise demand that consists of the background noise plus a margin. The option is used in France among other places.

WTG noise is compared to ambient noise plus margin: Like the option above except that only the contribution from the wind turbines is considered and compared to the background noise plus the allowed margin. This option is used, for example, . in the UK and Austria.

Noise values in calculation
All vales are mean values (L_{WA}): This is the normal setting. Both source data, background noise data and calculations are given in mean noise levels (L_{WA}).

All noise values are 90% exceedence values (L_{90}): With this special setting all noise values are considered L_{90} values. That is, the noise that will be exceeded 90% of the time. Background noise must then be entered as L_{90} values. For the turbines the L_{WA} values will be used but 2dB will be deducted as a fair approximation of the L_{90} level. In the printouts L_{WA} is replaced by L_{90} values. This setting is used in the UK.

Pure tones
Pure and impulse tone penalty are added to WTG source noise: In case of pure tones the penalty is added to the source noise level of the turbines. The penalty is dependent on the codes used. For modern turbines pure tones is a rare phenomenon.

<u>Pure tones penalty are added to the demand</u>: With this option the pure tone penalty is subtracted from the critical demand of the report instead of added to the source noise of the wind turbines. The penalty can be specified in the field to the right.

Height of immission point above ground level
This allows the user to specify the calculation height for the receptor. Different codes have different recommendations for this calculation height. Typical values are 1, 4 and 5 m height above ground. If the "Allow override…" checkbox is checked, then the calculation height of the individual receptors (noise-sensitive areas) will override the model immission height, though only if a specific height is given for the NSA.

Deviation from "official" noise demands
This allows the user to introduce a special adjustment to the noise demand. If for instance the authorities require a 2dB margin to the noise demand to accommodate the uncertainty the user can set this parameter to -dB. In the printout it will then say that the demand is, for example, (45-2) = 43dB.

4.1.1.2 ISO 9613-2 Germany

The ISO 9613-2 Germany calculation option is a special case of the general ISO 9613-2 code.

This option is set up to fit the usual settings used in Germany.

Calculation setup
In the figure below, the calculation setup is shown for ISO 9613-2 Germany. The fields with faded font are fixed and cannot be altered. As default they are not shown unless the "Show details" checkbox is checked. For detailed description of the fields please refer to the section on the General ISO 9613-2 codes

Wind speed
The source noise value is "Loudest up to 95% of rated power".

Ground attenuation
The alternative ground attenuation method is used.

Meteorological coefficient C_0
The meteorological coefficient can be set. The recommended maximum is 2dB.

Type of demand in calculation
Only the noise from the wind turbines is considered when compared to fixed critical demands at the receptors.

Noise value in calculation
All noise values are in L_{wa} units. This is average A-weighted noise pressure.

Pure tones
Pure tone and impulse penalties are added to the source noise values. The values come from the turbine catalogue and are typically 3 or 6dB.

Height of immission point above ground level
The height of the immission point at the receptor has been set to 5m as default, but can be changed by the user.

Deviation from official noise demand
This field is open to the user.

Octave data
Octave-band data are not required

Noise receptors
The critical noise level at the receptors must be given for each receptor. There are no requirements for background noise data.

The legal foundation for the noise problem in Germany originates from the "Bundesimmissionsschutzgesetz (BlmSchG)". The Ministry of Environment and Trade requires the buildings documented in proportion to the compatibility to environment and people according to the "TA-Lärm 1998" (Technical Guidance for Protection against Noise). The Ministry of Environmental Protection and partially The Ministries of Environment and Trade in the counties approve noise from buildings.

In the construction regulations (BauNVO, 1990) and the TA-Lärm, the construction surrounding types are decided according to a protection order with the following maximum values (at night):

· 35dB   Recreation / Exclusive residential areas
· 40dB   General residential areas
· 45dB   Rural villages, Mixed areas and Unzoned countryside areas
· 50dB   Enterprise zone

Usually the 45dB limit will apply in areas with WTG projects. The extent to which this limit is extended to includ pure tones will depend on the local authorities.

4.1.1.3 ISO 9613-2 UK

The ISO 9613-2 UK calculation option is a special case of the general ISO 9613-2 code.

This option is set up to fit the usual settings used in the UK as described by the ETSU-R-97 recommendations ("The Assessment & Rating of Noise from Wind Farms").

Calculation setup
In figure below shows the calculation setup for ISO 9613-2 UK. The fields with faded font are fixed and cannot be altered. As default they are not shown unless the "Show details" checkbox is checked. For detailed description of the fields please refer to the appendix on noise propagation models.

Wind speed
The source noise value for wind speeds between 4 and 12 m/s is used with an interval of 1 m/s. If these data are not available the user is asked for data.

Ground attenuation
The general ground attenuation method is used. A ground porosity figure must be provided by the user. In the UK a porosity of 0 is usually used.

Meteorological coefficient C_0
The meteorological coefficient can be set. The recommended maximum is 2dB.

Type of demand in calculation
The noise from the wind turbines is compared to the background noise at each individual receptor plus a margin. For recommended values on noise receptors, see below.

Noise value in calculation
All noise values are in L_{90} units. This is the noise level that will be exceeded 90% of the time. Background noise should be entered in this unit. For the turbine source noise values the conversion from L_{wa} to L_{90} is done by deducting 2dB.

Pure tones
Pure tone and impulse penalties are added to the source noise values. The values come from the turbine catalogue and are typically 3 or 5 dB.

Height of immission point above ground level
The height of the immission point at the receptor has been set to 4m.

Deviation from official noise demand
This field is open to the user.

Octave data

Octave-band data are required. If they are not available in the turbine catalogue the user is asked for data when starting the calculation.

Noise receptors

Background noise data must be entered for each wind speed from 4 to 12 m/s in L_{90} units. A margin must be set up for the noise level from the wind turbines. The standard day and night figure is 5dB. The British rules (ETSU-R-97) also defined a fixed lower limit noise from the turbines at L_{90} =35-40 dB (day time) and L_{90}=43 dB (night time) for dwellings with no financial involvement in the project. Dwellings with a defined financial involvement have a limit of 45dB, day and night. In other words, any noise level from the wind farm below these values across the wind speed range stated will be accepted. The lower fixed limit is set up in the noise receptor object, in the field "value always accepted"

4.1.1.4 ISO 9613-2 France

The French noise codes do not require a specific noise propagation model for wind turbine noise. Instead the propagation model is expected to calculate the correct noise level and provide specific result parameters. The ISO 9613-2 propagation model can be used and by selecting the special French version some parameters will be fixed in accordance with the French codes.

Wind speed

The recommended wind speed is 8 m/s at 10m height, though other wind speeds or a range of wind speeds can be used.

Octave data

There are no requirements for octave data specifically, but it can be required if the general ground attenuation is selected or if a spectral distribution is required.

Spectral distribution

Users may be required to analyze specific frequencies. In that case the frequency interval can be specified. Such an analysis will require an octave band distribution for the turbines.

Ground attenuation
There is no specific requirement to modify the calculation method for ground attenuation. As a general rule the General method be used when acoustic porosity is special (e.g. over water), while the Alternative method can be used when the terrain shape is special (e.g. hilly terrain). If a spectral distribution is required then the General method must be used.

Meteorological coefficient C_0
The meteorological coefficient can be set. The recommended maximum is 2dB.

Type of demand in calculation
The demand specification is locked to "WTG plus ambient noise is compared to ambient noise plus margin". The noise receptors must be setup accordingly.

Noise values in calculation
Locked to regular L_{WA} noise values.

Pure tones
Pure tone penalty are added to demand.

Height of immission point above ground level
The receptor height is default set to 5 m, but can be changed by the user.

Deviation from official noise demand
This field is open to the user.

Noise receptors
The noise receptors can be setup with specific settings for France. There are two types of setting: Standard and Spectral.
For the Standard calculations the ambient noise at the receptor must be stated and the allowed additional exposure is set to a fixed level. This may be for a single wind speed but can also be for a range of wind speeds. Sound level from the turbines below 30dB is always accepted.
For Standard day the allowed additional exposure is 5dB.
For Standard night the allowed additional exposure is 3dB.

In an analysis of the spectral distribution the ambient noise must be stated for individual frequencies, while the allowed additional exposure varies with frequency
The allowed additional exposure from 125 to 250Hz is 7dB, while from 500 to 4000Hz it is 5dB.

4.1.1.5 ISO 9613-2 Norway

The Norwegian noise codes are described in the document: "Veileder til Miljøverndepartementets retningslinje for behandling av støy i arealplanlegging (støyretningslinjen)", TA-2115/2005, publiced by Statens Forurensningtilsyn (SFT).

The noise codes recommend the use of either the Nordic noise model (Nord2000) or the ISO 9613-2 noise propagation model. While the ISO 9613-2 model is not able to fully comply with the requirements in the Nordic codes, choosing ISO 9613-2 will make a best approximation to the codes.

Wind speed
The Norwegian codes require a calculation based on the actual wind distribution. However when using the ISO 9613-2 model it has been generally accepted to use 8m/s at 10 m height as this is close to the maximum noise level for turbines.

Ground attenuation
It is not specified what kind of ground attenuation should be used, but instead stated that the ground attenuation should reflect the nature of the landscape. Given the nature of Norwegian landscape the alternative ground attenuation is used. This means that octave data is not required.

Meteorological coefficient, C_0
The Norwegian codes distinguish between receptors downwind from the primary wind direction and receptors in other directions. This could be represented by adjusting the meteorological coefficient, however it is not recommended.

Type of demand in calculation
Only noise from WTG's is taken into account.

Noise values in calculation
Norwegian noise values are given as L_{den} values. WindPRO will on its own present all values as L_{den} values.

Pure tones
Pure tone penalty are added to demand.

Height of immission point above ground level
The receptor height is default set to 4 m.

Deviation from official noise demand
This field is open to the user.

Edit period

The Norwegian codes operate with noise values as L_{den}, where den is an abbreviation of day-evening-night. It represents a weighted average of noise, where noise during evening and night is penalized. The conversion from L_{WA} to L_{den} is exemplified by an official spreadsheet from SFT called lden_lekv_driftstid.xls. The parameters can be seen or modified by pressing the Edit period button as seen below.

The period definition of day, evening and night can be set here, as well as the penalty due for each period. As L_{den} is an average noise the number of days in a year with noise must be stated. SFT recommends 290 days for wind turbines (to account for periods of non-operation).

A full explanation on the calculation of L^{den} can be found in the Decibel Appendix.

Level	Name	From hour	To hour	Hours	Penalty [dB]	Days per year
0	Day	7	19	12	0	290
1	Evening	19	23	4	5	290
2	Night	23	7	8	10	290

Ok   Cancel

Noise receptors
In Norway the planning authority must divide the receptors into two categories: Yellow and red zone. In yellow zone the critical noise limit is 45dB while in red zone it is 50dB. This assumes that the noise receptor is in wind shadow. The definition of wind shadow is loose and only state that 30% of the year there is less wind than at the turbine.
If the receptor is outside wind shadow 5dB can be added to the noise limit.

Noise data for WTG
As described in a separate section below an individual noise mode can be selected for the three periods as part of advanced settings of the turbine.

4.1.1.6 The German rule VDI 2714 (outdated)

Until 01.10.1998 calculations were performed from VDI-Guideline Directions "Noise emission in open air".

Wind speed
The noise calculation is made for a fixed wind speed, typically 8 m/s.

Type of demand in calculation
The noise from the turbines is compared to the demand.

Addition for pure tones (pure tone content)
Gear, generator, hydraulics to blade angle regulation etc. are all potential pure tone sources. Pure tones should be removed through construction alterations or at least reduced. It is an audible pure tone (larger than 2 dB(A)) according to VDI 2058, Section 1, if "the increased inconvenience effect results in using an addition to the calculated noise level. The addition is set for 3 or 6 dB(A) dependent on how striking the pure tone is."

Addition for impulses (Impulse tone /Impulse tone content)
Impulse tone contents can be experienced when a rotor blade passes the tower. An evaluation can be done by means of the DIN 45645 if there are impulse tone contents. If the noise source contains significant impulse noise or frequent changes in the noise level (from measurement) of several times per minute, under the VDI 2058, an additional 3 or 6 dB(A) needs to be added to the calculated noise level as described under pure tones.

Pure tone addition in practice
In the WindPRO WTG Catalogue it is possible to add information regarding possible pure tone content and whether or not an additional 3 or 6 dB(A) should be added respectively to the calculated values. If this is the case, DECIBEL will, when checking if a given noise level is met, add the given values to the calculated noise level from each source according to the VDI-standard, contrary to the Danish regulations, where you simply raise the demand (with 5dB(A)) if just one WTG has a pure tone content. If you know that there is an additional pure tone, but it is not listed in the WTG Catalogue, you can create an extra set of noise data with the addition of either 3 or 6 dB(A) yourself.

Generally, we recommend contacting the relevant authorities and/or manufacturers when having doubts about these demands.

Height of immission point above ground level
The receptor height is set to 5 m.

Deviation from official noise demand
This field is open to the user.

Noise receptors
As the VDI codes are outdated the relevant noise limits at receptors must be historic values.

4.1.1.7 The Danish Rules

Former Danish rules (1991)

The former Danish rules are outlined in "Bekendtgørelse om støj fra vindmøller" (Statement from the Department of Environment) No. 304 of 14/5/91.

The propagation model is described in the Decibel appendix.

The former Danish codes require a calculation at 8 m/s at 10 m height. It is voluntary whether octave band distributions should be used, but in practice the calculations are almost always done on the total source noise level.
Noise values are compared to a critical demand (see below) and in the case of pure tones a penalty of 5dB is deducted the critical demand.

Noise receptors
The noise impact from WTGs must not exceed 45dB(A) at outdoor areas which lie in connection to neighboring settlements in the open land. The noise impact from WTGs must not exceed 40dB(A) at any outdoor recreational areas within housing zones or at any other Noise-sensitive Areas.

Current Danish codes (2007)

From 2007 new noise codes for Denmark are used in Denmark based on "Bekendtgørelse nr. 1518 af 14. December 2006, Bekendtgørelse om støj fra vindmøller".

The propagation model here is changed with a separate damping for offshore wind turbines.
The revised propagation model is described in the Decibel appendix.

Wind speed
The noise impact must be calculated for two wind speeds: 6 and 8 m/s at 10 m height.

Octave band
Octave band distribution is required for the calculation.

Terrain reduction (correction)
The user must select whether the calculation is for on- or offshore turbines. This affects the ground attenuation. Note the correction is added to, not reduced from the calculated noise. The higher figure offshore thereby gives higher calculation values offshore.

Pure tones
Pure tone penalty are added to demand. Like the former Danish codes a standard of 5dB is deducted the critical noise limit of the receptors in case of pure tones.

Height of immission point above ground level
The receptor height is default set to 1.5m.

Deviation from official noise demand
This field is open to the user.

Noise receptors
The critical limits at noise receptor are defined below.

DANISH RULES FOR NOISE CALCULATION.

The calculation is based on the "Bekendtgørelse nr. 1518 af 14. dec 2006" from the Danish Environmental Agency.

The noise impact from WTGs are not allowed to exceed the following limits: (Wind speeds in 10 m height)
1) At outdoor areas maximum 15 m from neighbor settlements in the open land.
  a) 44 db(A) at wind speed 8 m/s.
  b) 42 db(A) at wind speed 6 m/s.
2) At outdoor areas in residential or recreational areas.
  a) 39 db(A) at wind speed 8 m/s in residential areas.
  b) 37 db(A) at wind speed 6 m/s in residential areas.
If a WTG has pure tones in the noise emission, a penalty of 5 dB is added.

4.1.1.8 The old Swedish codes

The old Swedish codes are based on the "Metod för mätning av bullerimmission kring vindkraftverk" from Statens Narturvårdsverk, Sten Ljunggren, FFAP-A-935, 1992. These follow the Danish rules except on a few points:

The maximum noise impact from WTGs at a wind speed of 8 m/s is:
- Light industrial areas: 50dB.
- Houses etc.: 40dB.
- Recreational areas: 35dB.

The damping coefficient α_a is set to 0.003dB/m instead of 0.005dB/m

4.1.1.9 Swedish, January 2002.

By the end of 2001, new guidelines for calculating noise from WTGs were released in Sweden. They are called "Ljud från Vindkraftverk", Naturvårdsverket 2001, ISBN 91-620-6241-7. They replace former calculation methods and distinguish between onshore and offshore conditions.

Naturvårdsverket has released a spreadsheet for each method and a calculation must be according to these spreadsheets in order to be approved. A verification report that documents that WindPRO fulfills these demands can be downloaded at www.emd.dk and is called "Dokumentation af WindPROs beregning af svensk støj - vers2.pdf".
At the time of preparation of this edition of the manual the Swedish codes are being changed. Until the new version is made public noise is Sweden can be calculated as maximum noise values. A document describing the procedure for maximum noise can also be found on our homepage..

Noise calculation model
Swedish, Jan 2002, Land

Wind speed
Fixed wind speed   8,0 m/s
☑ Octave data required
☐ Spectral distribution

Type of demand in calculation
1: WTG noise is compared to demand (DK, DE, SE, NL etc.)
Noise values in calculation
All noise values are mean values (Lwa) (Normal)

Roughness class
      3,0

Pure tones (Note: ONLY used if at least one WTG is informed to have pure tones)   Pure tone penalty
Pure tone penalty are added to demand   5,0 dB(A)

Height of immision point above ground level, used when no value in NSA object
      1,5 m   ☐ Allow override of model height with height from NSA object

Deviation from "official" noise demands. Negative is more restrictive, positive is less restrictive.
      0,0 dB(A)   ☑ Show details   Air absorption

   Ok   Cancel

Calculation setup
There are two calculation modes: land and offshore.

For the on-land codes, the user is asked to give the roughness of the surrounding land. The unit used is roughness class. This is in order to modify wind speed at hub height based on the wind shear. The wind speed difference corresponds to a source noise level difference for which the codes assume a linear relation with a slope of k.

The parameter k is fixed at k = 1, as it is unclear from the guidelines in what interval of wind speeds this factor should be derived.

Onshore calculations do not require an octave band distribution if the receptors are all closer than 1000 m to all turbines. This is however rarely the case, so for all practical purposes 1/1 octave band distributions must be available for the turbines.

If offshore codes are selected no roughness needs to be selected. Also 1/1 octave band distributions are required for all turbines.

All noise calculations are calculated for 8 m/s at 10 m height.

Swedish noise requirements
Noise limits at receptors generally follow the following rules:

Day	Light industrial locations	60 dB(A)
Day	Dwellings	50 dB(A)
Day	Recreational locations	40 dB(A)
Evening/holidays	Light industrial locations	55 dB(A)
Evening/holidays	Dwellings	45 dB(A)
Evening/holidays	Recreational locations	35 dB(A)
Night	Light industrial locations	50 dB(A)
Night	Dwellings	40 dB(A)
Night	Recreational locations	35 dB(A)

4.1.1.10 Dutch, 1999.

The Dutch, 1999 method follows the guidelines described in "Handleiding meten en rekenen Industrielawaai" from Ministerie van VROM, Zoetemeer, 1999, ISBN 90 422 0232 7.

The section dealing specifically with noise from WTGs is Module C, method II.8.

```
Noise calculation model
[Dutch, 1999                                                    ▼]

Wind speed                               From        To          Step
[Wind speed range                    ▼]  [  3,0] m/s [ 12,0] m/s [  1,0] m/s

  ☐ Octave data required
  ☐ Spectral distribution
Terrain reduction
[0 dB(A) Hard terrain               ▼]



Type of demand in calculation
[1: WTG noise is compared to demand (DK, DE, SE, NL etc.)     ▼]
Noise values in calculation
[All noise values are mean values (Lwa) (Normal)             ▼]



Pure tones (Note: ONLY used if at least one WTG is informed to have pure tones)  Pure tone penalty
[Pure tone penalty are added to demand                       ▼]  [  0,0] dB(A)
Height of immision point above ground level, used when no value in NSA object
[  5,0] m   ☐ Allow override of model height with height from NSA object

Deviation from "official" noise demands. Negative is more restrictive, positive is less restrictive.
[  0,0] dB(A)                    ☑ Show details          [ Air absorption ]

[  Ok  ]        [ Cancel ]
```

Wind speed
The wind speed used for the noise calculation is a range from 3 to 12 m/s at 10 m height.
Only the total noise level is required (no need for octave band data.

Terrain reduction
The user is asked to set the terrain damping (D_{bodem}), a value between 0 and –3, where 0 is a hard surface and –3 is a very soft surface.

Height of immission point above ground level
The receptor height is default set to 5 m.

Deviation from official noise demand
This field is open to the user.

Noise receptors
The critical limits at noise receptor are defined as a function of wind speed as shown in the table below.

Wind speed, m/s	Critical noise limit, dB(A)
4	41,1
5	41,7
6	42,5
7	43,4
8	44,5
9	45,6
10	46,9
11	48,3
12	49,7

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4.1.1.9 IL-HR-13-01 (The Netherlands)

This is the previous Dutch method for calculating noise propagation from WTGs. In WindPRO the only difference between this and the 1999 edition is that this method assumes acoustic hard terrain (B = 0).

4.1.2 Entering Data for Noise and Distance in DECIBEL

A background map is required, but it can be a blank map.

If one or more maps have been linked to the project, clicking on the map icon can activate these maps. Please also refer to Chapter 2 in WindPRO BASIS for further information about the use of maps.

Please notice that when entering objects via maps, you can create a default tool by holding down the <shift> key while selecting a tool. This function will allow you to enter several objects with the same properties, (e.g. a series of noise-sensitive objects with the same requirements to distance and noise level or a number of parallel rows of WTGs of the same turbine type).

4.1.2.1 Entering WTGs

See Chapter 2 BASIS, Section 2.5.2 on entering WTGs and Section 2.6.3.2 on noise data in the WTG catalogue.

WTGs may hold different forms of noise data. Noise data may be given for different wind speeds (most common are 8 or 10 m/s) and different hub heights and the noise value may be given as either a source emission level ($L_{wa,ref}$) or as octave-divided data (or even subdivided as third octave data). The form needed in your calculation depends on the calculation method (see Section 4.1.1) and the local regulations.

WindPRO will usually detect which value is relevant for the chosen calculation type, but you can also manually select a specific noise emission level in the WTG object properties (see Section 2.5.2.1).

If the WTG type has no noise data of the type needed for your calculation, you can usually obtain it from the manufacturer.

WindPRO 2.7 includes a tab for wind speed at hub height. So this is only implemented the Nord2000 noise calculation. For all calculations in the Decibel module this tab is inactive.

Noise modes

Many turbine types come with noise reduced modes of operation. This can often be recognized from the name in the wind turbine catalogue. A noise record at Level 0 will always be standard, unreduced, while following levels often relates to successive modes of reduced noise level. A noise record with the name:

Level 3 – calculated – 103dB – 09/2009,

will represent the third reduced mode (a standard followed by three reduced modes). The type of noise data is calculated, the name of the mode from the manufacturer is 103dB (not necessarily the actual noise level) and the date of the technical specification September 2009.

Selection of noise mode

When inserting a WTG it is possible to specify the noise level by removing the check from "Always use default values". Remember that a reduced noise level must always be accompanied with similarly reduced power curve.

Advanced noise curve selection

Checking the "Adv." Box opens up advanced settings.

There are two types of advanced mode, selected on the right side: Optimize or L_{den}.

If Optimize is selected (see above) then a number of settings must be selected. These are the possible operation modes you want an optimization run to go through during noise optimization (see Chapter 8).

Press the + button to add a setting and – to remove a setting. You can move up and down through your settings with the arrow buttons.

There is a radio button called "Use" next to the setting name. The setting where this button is filled is the one which will be used in calculations.

If L_{den} is selected then the three L_{den} periods (day, evening, night) can be defined.

There are automatically three settings, which by default have the same property. It is possible to freely define which should be used for each of the period.

An L_{den} calculation is a single calculation that combines three individual noise calculations so all three noise settings are used. The energy calculation can unfortunately not be combined in a similar way to here the "Use" button still indicated which power curve is used in a production calculation.

4.1.2.2 Entering noise-sensitive areas

Graphic input of a noise-sensitive area object (NSA object): Click the icon shown to the left; double-click with the left mouse button on the map to create an NSA Object as a point.

Alternatively, when the object is selected from the icon list, click with the left mouse button on the map to define the first corner of an area, and continue to click on the map to define the other vertices of the polygon until you right-click to close the polygon.

For tab sheet Position, see BASIS Section 2.5.2.2. .

Note: The z-coordinate of a noise-sensitive area has to be entered in the same reference system as the z-coordinate of the WTGs. If the WTG(s) have been entered with the default value "0", you have to enter the z-coordinates for the noise-sensitive areas relative to the elevation of the WTG foundation, i.e. if the noise-sensitive area has a lower elevation than the WTG foundation then the z-coordinate will be negative. It is recommended to generally enter z-coordinates for all objects relative to the sea level. Here the use of automatically detected z-values from a line object is a very useful help.

Noise-sensitive areas can be entered as:

- Points
- Areas

When you enter a point, you have to enter the coordinates of the neighbor or noise-sensitive area, which, according to the actual requirements, has the highest noise impact from the WTG(s). This usually means the point nearest to the WTGs, but it may be difficult to define this point straight away. Especially if the WTGs are spread all around the neighbor or if different WTG types are sited parallel to a noise-sensitive area. Therefore, it may be relevant to enter a noise-sensitive area as a polygon, where the vertices of the polygon encircling the

noise-sensitive area are entered. The program will then calculate the most critical impact point - also if this point lies between two vertices of the polygon (on a line which connects two vertices).

Demands
The tab "Demands" defines the noise receptor in term of critical noise limits (demands).

The noise receptor will automatically detect the country of the project and choose a country specific form (above) relevant for that country. This will lock the parameters to those relevant and allow manipulation in those fields where the user has to make decisions. In the example above a site located in Denmark will automatically link to the Danish 2007 codes and freeze noise demands for 6 and 8 m/s. The user has to define whether the receptor is in open land or a residential area, in which case the noise demands will reflect the critical noise limits for that type of area.

There are only country specific forms for a limited number of countries.
If not in one of these countries or if more options are needed the user can choose "Free definable form".

A distance demand and noise demand can be entered for each noise object.

The distance demand can be defined when recommendations or limits about the minimum distance to the dwellings have to be fulfilled. The Decibel calculation will then check if this demand is fulfilled or not. The

distance demand can be shown on the map (Section 4.1.2.3) and help in the design of the layout of the wind farm. It is can also be included in an Optimize calculation (Section 8.1.4.1).

For the default NSA, the selected calculation model decides the immission height above ground for the calculation and there is no need to enter a specific value. There may be situation however where special needs may require a different calculation height (e.g. a tower or a tall building). In that case, the checkbox can be de-selected and a specific calculation height entered.

If no demand is checked, then the requirement is not included in the calculation and will not appear in the printout. All noise values are considered L_{wa} values unless L_{90} units are selected in the calculation setup. In that case, all values are L_{90} values.

There are two types of noise demand:
- · Only noise from the WTG's is considered
- · Ambient noise is considered.

If "Only WTG noise…" is selected the user can type in the critical noise limit for the receptor.

If the noise demand is different for different wind speeds, then selecting "Check for more wind speeds" makes it possible to enter specific critical limits (see figure below).

Here it is also possible to define critical noise levels for specific frequencies using "Check for spectral distribution".

In some areas the background noise level is relevant for the calculation. In such cases, the ambient noise exposure (background noise level) must be entered. If the background noise is relevant for several different wind speeds, selecting "Calculate for more different wind speeds" makes it possible to type in specific noise values.

If background noise is required, it is usually because the noise demand is a function of background noise plus a margin (allowed additional exposure). The margin can be given as a fixed value, or can be dependent upon wind speed. In that case, selecting "Calculate for more different wind speeds" enables the user to input these different margins.

There may be a certain noise level from the turbines which is always accepted regardless of the background noise level. This noise level can be entered in the "WTG noise always accepted" box.

Area

If the NSA has been entered as an area rather than a point, it is possible to edit the node points of the area in the Area tab sheet. Node points can be added, edited, or deleted. If the node points need to be copied to Excel, or from Excel to WindPRO, then the entire object needs to be copied to or pasted from Excel.

Position	Layers	Demands	Area	Description		Ok
Area						Cancel
#	X		Y			
1	551849		6287909			
2	552048		6287995			
3	551961		6288225			
4	551646		6288221			
5	551701		6287980			Prev
6	551798		6287751			Next
	Edit	Add	Del	Copy	Paste	

When the NSA is entered as an area, WindPRO will calculate the noise level for each point at the edge of the area and give as a result the one with the highest level.

Since a polygon can only be provided with one elevation (z-coordinate), it might be relevant to enter the noise-sensitive areas as several adjacent polygons with different heights. The description for the areas could be the name of the neighbor that the noise object refers to.

4.1.2.3 Showing Distance Requirements on the map
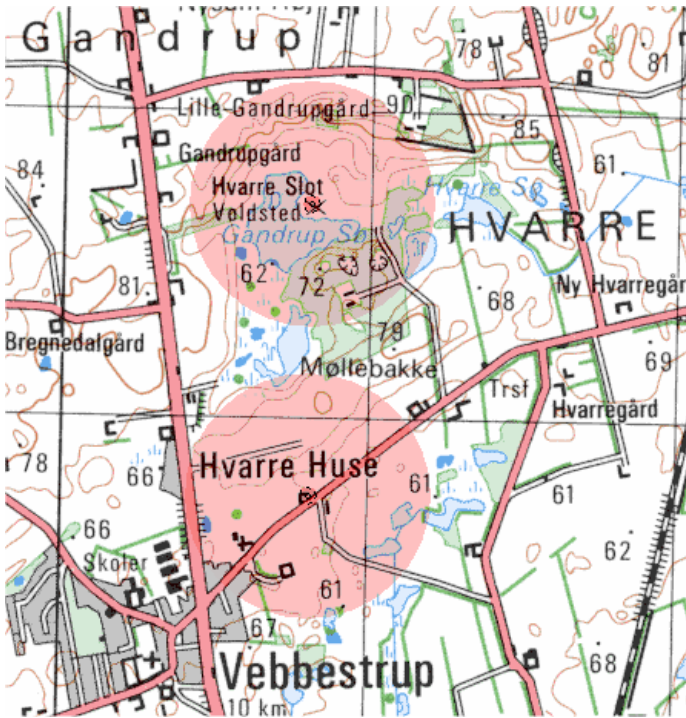
When you click with the right mouse button on an NSA object you gain access to switch the distance marker on/off. The selected mode covers all NSA objects. If the distance marker is activated, the program will produce a faded red circle, which indicates the distance requirement entered for each object (see figure).

4.1.3 DECIBEL - Calculation and printout

Click on the green arrow next to the DECIBEL heading in the calculation menu to select the calculation mode. Once the calculation mode has been selected you will be asked to complete the calculation setup.

4.1.3.1 DECIBEL - Calculation Setup

The calculation setup for the DECIBEL calculation follows the general system for calculation in WindPRO. You may find more detailed explanation of some of the general functions in other sections of the manual.

Main
The Main tab is used to set up which calculation you want AND which model to use. See in 4.1.1. how the different parameters for the different models shall be decided. Note the model choice in general shall match the specifications in the Noise Sensitive Areas if such shall be used in calculations.

The name in the name field is the name headlining all the pages of the calculation report.

It is possible to make three types of calculations. Depending on which type of calculation is selected different tabs will become available.

The three types are:
- Standard calculation
- Interactive noise lines on map for layout optimization
- Noise allowance map

The second and third options are explained in detail in Sections 4.1.3.4 and 4.1.3.5. In this section the focus is on the standard calculation.

If standard calculation is selected it is possible to choose only to get a noise calculation for the receptors or a noise iso-line map or both.

Finally a noise calculation model must be selected. Depending on the codes selected, the calculation options for the particular code can be inspected or changed using the "Edit model parameters" button. For a description of these options please refer to the description of the appropriate model in Section 4.1.1.

WTGs
WTGs to be included in the calculation: Here you can uncheck those WTGs from the object list that you do not want to include in the calculation. A good idea is to have different layouts organized in particular layers and then select wind turbines by the layer.

NSA (Noise-sensitive areas)
Noise-sensitive objects to be included in the calculation: Again, you can uncheck those receptors from the object list that are not required in the calculation. Note that the receptors are grouped by layer. You can therefore specify receptors in one layer to for example day limits while another is night limits.
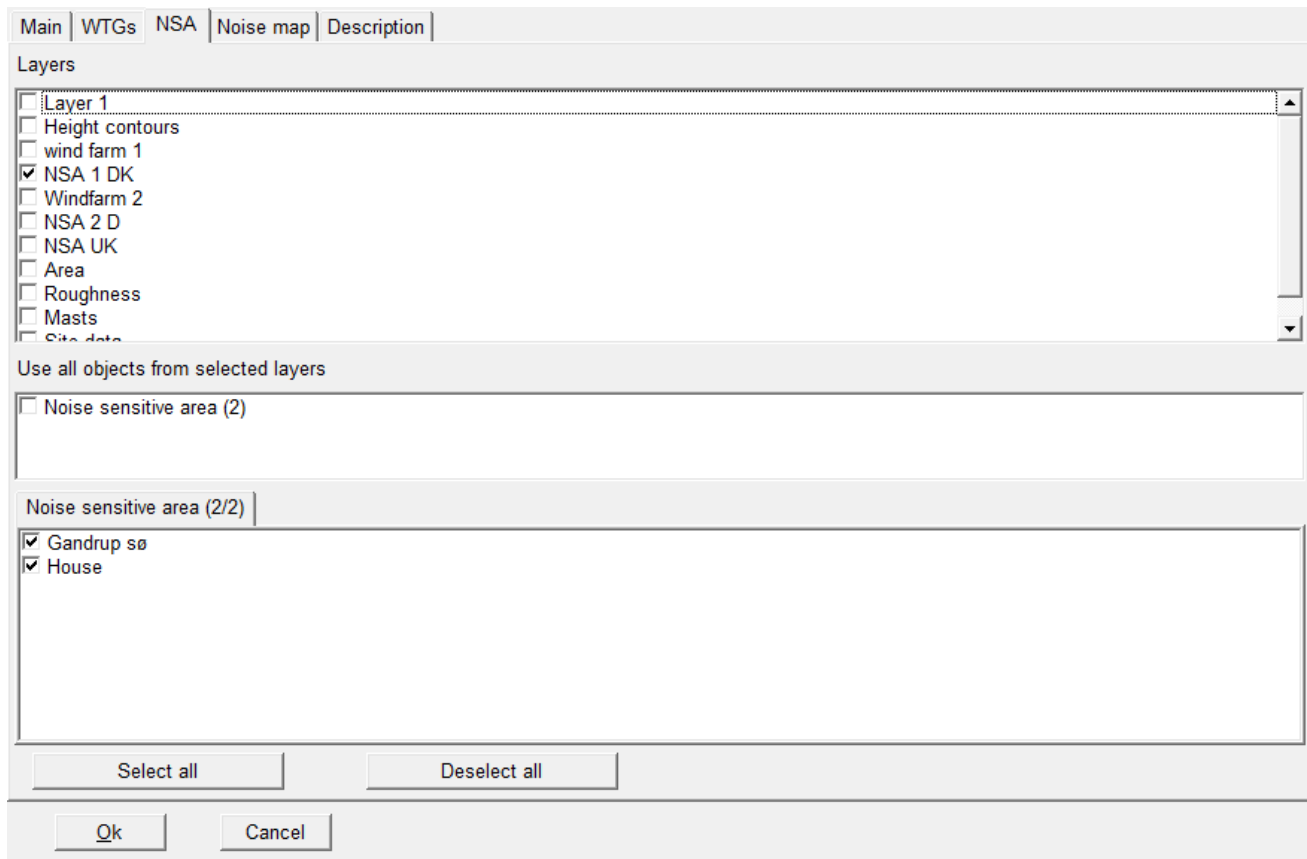
Noise map

If you have selected to calculate a noise map or Interactive noise lines you can access the Noise map tab. This is where you specify the noise iso-line maps to be included in the report.
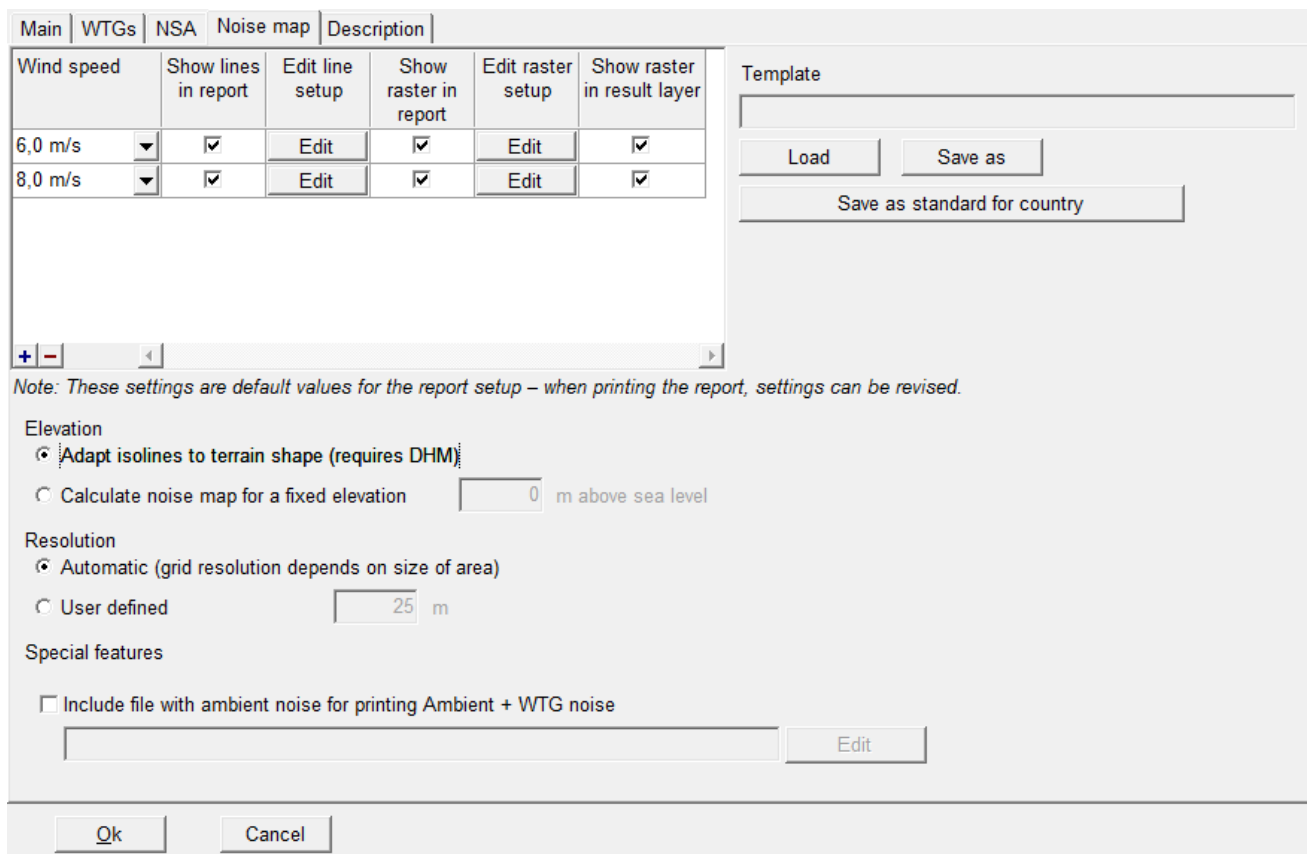
Based on the model you have selected to use one or more maps will be available. In the above example the Danish codes have been selected. The Danish codes define two wind speeds, 6 and 8 m/s, so maps for these two wind speeds have been listed.

Three kinds of map reporting are possible:
- · Show lines in report, creating a page with noise iso-lines in the report
- · Show raster in report, filling up the interval between lines with color
- · Show raster in result layer, producing a result layer in Maps and objects with noise intervals filled with color.

It is possible to select as many maps as you have wind speeds in your calculation and thus attach several maps to the report.

Pressing the edit button makes it possible to edit the lines or raster definitions for the maps.

The line setup looks like below, which is similar to the setup options in the print report setup.

Number of legends :	2		Gray scale	
Minimum value :	42 dB(A)		100	
Maximum value :	42 dB(A)		100	

Line type	Value	Line width	Line color	Gray scale	
1	37,0	2	(red)	100	Auto value
►	42,0	2	(blue)	100	Auto color
					Auto gray
					Load
					Save

Ok   Cancel

Select the number of lines wanted and then define the noise value and color for each line. With save you can save a template so you do not have to set this up every time you run the calculation. Pressing the "Load" button loads previously-saved templates. Pressing "Save" saves the current settings as a template (by default in C:\WindPRO Data\Standards.

In a similar way the raster setup can be edited.
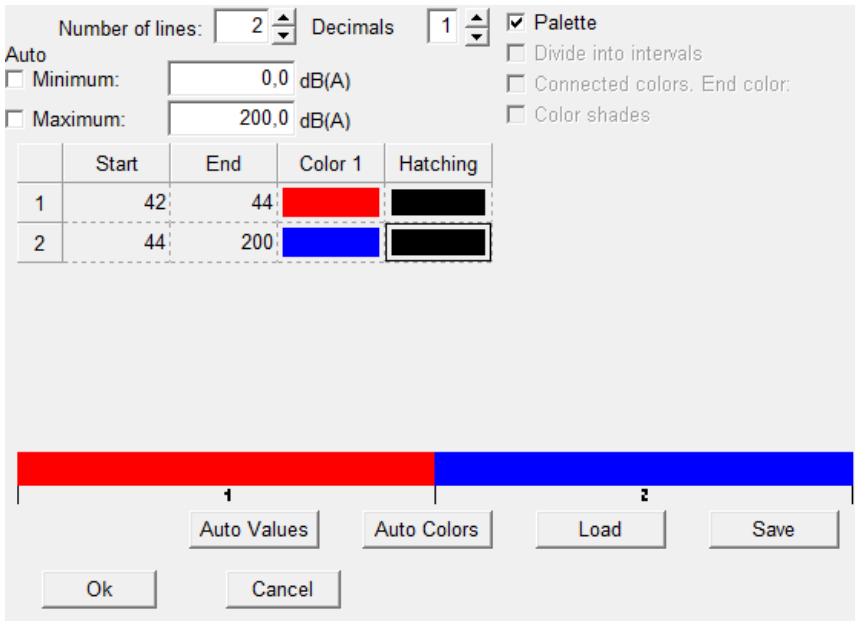
Again this is similar to the print report setup and the interface is used in several other locations in WindPRO. A typical good choice is to use the Palette format to get a single color for each interval. Then select the same number of lines as in the line definition and mark the same intervals and colors.

Back on the Noise map tab it is possible to save the entire definition as a template and even make it a standard for the country you are working in. In this way simply by making a calculation in the country WindPRO will default choose the settings saved as standard.

In the Elevation part WindPRO will default choose to use the digital height model of the project when it calculated the noise map. Alternatively it is possible to choose a fixed elevation. Just be aware that WindPRO then calculates the line of sight distance from the base elevation of the turbines + hub height to the fixed height selected. In mountainous terrain this can potentially be quite wrong.

The resolution is automatically selected based on the area size keeping the calculation time down by increasing the grid size when the area calculated is increased. Alternatively a fixed grid size can be selected.

If the calculation model requires a comparison to ambient noise it is possible add the ambient noise to a noise map by adding a shape file with ambient noise. Be sure to select the right coordinate system and the database column with ambient noise values.

4.1.3.2 DECIBEL - Calculation

If all required data are available for the wind turbine types being calculated, the DECIBEL calculation will commence when OK is pressed.

If some of the source noise data are missing, the window shown below will appear
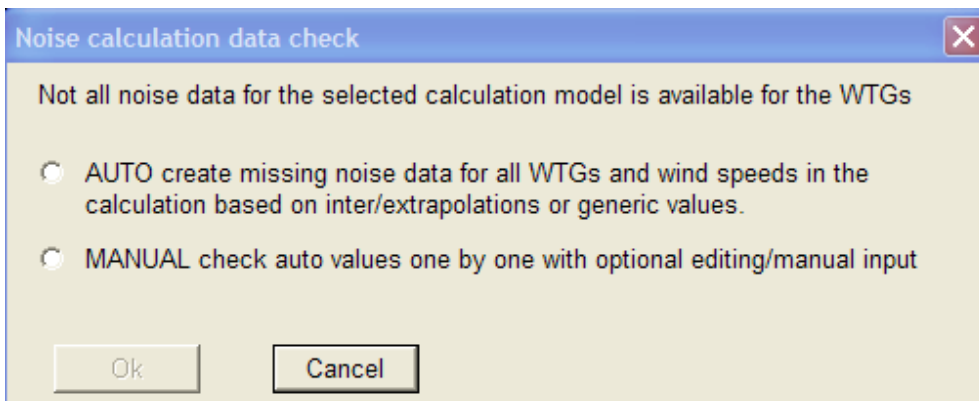
It is now possible to let WindPRO suggest some source noise values for the missing values.

It is advisable to manually review the suggestions or override them with manually-selected noise data.

Selecting the MANUAL option will open the selection window shown below.

Now noise source data must be defined for all the missing parts.

The name of the turbine type is shown in the top of the window. The noise data selected for this turbine type is shown in the window below. If anything in this window is shown with a red background, it means that the noise data record is incomplete for the selected calculation.

The available data are listed in the central field with red fields showing where data are missing. In the above example, data are missing for 60 m hub height for the 6 m/s wind speeds. The left red markings indicate that the source noise level is missing and the right red marking indicate that an octave-band distribution of the source noise is missing for both the wind speeds. WindPRO has filled in suggestions in those fields.

If the first line is highlighted you can see what WindPRO suggests.

WindPRO has extrapolated noise values from other wind speeds resulting in the suggested $L_{wa,ref}$. It also concluded that since those other wind speeds held pure tones, so must the one with missing data. Finally it suggests a generic octave band distribution that summed together will result in the total $L_{wa,ref}$.

The user can revise these values in which case you will have to press "Update list with current values", or simply accept the suggestions and move to the next turbines or start the calculation.

Please note that all these steps must be repeated if you do a re-run of your calculation. There is no way to save the input data. If you have the required noise data, the right place to input them is in the wind turbine catalogue, where you can enter user-defined noise data.

If you use generic data, the calculation report will say which data were generic.

Decision making for missing data
While it is best to have complete and correct data for the noise impact calculation it is often the case that data are missing. In those cases EMD strongly recommend to obtain the missing data from the wind turbine manufacturer and enter those value into the wind turbine catalogue. However analyses are often made at an early stage or data simply does not exist for the turbine type. For these situations WindPRO can assume generic or derived values.

Essentially noise data are required for the wind speed of the calculation, the tower height of the turbine, and in many cases the noise value must be based on a 1/1 octave band distribution.

If the proper wind speed is missing WindPRO can interpolate between the two closest wind speeds to find the noise value or extrapolate linearly using the two closest wind speeds. Extrapolated values must be used with caution as noise as a function of wind speed is not a linear function in reality.

If there is only one wind speed available WindPRO will use the Wind speed dependency value for this turbine.

If no noise value is available at all, WindPRO will look up the noise level in the noise vs. generator size experience function shown below.

Source noise (LWA,ref, dBA) for a sample of Danish WTGs (typical increase: 3,3 dBA per MW)

y = 0,0033x + 97,666
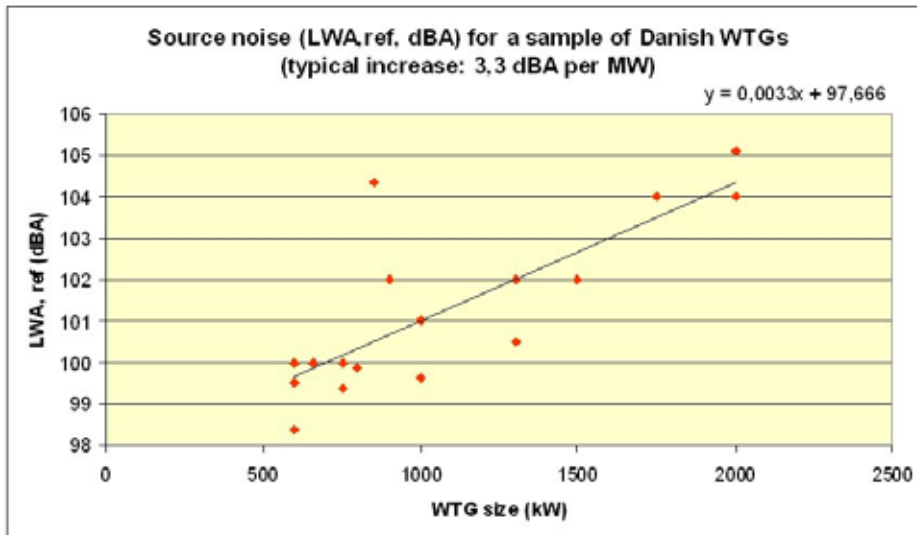
As would be noticed from the figure this is a highly uncertain approach as there is a large amount of scatter to this function.

Please note that the 95% of nominal power noise level cannot be used for extrapolation as there is no information on at which wind speed this noise level is valid.

Missing hub height
In case there are no data for the hub height selected WindPRO will interpolate between the two closest hub heights for the particular wind speed in question. If it is not possible to interpolate, the value will be found through extrapolation. In case there is only one available hub height, values from this height will automatically be used.

Only if the particular wind speed is not available from the other heights will WindPRO start the interpolation or extrapolation routines from its own height. If it is possible to interpolate or extrapolate between wind speeds in neighboring heights that will be done before using the wind speed dependency on a single wind speed for the height in question. In the same way if a single value and wind speed dependency is available for another height this will be done before looking up the above experience function to guess a noise level for the wind turbine.

Note that it is possible to define or select a hub height independent column in the wind turbine catalogue.

Octave-band distribution missing
When octave band distribution is required but missing from the data, WindPRO will suggest a distribution. Common for all suggested distributions are that they are A-weighted and when summed together they will result in the correct total noise level for that particular hub height and wind speed. The octave band distribution used as a base will be fitted by adding or deducting equally on all frequencies to achieve the wanted total noise level.

If octave band distributions are available for other wind speeds with the same hub height the closest wind speed will be used as base for the fitting.

If no octave band distribution is available for the particular hub height WindPRO will look to other heights to find the closest wind speed for a base distribution.

If that is not possible either (there simply are no octave band distributions available for this noise record) WindPRO will assume a generic distribution and fit this to the required noise level. The distribution used is a typical distribution, which by experience tends to fit many turbine types fairly well.

It must however be emphasized that while adopting a octave band distribution from a another wind speed of the same turbine will result in only marginal error, it is strongly encouraged to obtain the correct octave band distributions from the manufacturer, especially if no other distribution is available for the turbine.

4.1.3.3. DECIBEL - Printout

After the calculation has been completed, a window like the one shown below will appear which lists the available reports that can be printed.
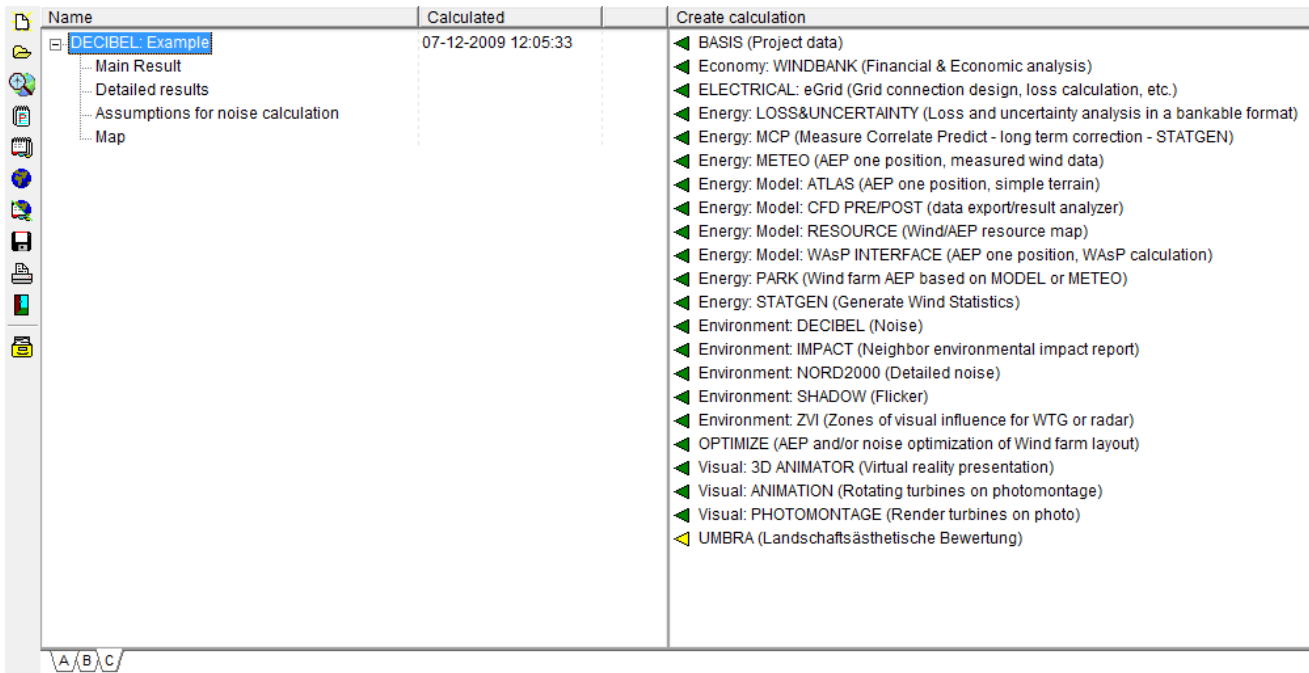
Next to the calculation name a number of properties can be selected, such as date, calculation time, etc. by right-clicking in the top bar and selecting the relevant properties.

The reports will automatically pop-up on the screen if you double-click the report page name.

If you right-click on the calculation name and select "Print", you access the Report Setup where it is possible to customize the calculation report and view all pages at the same time (see below).

Reports	Pages
☑ Main Result	1
☑ Detailed results	1
☑ Assumptions for noise calcu	1
☑ Map: 6,0 m/s	1
☑ Map: 8,0 m/s	1
	5

Options | Map: 6,0 m/s | Orientation and legend position

Map   KMS map: DISC06.IT ▼

Map scale   1:25000 ▼

Print scale / Size of map

Automatic based on used objects ▼

Center of map on report

Center of all objects in calculation ▼

Background map quality
◉ Normal   ○ Enhanced

Objects included on map

☑ New WTG
☑ Noise sensitive area
☐ Line object
☑ Noise raster
☑ Noise lines

Result to file

Report language

English ▼

☐ Use selected as default
☐ Clear default

Preview   Print
Ok   Cancel

In the checkbox to the left, the individual report elements can be selected or deselected for printout. By clicking on the report name you gain access to the setup mode for the selected report in the right half of the window. Here, details regarding the individual reports can be set (e.g. the map scale which is to be used on the printout, which maps to include, etc).

Please notice the option to plot noise-level contours on the map, which can be set up individually. This works in an identical way to the calculation setup and gives you the option to reconsider your graphical settings.

Further details on printing can be found in Chapter 2 BASIS.

You will find examples of printouts from all the modules in "Module descriptions".

At this point please note that the printout is slightly different for the various codes implemented. Most different are calculations where a range of wind speeds have been chosen. Here, the main report will present the most critical wind speed results for each of the receptors. An extra report page is included showing the calculation result as a graph and in a tabular form (see below).

Farm (A)

		Demands		Sound Level	
Wind speed	Ambient noise	Margin	Demands	WTG noise	Demands fulfilled ?
[m/s]	[dB(A)]	[dB(A)]	[dB(A)]	[dB(A)]	
4,0	28,0	5,0	33,0	32,3	Yes
5,0	29,0	5,0	34,0	33,3	Yes
6,0	30,0	5,0	35,0	34,3	Yes
7,0	32,0	5,0	37,0	35,3	Yes
8,0	34,0	5,0	39,0	36,3	Yes
9,0	36,0	5,0	41,0	37,3	Yes
10,0	37,0	5,0	42,0	38,3	Yes
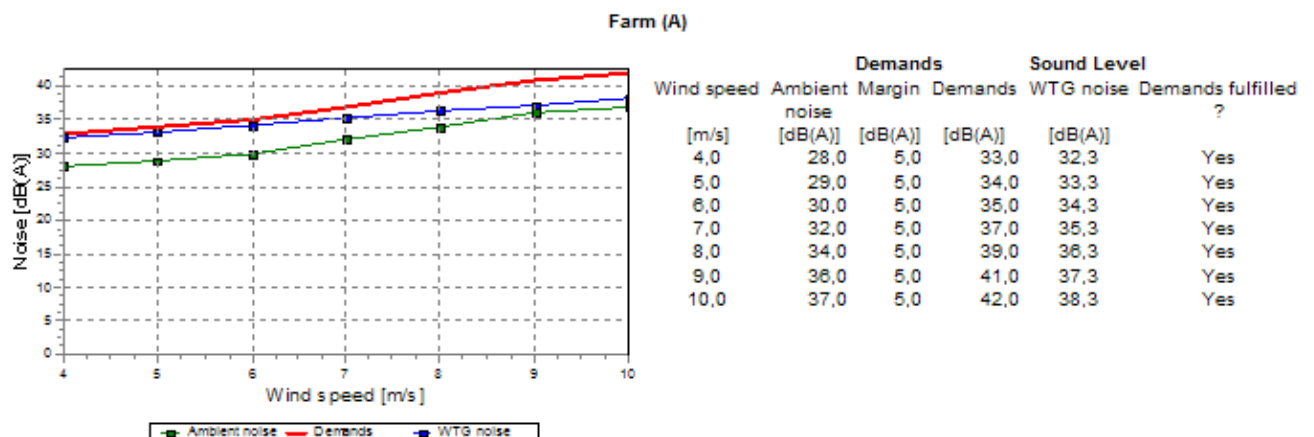
Here the ambient (background) noise level is shown. The critical level (demand) is shown as a red graph and the calculated sound level, whether it is the noise from the wind turbines or a combination of ambient and WTG noise is shown in blue. For each of the wind speeds included, the calculated noise levels are compared against the demands to determine whether or not the demands are fulfilled.

If the NSA was entered as an area, the result will give the coordinates of the point of the area with the highest noise level and the calculated level.

Result to file
Both from the print setup and by right-clicking the calculation headline it is possible to send "Result to file"

From here it is possible to either save selected data to a text or shape file or copy them to clipboard and for example paste them into Excel or similar packages.

4.1.3.4 Noise optimization using the result layer

It is possible to show the noise iso-lines on the background map and have them automatically update when the WTGs are moved. This can be a great help in finding the optimal layout with regards to noise emission.

The procedure is to perform the DECIBEL calculation as described above. On the "Main" tab "Interactive noise lines on map for layout optimization" calculation option must be selected (see below).

On the "Noise map" tab only one wind speed is allowed. If you have several wind speeds you will have to use the minus button to remove you excess wind speeds.

When you run the calculation WindPRO will now produce a Result layer on the maps in Maps and Objects. Where the Result layers in a standard calculation are static, this result layer is dynamic, meaning that every time a change is registered (i.e. a turbine is moved) WindPRO will update the noise lines.
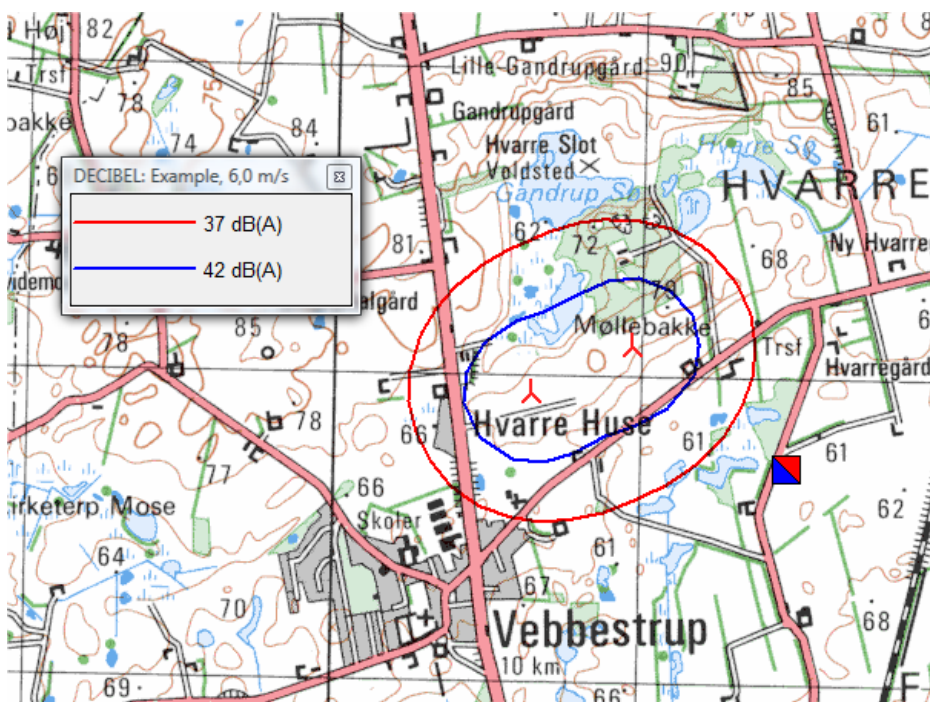
You can move the turbines, change noise settings or turbine types, remove turbines or add turbines (in the layers used for the calculation). When the turbines are deactivated (no turbines selected anymore) the update

takes place. It can therefore be a good idea to jump directly from turbine to turbine to make the changes and only then release the turbines in order to minimize update time.

The generation of the noise iso-line is faster than for the reports because the grid size is deliberately larger. However with large wind farms these updates may still run very slowly. It may therefore be useful to reduce the amount of detail by choosing a simpler code or flat terrain for the noise optimization and then re-apply the full details for the final report,

Right-clicking on the result layer gives access a few selections of the result layer. The noise lines can be switched on or off, the legend can be switched on and off and it is possible to switch to Manual update. If Manual update is selected the noise line will be frozen until released be selecting Manual update again.

It is also possible to enter the properties of the Result layer.

As this result layer is linked to a particular calculation the most relevant option is to link to a different calculation. Please note that this have to be a calculation setup for automatic noise iso-line map.
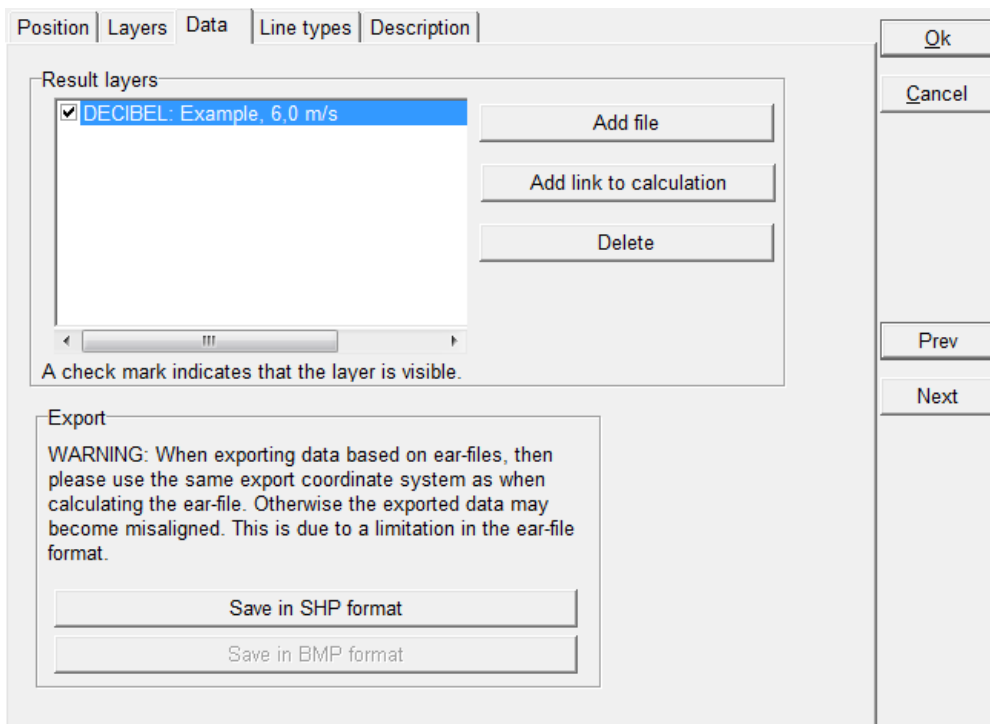
It is also possible at this stage to save the noise line in shape file format.

In the tap Line types it is possible to change the configuration of the lines as described in previous sections.

When you are finished using the noise optimization it is a good idea to delete the result layer. Otherwise it will keep updating every time you manipulate you project. You can always recreate the lines by running the calculation again.

4.1.3.5 Noise allowance map

A third calculation option from the Decibel calculation is to generate a map that shows the maximum allowed noise. This map considers the area available for turbines and the noise sensitive points and areas surrounding the site and can be used to find out if there is room for wind turbines on the site.

A prerequisite for the calculation is a WTG area object. WTG area objects are described in detail in Section 8.1.2.1. The area needed for this calculation only need to contain the boundaries of the site. There is no need to define turbine numbers and spacing, nor exclusion zones etc.
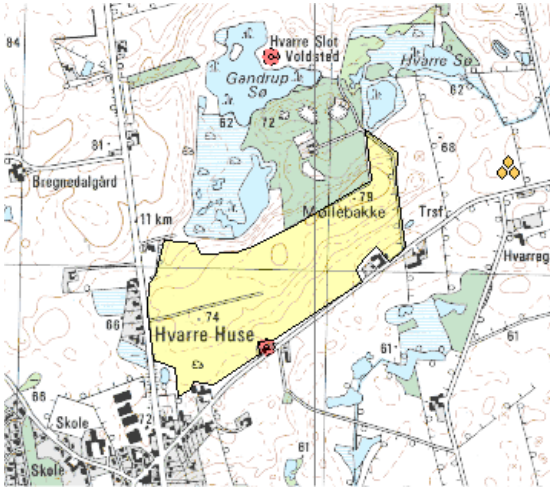
The Noise allowance map calculation is selected on the main tab when running a Decibel calculation.

Note that the calculation model is disabled.

The tabs now available are the NSA and the Noise allowance map tabs.

On the NSA tab the noise receptors limiting the site are selected by layer.

The selections on the Noise allowance map tab relate to map to be created. The WTG areas defining the area are selected in the top part. Below this it is possible to select the grid size (resolution) of the map. The smaller the grid size the slower the calculation. Calculation hub height defines the height of the noise source.

If you want the resulting map displayed on the map in Maps and Objects you can hatch the box for "Show result in a result layer on the working map". Otherwise the map will only be shown in the calculation report.
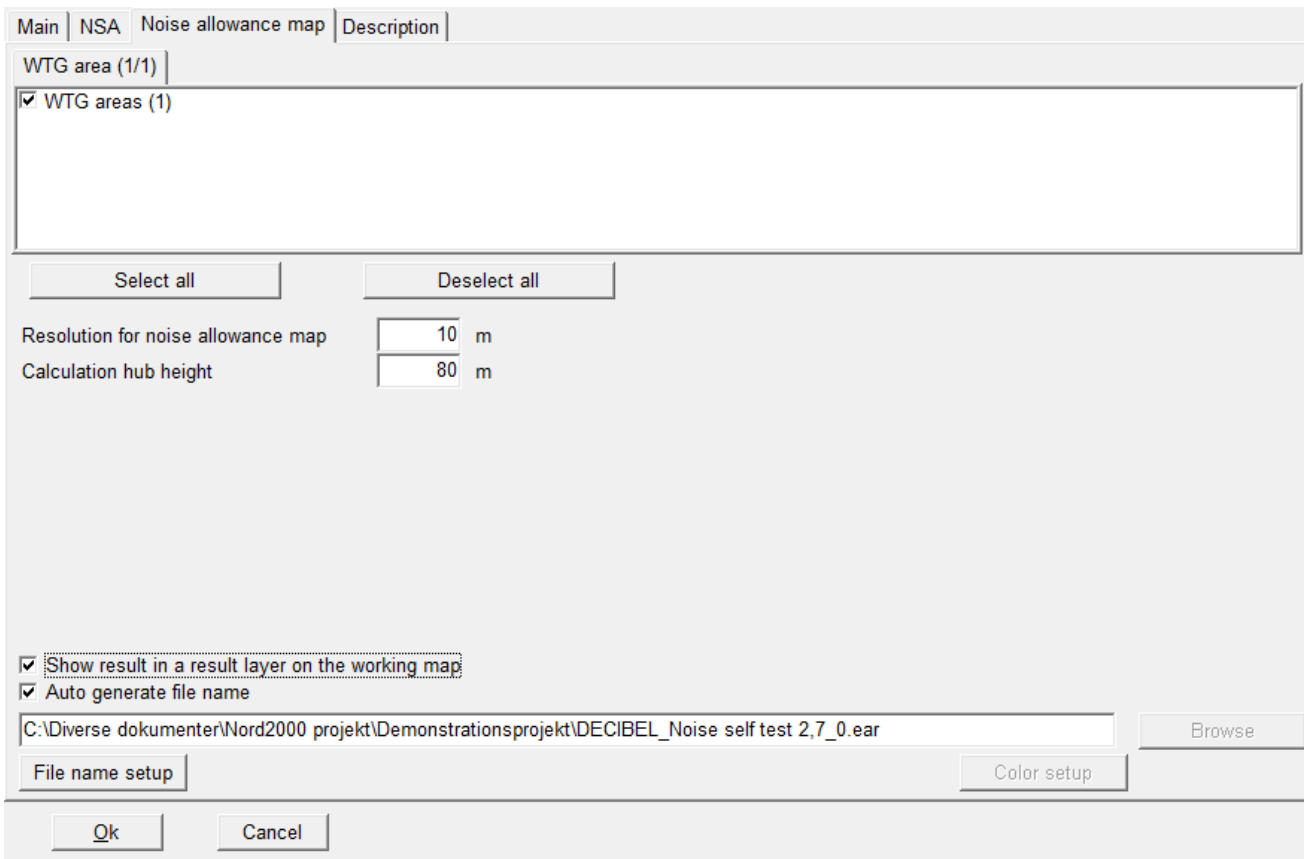
The resulting map is shown below in Maps and Objects. Right-clicking on the Result layer gives access to a legend.
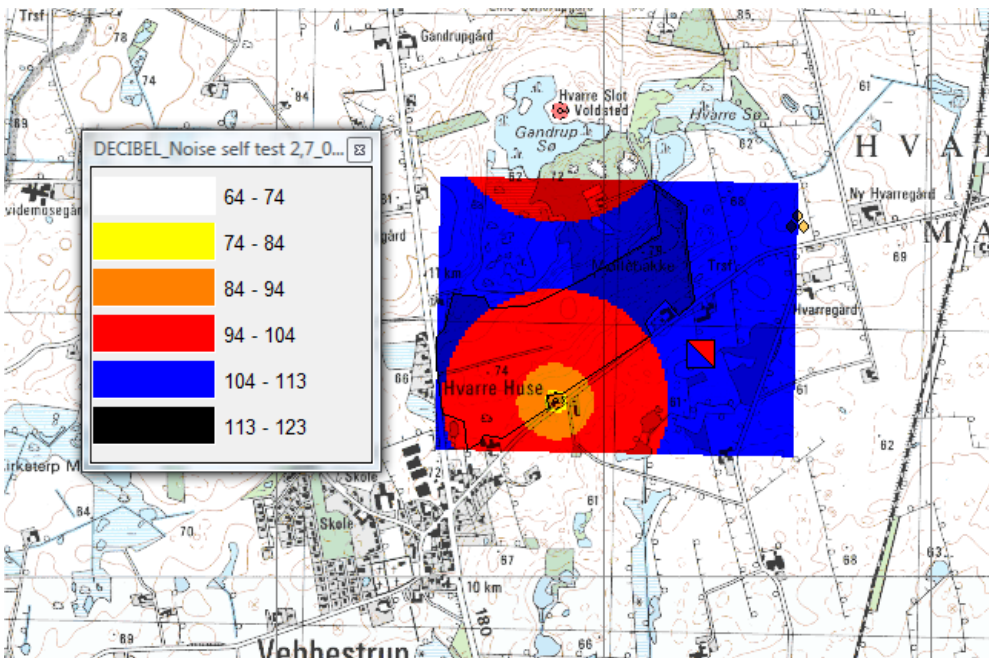
The map shows in a color code how much noise (L_{WA}) a turbine will be allowed to make depending on location.

4.1.4 Appendix. Theoretical background for noise propagation models

4.1.4.1 The International rule DIN ISO 9613-2, general

The ISO 9613-2 "Attenuation of sound during propagation outdoors, Part 2. A general method of calculation" describes the calculation of damping of the noise during propagation outdoors.
This text describes the theoretical basis of the ISO 9613-2 as implemented in WindPRO.

Calculation formulas if octave data are not available

Normally, the A-weighted noise source (without octave division/classification) is determined for one WTG type through measurements. The damping values at 500 Hz are used to determine the resulting damping of noise emission. The general method for calculation of ground attenuation cannot be used. The resulting noise level from each source is thereafter calculated from the ISO 9613-2 as follows:

$$L_{AT}(DW) = L_{WA} + D_C - A - C_{met} \qquad (1)$$

LWA: Source noise, A-weighted.

D_c: Directional correction for noise source without directional effect (0dB), but taking the reflection from the terrain into consideration, D_W (Needed because the alternative method for calculating ground attenuation, Agr is used)

$$D_C = D_W - 0 \qquad (2)$$

D_W is calculated as:

$$D_W = 10 \lg\{1 + [d_p^2 + (h_s - h_r)^2] / [d_p^2 + (h_s + h_r)^2]\} \qquad (3)$$

Where:
h_s: Noise source height above terrain (hub height)
h_r: Noise receptors height above terrain (usually 5m, but can be set individually in the calculation setup)
d_p: Distance between noise source and recipient projected on level terrain

The distance is determined by the (x,y) coordinates for sources (index s) and recipient (index r).
$$d_p = \ddot{Q}(x_s - x_r)^2 + (y_s - y_r)^2] \qquad (4)$$

A: Damping between the noise source (WTG-Nacelle) and the noise critical point:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} \qquad (5)$$

A_{div}:   Damping due to geometry

$$A_{div} = 20 \lg(d/1m) + 11 \text{ dB} \qquad (6)$$

d: Distance between noise source and recipient
A_{atm}:   Damping due to air absorption

$$A_{atm} = a_{500} \, d / 1000 \qquad (7)$$

a_{500}:   Air absorptions coefficient (= 1,9 dB/km)
The value for a_{500} is based on the most optimal noise emission conditions (temperature 10 Gr. C and 70% relative atmospheric humidity)
A_{gr}:   Terrain damping:

$$A_{gr} = 4,8 - (2h_m / d)[17 + (300 / d)] \qquad (8)$$
IF $A_{gr} < 0$ then is $A_{gr} = 0$

h_m: Average height above terrain (in meters) for noise emission
If there is no orography for the site:

$$hm = (hs + hr) /2 \qquad (9a)$$

If there is a DHM in the area between line of sight and the terrain surface between the WTG and the immission point, it will be calculated based on a grid (grid size set in the calculation setup) with a calculation for each grid point the line of sight passes through. The medium height is calculated by:

$$h_m = F/d \qquad (9b)$$

F: Integrated area from emission point to receptor (immission point)
$F = F_1 + F_2 + \ldots + F_{100}$
d: distance from emission point to receptor (immission point)

A_{bar}: Damping due to shielding (noise protection) normally no
shielding protection: $A_{bar} = 0$.

A_{misc}: Damping due to different other effects (vegetation, buildings, industry). Usually these effects are not included in the calculation. $A_{misc} = 0$.

C_{met}: Meteorological correction which is determined by means of the equation:
$C_{met} = 0$ for $dp < 10 (h_s+h_r)$
$C_{met} = C0 [1-10(h_s+h_r)/dp]$ for $dp > 10$,
d_p: Distance between noise source and recipient projected on level terrain.

where the factor C0, dependent on weather conditions, can be between 0 and 5 dB. In exceptional cases, values over 2 dB may occur. In WindPRO, C0 can be defined individually for each noise calculation.

Calculation method with octave-divided noise data
Using the ISO 9613-2 it is possible to calculate according to octave-divided noise figures for a WTG. If such data are available and entered into the WindPRO WTG catalogue, they will automatically be used in calculations. Using octave-band data also makes it possible to use the general ground attenuation method. In the following formula is only demonstrated the difference from calculation with 500 Hz frequency as average value. The resulting noise is calculated as follows:

$$L_{AT} (DW) = 10lg[10^{0,1LAfT(63)} + 10^{0,1LAfT(125)} + 10^{0,1LAfT(250)} + 10^{0,1LAfT(500)} + 10^{0,1LAfT(1k)} + 10^{0,1LAfT(2k)} + 10^{0,1LAfT(4k)} + 10^{0,1LAfT(8k)}) \qquad (10)$$

where:

L_{AfT}: A-weighted noise source for each noise sources at different frequencies (63, 125, 250, 500, 1000, 2000, 4000, 8000 Hz)

The A-weighted noise source L_{AfT} at average frequencies for each noise source is calculated from:

$$L_{AfT} (DW) = (L_W + A_f) + D_C - A \qquad (11)$$

where:

L_W: Octave noise source for non A-weighted point source. LW + Af constitute the A-weighted octave-divided noise source LWA according to IEC 651

A_f: standardized A-weighted from IEC 651. WindPRO calculates the A-weighted values for the noise source according to this.

D_c: Directional correction for noise source without directional effect (0dB), but taking the reflection from the terrain into consideration. If general ground attenuation is used $D_W = 0$, which means $D_c = 0$. If alternative method is used D_c is calculated as in the non-octave band case.

A: Octave damping, damping between point source and recipient which is determined as described above by the following damping types:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} \qquad (12)$$

A_{div}: Damping due to geometry (= VDI 2714 Distance figure Ds)
A_{atm}: Damping due to air absorption, frequency dependent (=VDI 2714 air absorption figure DL)
A_{gr}: Terrain damping:(=VDI 2714 Terrain and meteorological damping figures DBM)
A_{bar}: Damping due to shielding (noise protection), worst case, no noise protection $A_{bar} = 0$
A_{misc}: Damping due to different other effects (growth, housing, industry). Worst case $A_{misc} = 0$

At octave-divided noise emissions, the damping due to air absorption depends on the frequency due to the air absorption:

$$A_{atm} = a_f \, d \, / \, 1000 \qquad (13)$$

where:

a_f: absorption coefficient for each frequency band.

The air-damping coefficient depends strongly on the noise frequency, surrounding temperature and the relative atmospheric humidity. The adverse conditions are at 10 degree Celsius and 70% relative atmospheric humidity. The following values are:

Band, mean frequency, [Hz]	63	125	250	500	1000	2000	4000	8000
a_f, [dB/km]	0.1	0.4	1	1.9	3.7	9.7	32.8	117

For the terrain damping there is two methods available for calculation the ground attenuation, A_{gr}. The alternative method is as described for the non-octave band case above. The general method is calculated as:

$$A_{gr} = A_s + A_r + A_m \qquad (14)$$

Where

A_s: The attenuation for the source region spanning $30h_s$, though max d_p. This region is described by the ground factor G_s, which gives the porosity of the surface, a value between 0 (hard surface) and 1 (porous surface).
A_r: The attenuation for the receiver region spanning $30h_r$ from the receiver. This region is described by the ground factor G_r.
A_m: The attenuation for the middle region. If the source and receiver region overlaps, then there is no middle region. This region is described by the ground factor G_r.

In WindPRO only one parameter for G (porosity) is used

$$G = G_s = G_r = G_m \qquad (15)$$

The porosity is set in the calculation setup.

The below extract from the ISO 9613-2 document explains how the three ground attenuations are calculated.

Nominal midband frequency	A_s or A_r[1]	A_m
Hz	dB	dB
63	$-1,5$	$-3q$[2]
125	$-1,5 + G \times a'(h)$	
250	$-1,5 + G \times b'(h)$	
500	$-1,5 + G \times c'(h)$	
1 000	$-1,5 + G \times d(h)$	$-3q(1-G_m)$
2 000	$-1,5(1-G)$	
4 000	$-1,5(1-G)$	
8 000	$-1,5(1-G)$	

NOTES

$$a'(h) = 1,5 + 3,0 \times e^{-0,12(h-5)^2}\left(1 - e^{-d_p/50}\right) + 5,7 \times e^{-0,09h^2}\left(1 - e^{-2,8 \times 10^{-6} \times d_p^2}\right)$$

$$b'(h) = 1,5 + 8,6 \times e^{-0,09h^2}\left(1 - e^{-d_p/50}\right)$$

$$c'(h) = 1,5 + 14,0 \times e^{-0,46h^2}\left(1 - e^{-d_p/50}\right)$$

$$d'(h) = 1,5 + 5,0 \times e^{-0,9h^2}\left(1 - e^{-d_p/50}\right)$$

1) For calculating A_s, take $G = G_s$ and $h = h_s$. For calculating A_r, take $G = G_r$ and $h = h_r$. See 7.3.1 for values of G for various ground surfaces.

2) $q = 0$ when $d_p \le 30(h_s + h_r)$

$$q = 1 - \frac{30(h_s + h_r)}{d_p} \quad \text{when } d_p > 30(h_s + h_r)$$

where d_p is the source-to-receiver distance, in metres, projected onto the ground planes.

Long-term average noise level (resulting noise level)

Noise source figures and distances to noise critical points will be overlaid (superimposed) if the calculation contains n noise sources (wind farm). The resulting noise L_{AT} is calculated according to following:

$$L_{AT}(LT) = 10 \times \lg \sum_{i=1}^{n} 10^{0,1(L_{ATi} - C_{met} + K_{Ti} + K_{Ii})} \tag{14}$$

L_{AT}: Resulting noise at noise critical points
L_{ATi}: Noise at noise critical point from noise source i
i: Index for all noise sources from 1-n
K_{Ti}: Addition for pure tone content for a noise source i, depends on the local rules
K_{Ii}: Addition for impulse tone content for a noise source i, depends on the local rules
C_{met}: Meteorological correction which is determined by means of the equation:
$C_{met} = 0$ for dp < 10 ($h_s + h_r$)
$C_{met} = C0 [1-10(h_s + h_r)/dp]$ for dp > 10,
d_p: Distance between noise source and recipient projected on level terrain.

where the factor C0, dependent on weather conditions, can be between 0 and 5 dB. In exceptional cases values over 2 dB may occur. In WindPRO the C0 can be defined individually for each noise calculation.

4.1.4.2 Calculation of Lden

L_{den} is a weighted average of the noise over a period of time. The den label refers to day-evening-night and means that the noise is calculated independently for each period with special penalties for evening and night.

The noise for each period is calculated as L_{eq24}, which corresponds to the standard L_{WA} noise calculated normally in WindPRO. The formula for converting L_{eq24} noise to L_{den} is given in the formula below, adapted from Statens Forurensningstilsyn's spreadsheet lden_lekv_driftstid.xls.

$$L_{den} = 10 * \log\left(\frac{10^{\frac{L_{day,y}}{10}} * t_{day} + 10^{\frac{L_{eve,y}+P_{eve}}{10}} * t_{eve} + 10^{\frac{L_{night,y}+P_{night}}{10}} * t_{night}}{24}\right)$$

Where t gives the number of hours in the periods day, evening and night respectively. Typical values are 12, 4 and 8 hours
P is the penalty for evening and night respectively. Typical values are 5 and 10 dB.
$L_{day,y}$ is the annual average of daytime noise given as:

$$L_{day,y} = 10 * \log\left(\frac{10^{\frac{L_{day,d}}{10}} * O_y}{365}\right)$$

Where O_y is the operation days per year. This value is typically set to 290 days.
$L_{day,d}$ is the daily average of noise. Typically this will the same as L_{eq24} or L_{WA}. If the turbine is stopped parts of the day $L_{day,d}$ can be calculated as:

$$L_{day,d} = 10 * \log\left(\frac{10^{\frac{L_{eq24,day}}{10}} * t_{day}}{12}\right)$$

L_{eve} and L_{night} are calculated the same way.

$$L_{eve,y} = 10 * \log\left(\frac{10^{\frac{L_{eve,d}}{10}} * O_y}{365}\right)$$

$$L_{night,y} = 10 * \log\left(\frac{10^{\frac{L_{night,d}}{10}} * O_y}{365}\right)$$

$$L_{eve,d} = 10 * \log\left(\frac{10^{\frac{L_{eq24,eve}}{10}} * t_{eve}}{4}\right)$$

$$L_{night,d} = 10 * \log\left(\frac{10^{\frac{L_{eq24,night}}{10}} * t_{night}}{8}\right)$$

4.1.4.3 The German rule VDI 2714 (outdated)

Until 01.10.1998 calculations were performed from VDI-Guideline Directions "Noise emission in open air". The starting point for the calculation is a simple A-weighted noise emission. The formula below is the calculation formula for noise level at the distance S between the WTG and the noise-sensitive point:

LS = LW + DI + KO - DS - DL - DBM - DD - DG   in dB(A)

LS   : Calculated noise level in distance S
LW   : Noise emission for the WTG
DI   : Directional impact figure (= 0)
KO   : Solid angle figure (= 3 dB)
DS   : Distance figure DS=10 log(4 π S2)
DL   : Air absorption figure DL=α_L S
              α_L = 0.00209 dB/m

DBM   :Terrain and meteorological damping figure
DBM = Max(0, 4.8 - (hq+hA)/S(17+300/S))
          hq hub height
          hA Noise critical point height above terrain IP (= 5m)
DD   : Vegetation damping figure (= 0)
DG   : Build up damping figure (= 0)

Default values are shown in brackets. These are the so-called "worst case" values, which WindPRO uses. For instance, vegetation damping will normally always be >0 and therefore the measured noise should be below the value calculated.

If the noise originates from several sources (e.g. a wind farm) then each individual noise source contribution is add up and the resulting noise at noise critical points is calculated from there..

4.1.4.4 Danish noise codes

Former Danish codes 1991

The Danish rules are outlined in "Bekendtgørelse om støj fra vindmøller" (Statement from the Department of Environment) No. 304 of 14/5/91.

The key equation is:

L_{pA} = $_{LWA,ref}$ - 10 x log(l^2+ h^2) - 8dB - ΔL_a

Where

l is the distance between the WTG and the neighbor

h is the height difference between the nacelle and the neighbor (normally = hub height) and

ΔL_a is the air absorption.

ΔL_a is calculated as $\alpha_a\sqrt{(l^2+ h^2)}$

Where α_a is the damping coefficient (0.005 dB/m or from the table below).

Octave Band Damping Coefficient:

Center freq. (Hz)≤	125	250	500	1000	2000	4000	8000
α_a (dB/m)	0	0	0.002	0.004	0.007	0.017	0.06

If the noise emission from the WTG is given for each octave band (see Chapter 2, section 5 "WTG Catalogue" under WindPRO BASIS), the damping coefficient will be more correctly included in the calculations, but this is not a requirement.

Current Danish codes 2007

From 2007 new noise codes for Denmark are used in Denmark based on "Bekendtgørelse nr. 1518 af 14. December 2006, Bekendtgørelse om støj fra vindmøller".

The propagation model here is changed with a separate damping for offshore wind turbines.

The central equation for is:

L_{pA} = $L_{WA,ref}$ - 10 x log(l^2+ h^2) - 11dB + ΔL_g - ΔL_a

Compared to the former Danish codes the difference is in the damping.

The ground attenuation ΔL_g is 1,5 dB for onshore turbines and 3 dB for offshore wind turbines.

The air absorption ΔL_a is calculated as above but with revised damping coefficient as follows:

Center freq. (Hz)≤	63	125	250	500	1000	2000	4000	8000
α_a (dB/m)	0.0001	0.0004	0.001	0.002	0.0036	0.0088	0.029	0.1045

The noise must be calculated using 1/1 octaves.

The noise level from groups of turbines are added together using the formula:

$$L_{total} = 10 * \log\left(10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{P2}}{10}} + \cdots\right)$$

4.1.4.5 Swedish noise codes, 2002.

By the end of 2001, new guidelines for calculating noise from WTGs were released in Sweden. They are called "Ljud från Vindkraftverk", Naturvårdsverket 2001, ISBN 91-620-6641-7. They replace former calculation methods and distinguish between onshore and offshore conditions.

Swedish, Jan 2002, Land.

For distances from the WTG up to 1000 m, the following formula is used:

L_A = $L_{WA,corr}$ − 8 − 20 * log(r) − 0,005*r

where r is the distance from the receptor to the hub of the WTG.

$L_{WA,corr}$ is a corrected source emission value, which depends on the roughness of the terrain and noise as a function of wind speed.

$$L_{WA,corr} = L_{WA,measured} + k*Dv_h$$

Where $L_{WA,measured}$ is the measured, A-weighted noise emission level at hub height and 8 m/s at 10 m height.

k is the rate of change of noise with wind speed. In WindPRO k is set to 1 dB/(m/s).

Dv_h is the difference in wind speed at hub height compared to 10 m height and is calculated as:

$$Dv_h = v_h([ln(H/z_0)/ln(h/z_0)]*[ln(h/0,05)/ln(H/0,05)]-1)$$

where H is the hub height, h is 10 m and z_0 is the roughness length corresponding to a roughness class (see Chapter 3). In WindPRO, a general roughness class must be chosen for the calculation site.

If the distance between the receptor and the WTG is more than 1000 m, a different method is employed using octave-divided noise data. The noise level at the receptor is then calculated as:

$$L_A = L_{WA,corr} - 10 - 20*log(r) - DL_a$$

Here the damping DL_a is calculated as:

$$DL_a = 10*log(S10^{(Li+Ai)/10}) - 10*log(S10^{(Li+Ai-r*ai)/10})$$

where Li is the measured octave-band value and Ai is the A-weighting at the appropriate frequency.

r is the distance from the receptor to the WTG.

If no octave-divided data exists for the WTG, the calculation yields no result. This is true both for noise receptors and for the noise iso-line map.

Swedish, Jan 2002, Water

For the calculation of noise propagation over water surfaces, the Swedish guidelines recommends using a different formula.

$$L_A = L_{WA,corr} - 8 - 20*log(r) - DL_a + 10*log(r/200)$$

where:

$$DL_a = 10*log(S10^{(Li+Ai)/10}) - 10*log(S10^{(Li+Ai-r*ai)/10})$$

Thus octave-divided data is also required for calculation of noise emissions over water surfaces.

If no octave-divided data exists for the WTG, this calculation cannot be used (returns no values).

4.1.4.6 Dutch, 1999.

The Dutch, 1999 method follows the guidelines described in "Handleiding meten en rekenen Industrielawaai" from Ministerie van VROM, Zoetemeer, 1999, ISBN 90 422 0232 7.

The section dealing specifically with noise from WTGs is Module C, method II.8.

Theoretical background

The basic formula is:

$$L_i = L_{WR} - SD$$

Where L_i is the noise level at the receptor

L_{WR} is the noise level at the WTG

And SD is:

$$SD = D_{geo} + D_{lucht} + D_{refl} + D_{scherm} + D_{veg} + D_{terrein} + D_{boden} + D_{huis}$$

Which are the different damping elements.

In this method octave-divided values are used. Where these are not available, a source noise emission value is used.

In WindPRO the following assumptions are made:

- The noise receptor point is 5 m above ground
- No shelter effects or reflection of noise
- No significant noise levels at low frequencies (31,5 and 63 Hz)
- The distance between the receptor point and the WTG exceeds 1,5 times the rotor diameter.

D_{geo} is the geometrical damping and is calculated as:

$$D_{geo} = 20*log(d)+11$$

where d is the distance from the WTG to the receptor.

D_{lucht} is the damping due to air absorption. When using octave-divided data, a specific air absorption coefficient is used for each frequency. If only a source emission value is used, D_{lucht} is calculated as:

$$D_{lucht} = 0,002*d$$

D_{refl} is the damping from reflection. This is set to 0 in WindPRO.

D_{scherm} is damping from shielding. This is set to 0 in WindPRO.

D_{veg} is damping from vegetation. This is set to 0 in WindPRO.

$D_{terrein}$ is damping from industrial terrain. This is set to 0 in WindPRO.
D_{bodem} is damping from hardness (or softness) of the ground. It is possible in WindPRO to set the acoustic hardness B of the terrain with a value from 0 (hard terrain) to –3 (soft terrain, farmland with some trees). D_{bodem} is then calculated as:

$$D_{bodem} = -2 - B$$

D_{huis} is special case damping from houses. This is set to 0 in WindPRO

4.2. SHADOW – Flickering

4.2.0 Introduction to SHADOW

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). Shadow impact may occur when the blades of a WTG pass through the sun's rays seen from a specific spot (e.g. a window in an adjacent settlement). 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 also 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 Windenergianlagen" (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 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. In the UK, no official limits are in force, however an assessment must be made at all dwellings within ten rotor diameters of the turbine locations (PPS22 for England, TAN8 for Wales). In Ireland, a worst-case 30 hours per year, 30 minutes per day limit has been set.

The time of the day for which shadow impact is critical and the definition of a shadow receptor for which shadow impact is calculated are less rigidly defined by the guides and is often something which should be evaluated in each individual case.

As an example, a factory or office building would not be affected if all the shadow impact occurred after business hours, whereas it would be more acceptable for private homes to experience shadow impact during working hours, when the family members are likely to be at work/school anyway.

Also, it is sometimes questionable whether the shadow impact should be calculated for a window, the façade of a house or the full outdoor curtillage. Should a shadow in one end of the garden be added to a shadow in the other end of the garden?

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 also be taken into account.

As in the other WindPRO modules, input of data can be based solely on entering coordinates and characteristics for the individual WTG and shadow receptor objects manually.

A significant strength in the WindPRO system is the option of direct graphic on-screen input of WTGs and shadow receptors on a map.

4.2.1 The SHADOW calculation method

The calculation of the potential shadow impact at a given shadow receptor is carried out simulating the situation. 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. The following information is required:

  · The position of the WTGs (x, y, z coordinates)
  · The hub height and rotor diameter of the WTGs
  · The position of the shadow receptor object (x, y, z coordinates)
  · The size of the window and its orientation, both directional (relative to south) and tilt (angle of window plane to the horizontal).
  · The geographic position (latitude and longitude) together with time zone and daylight saving time information.
  · A simulation model, which holds information about the earth's orbit and rotation relative to the sun.
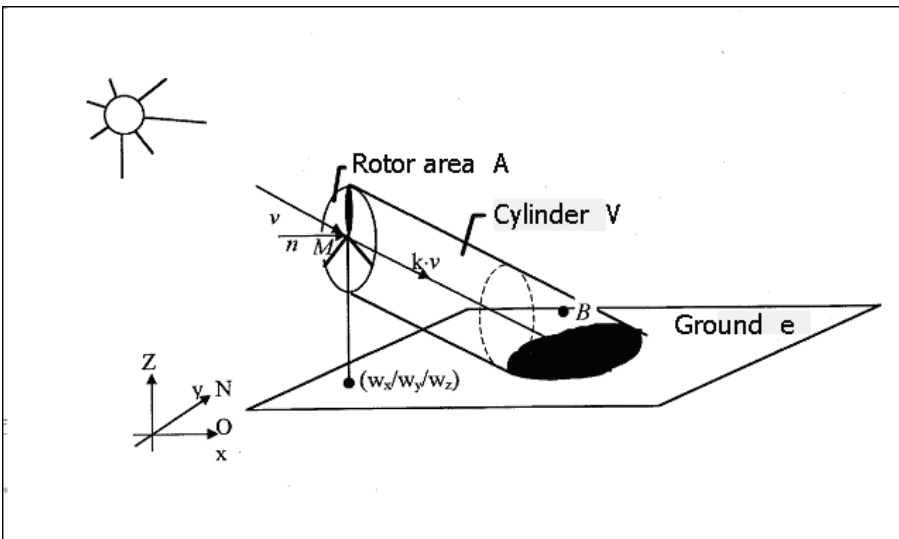
4.2.1.1 The SHADOW calculation model

In the shadow calculation model used by WindPRO the following parameters defines the shadow propagation angle behind the rotor disk

  · The diameter of the sun, D: 1,390,000 km
  · The distance to the sun, d: 150,000,000 km
  · Angle of attack: 0.531 degrees

Theoretically, this would lead to shadow impacts in up to 4.8 km behind a 45 m diameter rotor disk. In reality, however, the shadows never reach the theoretical maximum due to the optical characteristics of the atmosphere. When the sun gets too low on the horizon and the distance becomes too long, the shadow dissipates before it reaches the ground (or the receptor). How far away from the WTG the shadow will be visible is not well documented and so far only the German guidelines have set limits for this (see Section 4.2.0). The default distance in WindPRO is 2 km or coverage of 20% of the sun disk, whichever is the shortest, and the default minimum angle is 3 degrees above the horizon. If the German guidelines are used, the maximum distance from each WTG can be calculated using the formula

Max. distance = (5*w*d) / 1,097,780

where w is the average width of the blade. The value of 1,097,780 is derived from the diameter of the sun, reduced by a compensation factor for the fact that the sun disk is a circle and not a square.
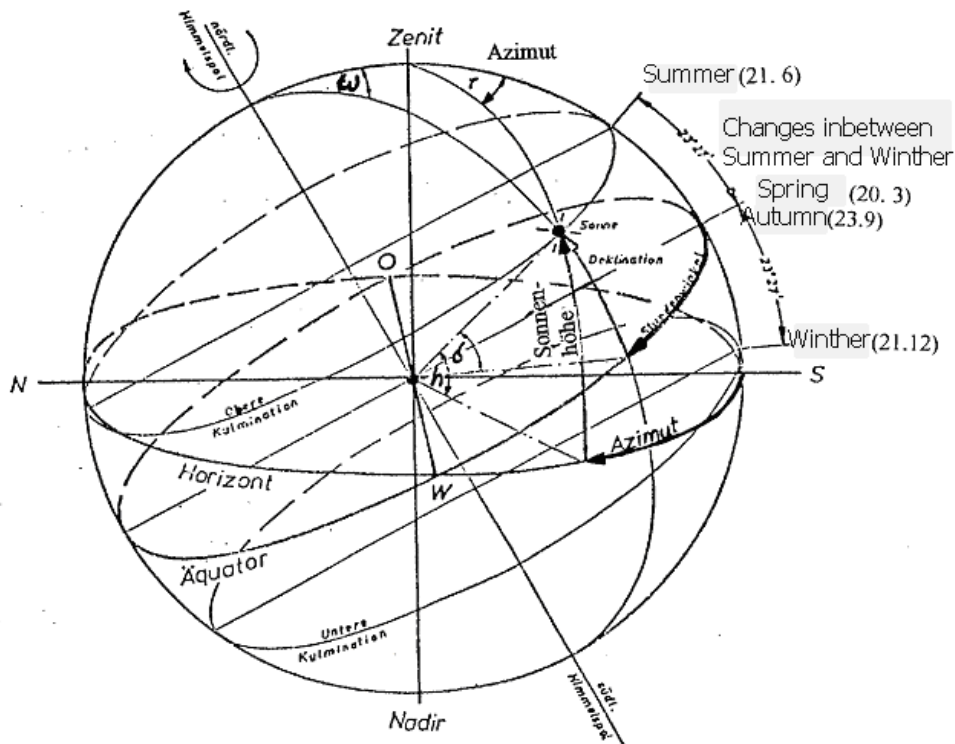
4.2.2 Entering data for Shadow Impact calculation

First of all, a background map is required, although a blank map can be used.
If one or more maps have been assigned to the project, click on the map icon to open one or all of them. Please refer to Chapter 2, WindPRO BASIS, for further information about the use of maps.

Please notice that, when entering objects via maps, you can create a default tool by holding down the <shift> key while selecting a tool. This function will allow you to enter multiple objects with the same properties (e.g. shadow receptors).

4.2.2.1 Entering WTGs

(See section Chapter 2. BASIS, Section 2.5.2)

4.2.2.2 Entering Shadow Receptors

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

Input a shadow receptor by selecting the icon shown to the left and place it on the map.

When you have selected the object with the mouse from the tool bar it is placed on the map with a click on the left mouse button.

After entering information on the receptor size and name, you can activate the shadow receptor again to align it. This is done by clicking on the icon, holding the stick and rotating it to align it towards the WTGs or along the side of the relevant house on your map. The shadow is thrown into the "bowl", so the stick gives the direction of the window.
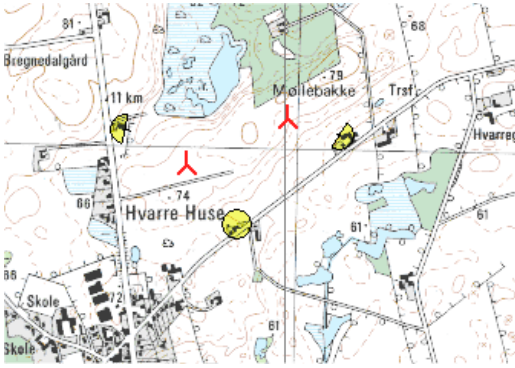
For Tab sheet Position, see Chapter 2.5.2.2. Basis.

Note: The z-coordinate of a shadow receptor must be entered in the same reference system as the z-coordinate of the WTGs. If the WTGs have been entered with the default value "0", you have to enter the z-coordinates for the shadow receptors relative to the elevation of the WTG foundation, i.e. if the shadow receptors have a lower elevation than the WTG foundation, then the z-coordinate will be negative. It is recommended to enter z-coordinates for all objects relative to the sea level.

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. This is useful if the actual properties of the receptor are unknown or if there are wind turbines on more sides of the house that will contribute to the flickering impact.

The figure shows the data input sheet for the above information.

4.2.3 Calculation and printout from SHADOW

Click on the green arrow beside the SHADOW heading to activate the calculation module (if the arrow is yellow you do not have a registration license for the module - please contact EMD). After having selected the calculation, you are given some options for setting up the calculation.

4.2.3.1 SHADOW - Calculation Setup

Main: The name of the calculation: Enter a unique descriptive name so that different calculations in the same project can be separated.

This is the tab where the type of calculation is selected.

It is possible to choose two types of calculation:
- · Shadow flicker at the shadow receptors
- · A shadow flicker map

The two calculations are not mutually exclusive. It is possible to calculate one or the other or both.

There is an Advanced settings box on the lower part of the main tab. If this is checked it is possible to modify the maximum distance for shadow flicker and the lower limit of the Sun above the horizon to include in the calculation.

According to the German guidelines described in Sections 4.2.0 and 4.2.1.1., flickering is only an issue when at least 20% of the sun disk is covered by the blade. Checking this box lets WindPRO use the blade width information from the wind turbine catalogue to 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 calculation requires that the blade width at 90% radius and at the maximum blade width has been entered in the catalogue for the particular turbine type.

As an alternative, or if there are no data for the specific WTG, the maximum distance can either be given by typing a fixed maximum distance (default 2000 m), choosing no limit, or using an individual distance for each wind turbine. The individual settings offer to use one of the WTG distance circles (see Chapter 2 Section 2.5.2.5).

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 of the atmosphere and becomes too diffuse to form a coherent shadow.

The reference year field makes it possible to specify a specific year. This will make the calendar use the daylight saving time dates correctly as well as the number of days in the year. The default year used is 1981.

Flicker at receptors
The theory for calculating flicker at the receptors is explained in Section 4.2.0.

The default selection is the worst case calculation, assuming no clouds, wind direction aligned with direction from turbine to receptor and always operation as described in Section 4.2.0.

It is also possible to calculate using "Real" case limitations in respect to the above parameters (see section below) and as an experimental option "Real case based on time series".

WTGs

Here you can define a sub-range of WTGs to be included. By default all visible WTGs (in all visible layers) are selected. Layers as well as individual WTGs can be checked or unchecked.

Receptors

On this tab the receptors being calculated are selected by selecting the layers in which the receptors are located. Alternatively the receptors can be selected individually.

ZVI

WindPRO will combine the ZVI and the Shadow calculation and thus exclude contributions from wind turbines that cannot be seen from the receptors. This is so also true for the shadow map, where only turbines visible from each calculation grid point will be included.

In order to perform the ZVI calculation, there must be a height model available in the form of a line object with height contours. Area objects defining blocking elements like forests or villages and obstacles can also be included.

The height above ground for the observer is set as the Eye height.

For more information on the ZVI calculation see Section 4.

Real case based on statistics

It is possible to add a real case calculation to the shadow flicker calculation. This gives access to the additional tab: Real case statistics.
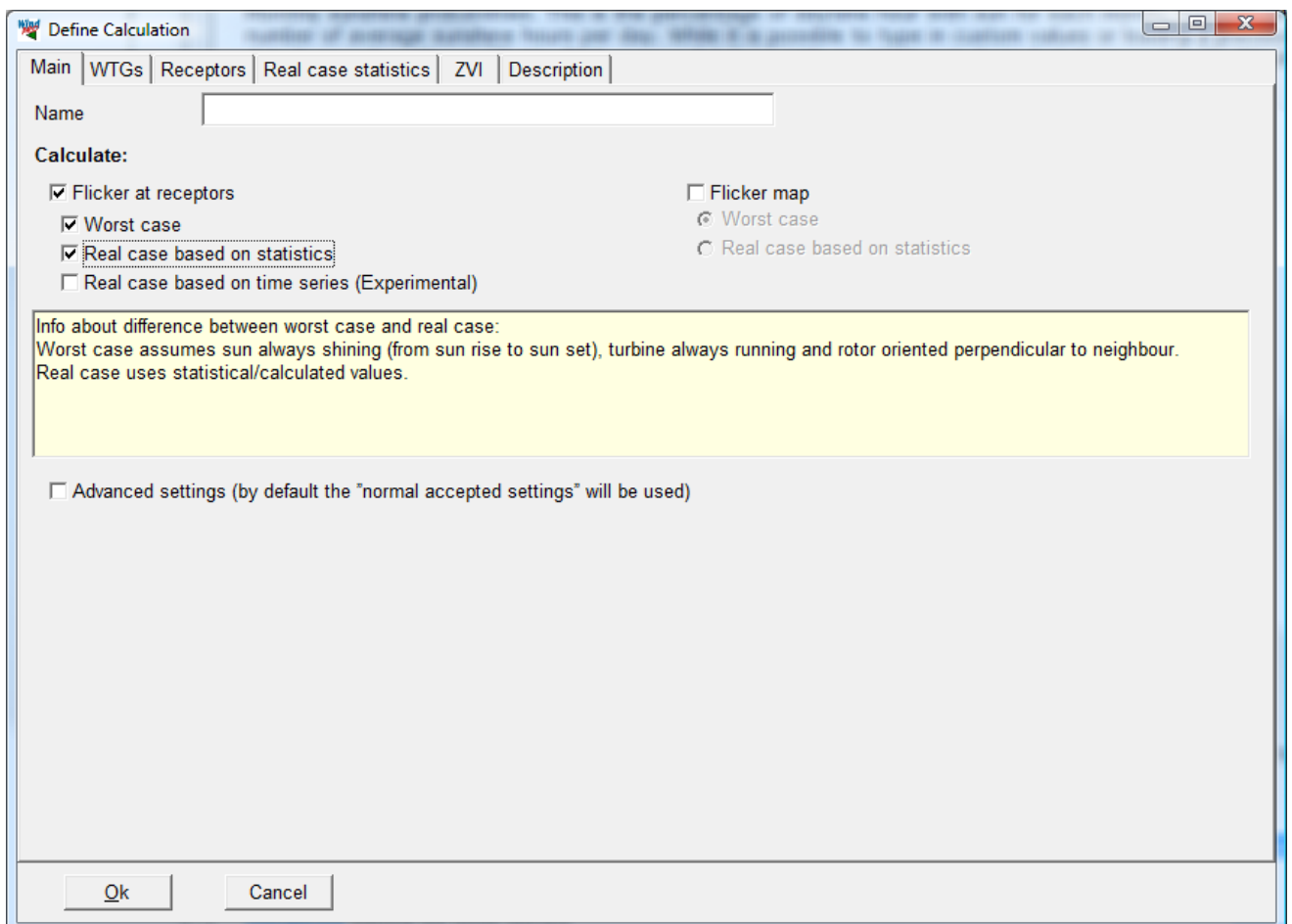
The Real case statistics tab is split in two parts: Operational hours and Monthly sunshine probabilities.
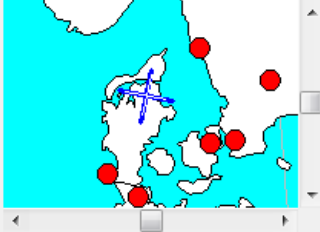
Operational hours statistics. This is the period that the WTG will be in operation from the different wind directions during the year. If an energy calculation has been prepared in the same project, this can be linked to the calculation. It is possible to link to a site data object set for WAsP calculation or a Meteo object with wind speed and direction data. Then a WAsP or a METEO calculation respectively will be performed at the beginning of the calculation, giving the probable hours of operation for each wind-direction sector. The operational hours statistics can also be typed manually or loaded from a template. Demonstration templates are available from Denmark and Germany.

If the turbine rotor starts rotating before cut-in (idling) the "User defined idle start wind speed" box can be checked and the start wind speed for idling can be entered.

Monthly sunshine probabilities. This is the percentage of daytime hour with sun for each month. This can be given as sun hours / possible sun hours or as the number of average sunshine hours per day. While it is possible to type in custom values or loading a previously made template, the default setting is to look up a data base value. Contained within WindPRO is a database with approximately 721 metrological stations worldwide. WindPRO selects the closest one to the project site by default, but it is also possible to press the "Select" button and manually pick another station.
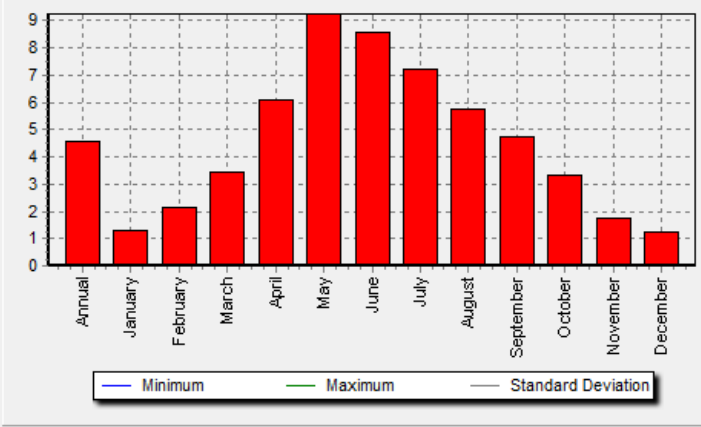
The station can be selected either from the list on the left or by selecting one of the red dots on the map to the right. It is a requirement that the station holds sun shine data. The sunshine statistics are displayed graphically in the lower diagram.

Real case based on time series
It is possible to use actual observed sunshine and wind condition observations to calculate how many shadow flicker hours the receptors have really experienced during the reference year.

This option is selected by adding the calculation option "Real case based on time series" from the Main tab. This option is currently only for experimental use.

Selecting this calculation option enables a new tab called "Real case time series"

The actual data set used must be selecting in the top of the tab.

If a .wti file has been created (see Section 3.3.3.4) the daily and monthly distributions can be read from this file. Otherwise an actual time series from a Meteo object can be used. Here the different heights in the Meteo objects of the project can be selected. For more information on the Meteo object see Section 3.32. The meteo object must also contain sunshine or cloud cover information. If you are uncertain whether your time series is sufficient for the calculation you can press the "View" button. This will show you the content and some statistics on the file including an evaluation of the suitability of the data.

Having selected the data source a filter must be setup to read the measurements.

Start date is by default the beginning of the time series.

Signal used for sunshine is the channel of the meteo object or .wti file holding the parameter that tells if the sun is shining. In the screen dump below, "Cloud Cover" has been selected, but it could also have been sunshine radiation level or other user-defined parameters.

"Sun shines when signal value" sets up a rule for the parameter. The sun shines when the parameter is either larger or smaller than the value given in the "Threshold value" box.

The .wti file and the meteo object time series give the relative variation in wind speed throughout the period analysed. In order to get the correct absolute values, the relative values must be scaled with the mean wind speed of the wind turbines. This mean wind speed is set in the "Mean wind speed in hub height for all WTGs" field.

Idling time can also be defined, see explanation above.

Flicker map
The second main type of calculation is a shadow flicker map.

The shadow flicker map calculates the shadow flickering in the grid across the site. The shadow receptor here is a horizontal 1x1m square at an elevation above the ground given by the eye height in the ZVI tab at the center of the grid cell. Since a site may hold a lot of grid cells the calculation resolution is reduced. There may therefore be small deviations between the result of a shadow map and the result for an actually defined receptor in that cell. The shadow map is used to visualize the extent of shadow flickering in the surroundings of the site.

The flicker map can be calculated either as a worst case calculation or as a real case calculation. If real case is selected the real case statistics must be defined as described above.

Main | WTGs | Flicker map | ZVI | Description

Name   Example

Calculate:

☐ Flicker at receptors   ☑ Flicker map
  ☑ Worst case   ⦿ Worst case
  ☐ Real case based on statistics   ○ Real case based on statistics
  ☐ Real case based on time series (Experimental)

Info about difference between worst case and real case:
Worst case assumes sun always shining (from sun rise to sun set), turbine always running and rotor oriented perpendicular to neighbour.
Real case uses statistical/calculated values.

☐ Advanced settings (by default the "normal accepted settings" will be used)

Ok   Cancel

Selecting the Flicker map option enables the flicker map tab.

In the upper part of the tab sheet, a shadow flicker map can be chosen and defined. An area for the calculation can be selected through the globe icon directly on the map or with the four fields that gives the distance in each direction from the site center. For the height model for the calculation, the choice is either a fixed elevation (z-level, which should then be the average height of the ground level of the surrounding area) or elevations from a line object (plus eye height from ZVI tab). The latter is more correct, and should always be used if the heights vary more than approximately 5-10 m.

The shadow map calculation can be very time consuming. A simulation of an entire year is carried out for each node in a rectangular grid, which is then used to print the iso-lines. The resolution can be set to Coarse, Normal or Fine. A calculation using the coarse setting will usually take minutes. The fine calculation may take hours. By selecting Edit, the parameters of the different settings can be inspected or modified.

The lower part of the tab defines the maps includes in the report. It is only possible to include one report. The report options are either for a worst case calculation or for a real case calculation. The type selected on the Main tab is shown as white and it is possible to select and edit those options.

The three maps available are Hours per year, Shadow days per year and Max minutes per shadow day.

Three kinds of map reporting is possible:
· Show lines in report, creating a page with noise iso-lines in the report
· Show raster in report, filling up the interval between lines with color

· Show raster in result layer, producing a result layer in Maps and objects with noise intervals filled with color.

Pressing the edit button makes it possible to edit the lines or raster definitions for the maps.

The line setup looks like below, which is similar to the setup options in the print report setup.

Select the number of lines wanted and then define the noise value and color for each line. With "Save" you can save a template so you do not have to set this up every time you run the calculation. "Load" loads templates.

In a similar way the raster setup can be edited.

Again this is similar to the print report setup and the interface is used in several other locations in WindPRO. A typical good choice is to use the Palette format to get a single color for each interval. Then select the same number of lines as in the line definition and mark the same intervals and colors.

Back on the Flicker map tab it is possible to save the entire definition as a template.

It the last column is hatched WindPRO will produce a Result layer object in Maps and Objects.

4.2.3.2 SHADOW - Calculation

The calculation starts automatically when you press OK in the calculation setup. Please notice that the calculation may take some time depending on the setup parameters.

If a real case calculation is selected the user may have to either accept the selection of terrain and wind data in the site data object or the shear values used in a Meteo calculation.

4.2.3.3 SHADOW - Printout

Name	Calculated	Create calculation
⊟ SHADOW: Example	10-12-2009 11:13:25	◄ BASIS (Project data)
Main Result		◄ Economy: WINDBANK (Financial & Economic analysis)
Calendar		◄ ELECTRICAL: eGrid (Grid connection design, loss calculation, etc.)
Calendar, graphical		◄ Energy: LOSS&UNCERTAINTY (Loss and uncertainty analysis in a bankable format)
Calendar per WTG		◄ Energy: MCP (Measure Correlate Predict - long term correction - STATGEN)
Calendar per WTG, graphical		◄ Energy: METEO (AEP one position, measured wind data)
Map		◄ Energy: Model: ATLAS (AEP one position, simple terrain)
		◄ Energy: Model: CFD PRE/POST (data export/result analyzer)
		◄ Energy: Model: RESOURCE (Wind/AEP resource map)
		◄ Energy: Model: WAsP INTERFACE (AEP one position, WAsP calculation)
		◄ Energy: PARK (Wind farm AEP based on MODEL or METEO)
		◄ Energy: STATGEN (Generate Wind Statistics)
		◄ Environment: DECIBEL (Noise)
		◄ Environment: IMPACT (Neighbor environmental impact report)
		◄ Environment: NORD2000 (Detailed noise)
		◄ Environment: SHADOW (Flicker)
		◄ Environment: ZVI (Zones of visual influence for WTG or radar)
		◄ OPTIMIZE (AEP and/or noise optimization of Wind farm layout)
		◄ Visual: 3D ANIMATOR (Virtual reality presentation)
		◄ Visual: ANIMATION (Rotating turbines on photomontage)
		◄ Visual: PHOTOMONTAGE (Render turbines on photo)
		◄ UMBRA (Landschaftsästhetische Bewertung)

\A\B\C/

When the calculation has finished, a list with all the reports that can be printed will appear on the screen (see above).

SHADOW can produce 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 is 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)
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 beginning and end of the shadow impact (please notice that the time between beginning and end of shadow impact may last longer than the total hours of impact if the shadow impact is generated from more than one WTG).
The number of the WTGs, which cause the shadow impact at the moment of beginning and end 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). You can decide whether you want a full-page print per receptor, or up to 6 receptors per page.

4. Calendar per WTG.

This is similar to the regular calendar, but is instead for the individual turbines, telling when the flickering it may cause 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 may 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 or raster grid of the shadow impact for the area in question. The settings for the iso-lines and the raster map were set in the calculation, but can be revised in the report setup using the same interface.

7. WTG data to file. 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.

The status shows how many pages will be printed if the full report is to be printed.

Please notice that a report will automatically pop up on the screen if you double click on the report name.

When you click with the right mouse button on the calculation header or one of the calculation reports, you gain access to the following features; recalculation, editing the assumptions for the calculation, change of printer setup or preview of the report on the screen.

When you click with the right mouse button on the report header under the printout setup menu, you can choose which pages to print. Also, the layout can be defined (see the example in the below figure).
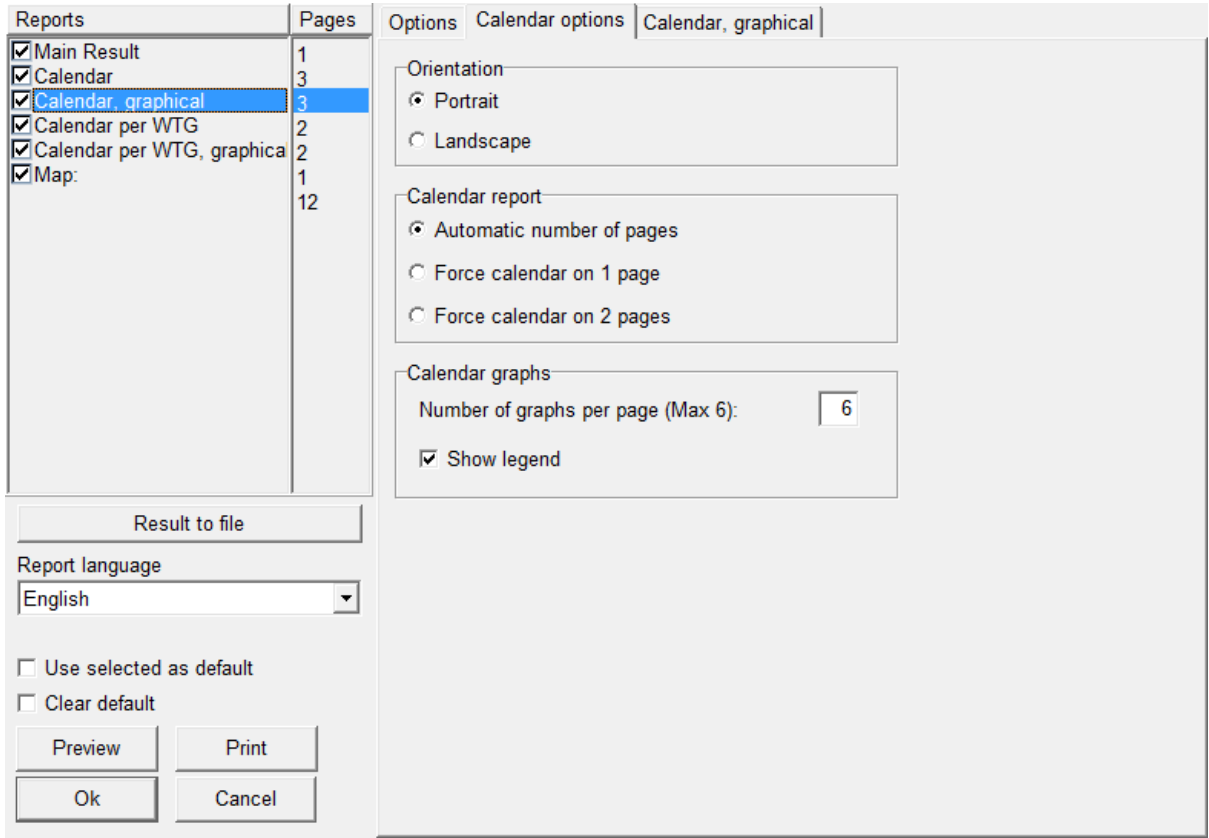
Click on the check box to the left of each object to select/deselect that object. By clicking on the report name you gain access to the setup window for the selected report. Here, you can enter details about the selected report, e.g. the shadow receptors for which a calendar printout is needed, the map scale which is to be used on printouts, what to include on maps, which maps to include, etc.

Regarding printing iso-lines and raster maps on the Map page: Click on the [...] button for setup, and check the box to activate, see below. Using this feature, you can create a map which shows, hours per year, max. minutes per day or days per year as lines and similar as a raster map.

Reports	Pages
☑ Main Result	1
☑ Calendar	3
☑ Calendar, graphical	3
☑ Calendar per WTG	2
☑ Calendar per WTG, graphica	2
☑ Map:	1
	12

Result to file

Report language

English ▼

☐ Use selected as default
☐ Clear default

Preview   Print
Ok   Cancel

Options | Map: | Orientation and legend position

Map   KMS map: DISC06.IT ▼

Map scale   Auto ▼

Print scale / Size of map

Automatic based on used objects ▼

Center of map on report

Center of all objects in calculation ▼

Background map quality
● Normal   ○ Enhanced

Objects included on map

- ☑ New WTG
- ☑ Shadow receptor
- ☐ Line object
- ☑ Shadow lines, hours per year
- ☐ Shadow lines, days per year
- ☐ Shadow lines, max. minutes per day
- ☑ Shadow raster, hours per year
- ☐ Shadow raster, days per year
- ☐ Shadow raster, max. minutes per day
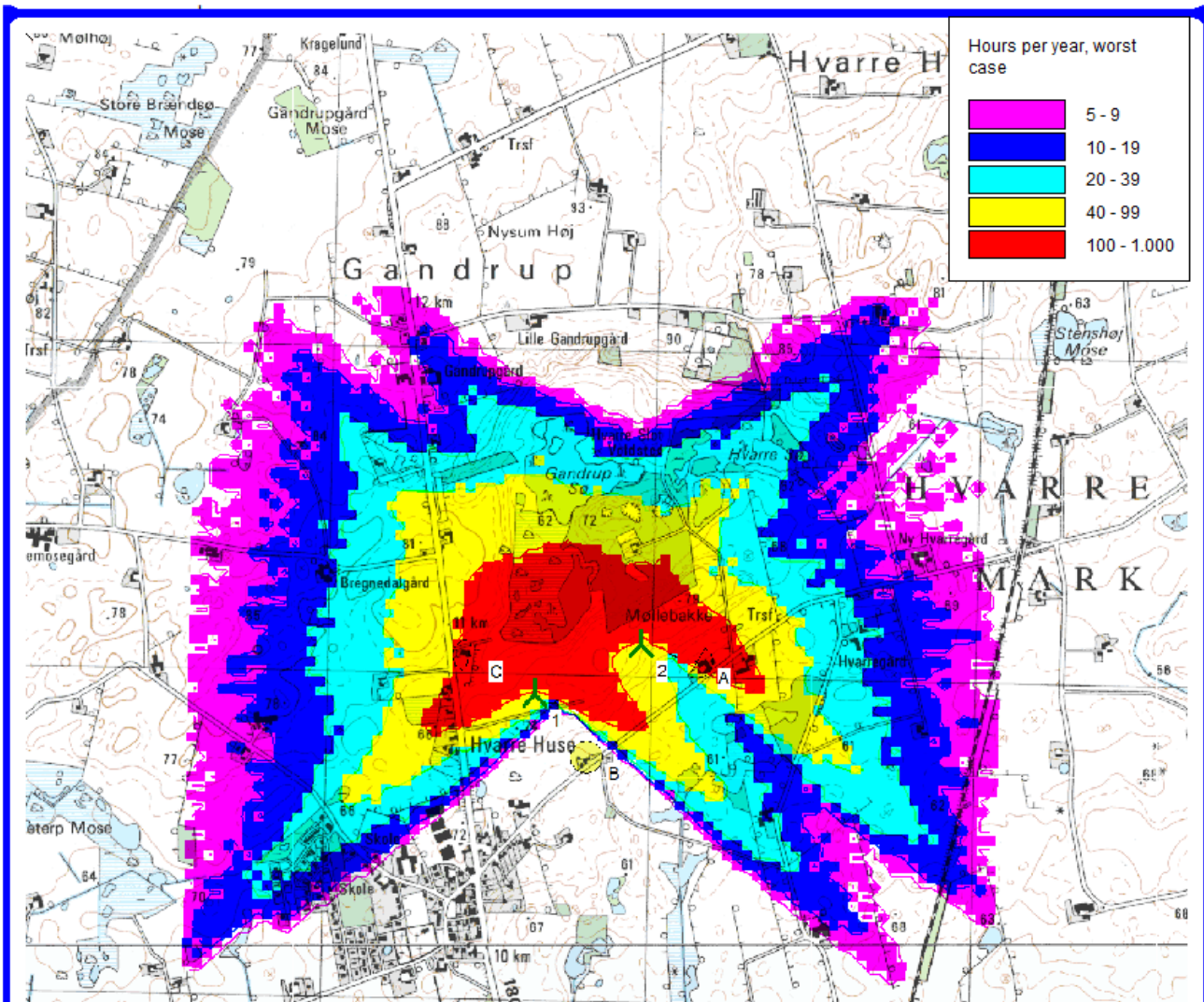
An example of a shadow flicker map is shown above.

4.3 ZVI – Zones of Visual Influence

4.3.0 ZVI - Introduction

ZVI is a WindPRO module that calculates and documents the visual impact (a ZVI is also known as a ZTV – a zone of theoretical visibility) of WTGs on the landscape, i.e. identifying the spots from where you will be able to see one or more WTGs. For example, the program calculates the percentage of a given area from where a given number of WTGs can be seen. A ZVI calculation can handle the cumulative impact of several wind farms (see Section 4.3.4).

In general, there are no acceptance criteria regarding the maximum allowable visibility of WTGs and indeed, it would be very difficult to make operational definitions on the matter.

ZVI calculations are often used in discussions regarding local and regional planning for new WTGs. For specific projects, the ZVI analysis can form part of the background material used for an environmental impact assessment of the project.

The ZVI analysis is particularly useful when assessing alternative projects or WTG planning proposals.

The ZVI module can also be used to calculate the visibility of wind turbines from radar locations. In some countries the impact of the wind turbines on the radar signals can indeed be problematic. With a ZVI calculation it is possible to perform a Line of Sight analysis which can point out whether the WTGs are visible from one or more radars (see Section 4.3.5).

4.3.1 ZVI - Calculation method

The calculations are based on a digital 3D model of the landscape established from digital height contours. Furthermore, local obstacles and surfaces (e.g. forest areas) can be included. In short, a ray is sent from the point of calculation towards each WTG top and it is checked whether the ray is interrupted by the landscape, a surface (with a defined height) or a local obstacle. The number of uninterrupted rays is then counted. The earth's curvature is also taken into account in the calculation. In radar mode the earth curvature is adjusted by a refraction constant k in order to compensate for the bending of radar signals in the atmosphere (see Section 4.3.5).The following information is needed:

- · The position coordinates of the WTGs (x,y,z)
- · Hub height and rotor diameter of the WTGs
- · A digital height contour map (through the line object – see Chapter 2.8)
- · Local obstacles (WAsP format - only obstacles with a porosity lower than 0.3 are included)
- · Surface objects (forests, cities) with defined elevations above the terrain, defined in the area object
- · The position coordinates and antenna height of the radars (x,y,z) if relevant.

4.3.2 ZVI - Input for the calculation

First of all a background map is needed – although it can be a blank map.

If one or more maps have been assigned to the project, click on the map icon to open one or all of them. Please refer to Chapter 2, WindPRO BASIS for further information about the use of maps.

Please notice that, when entering objects via maps, you can create a default tool by holding down the <shift> key while selecting a tool. This function will allow you to enter several objects with the same properties.

4.3.2.1 Input of WTGs

(See Chapter 2. BASIS, Section 2.5.2)

4.3.2.2 Input of digital height contours

Digital height contours are entered in a line object by loading a data file containing the contour lines in an appropriate format or by digitizing the curves directly on-screen with the mouse.

See Section 2.8 in WindPRO BASIS for detailed guidance.

4.3.2.3 Input of Area object

The procedure follows the one for input of height contour lines, the only difference being that surfaces in the area object have to be entered as closed polygons.

See Section 2.9 in WindPRO BASIS for detailed guidance. Notice that the area object has to be checked for use in ZVI calculation to take effect here.

4.3.2.4 Input of local obstacles

Local obstacles are entered graphically on-screen using the WAsP obstacles button. The dimensions are defined by dragging the object (click and drag first corner to set the length of the obstacle, then click and drag the next corner to set the width and finally click once more to finish the input).

Once the object has been positioned, the following window pops up for setting the height and porosity:

Note: We have chosen a minimum porosity of 0.3 for an obstacle to be included in the calculations as a "solid" that will interrupt the line of sight to the WTG. For higher porosities the obstacle will be treated as transparent, i.e. the WTG will be visible through the obstacle.

4.3.2.5 Input of Radars

When needed, Radars are entered with this icon . The effective (antenna) height of the radar above the ground shall be defined. It is the radar radiation centre above the ground level. The coordinates of the radar can be entered on the Position Tab.

4.3.3 ZVI - Calculation and printout

The calculation menu is invoked by clicking the green arrow beside ZVI (if this arrow is yellow you do not have a registered license to the model - please contact EMD). In the calculation menu you can set different parameters for the calculation.

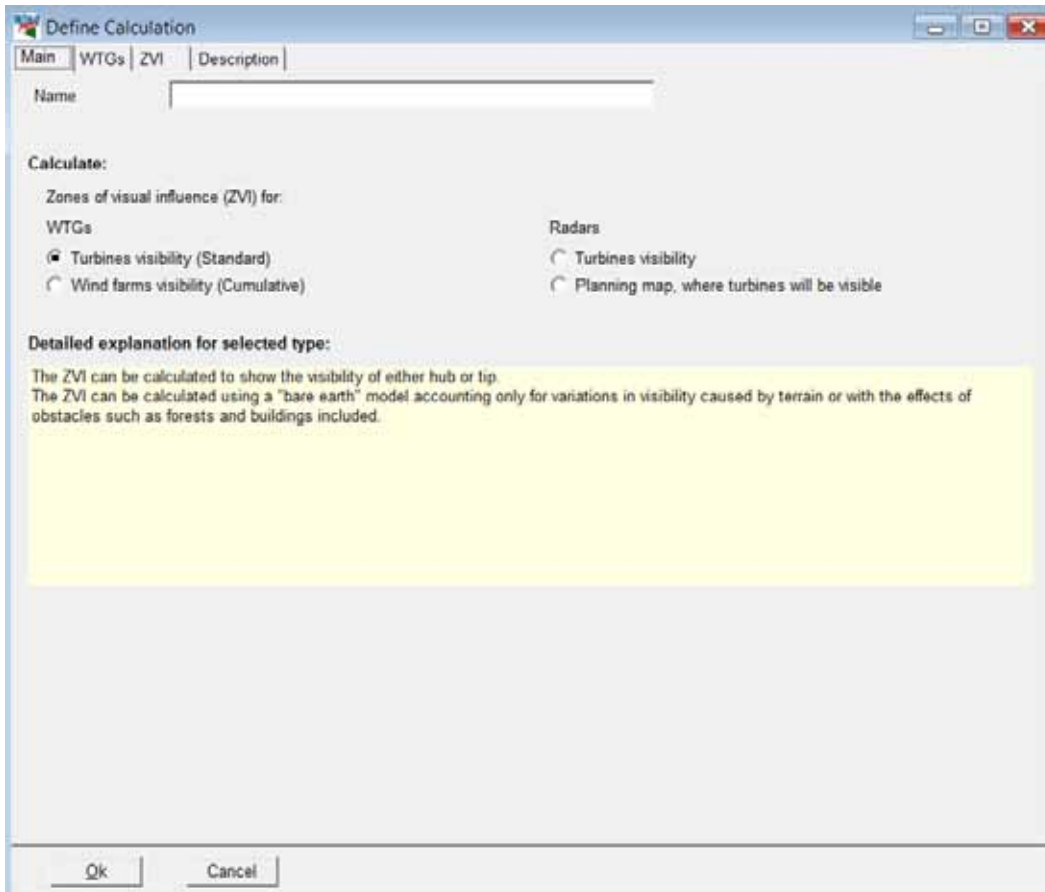## 4.3.3.1 ZVI – Setup and calculation

*Figure 1 At the Main tab, the type of calculation is chosen.*

Name of calculation: Here a name can be entered for the calculation to help you recognize it when there are more calculations in the same project.

The type of ZVI calculation is then selected from:
- **WTGs/Turbines visibility**: calculates and shows on a map the number of wind turbines which are visible within an area;
- **WTGs/Wind Farms visibility**: calculates the cumulative visibility of several wind farms (see Section 4.3.4);
- **Radars/Turbines visibility**: calculates whether the WTGs are visible from one or more radars (see Section 4.3.5);
- **Radars/Planning map**: calculates a map showing the areas where a specific WTG type could be installed without being seen by the radar(s) (see Section 4.3.5).

On the WTGs tab you can choose to leave out certain WTGs in the calculation if you only want the calculation to be carried out for selected WTGs.

The ZVI parameters for the calculation are defined in the following window:
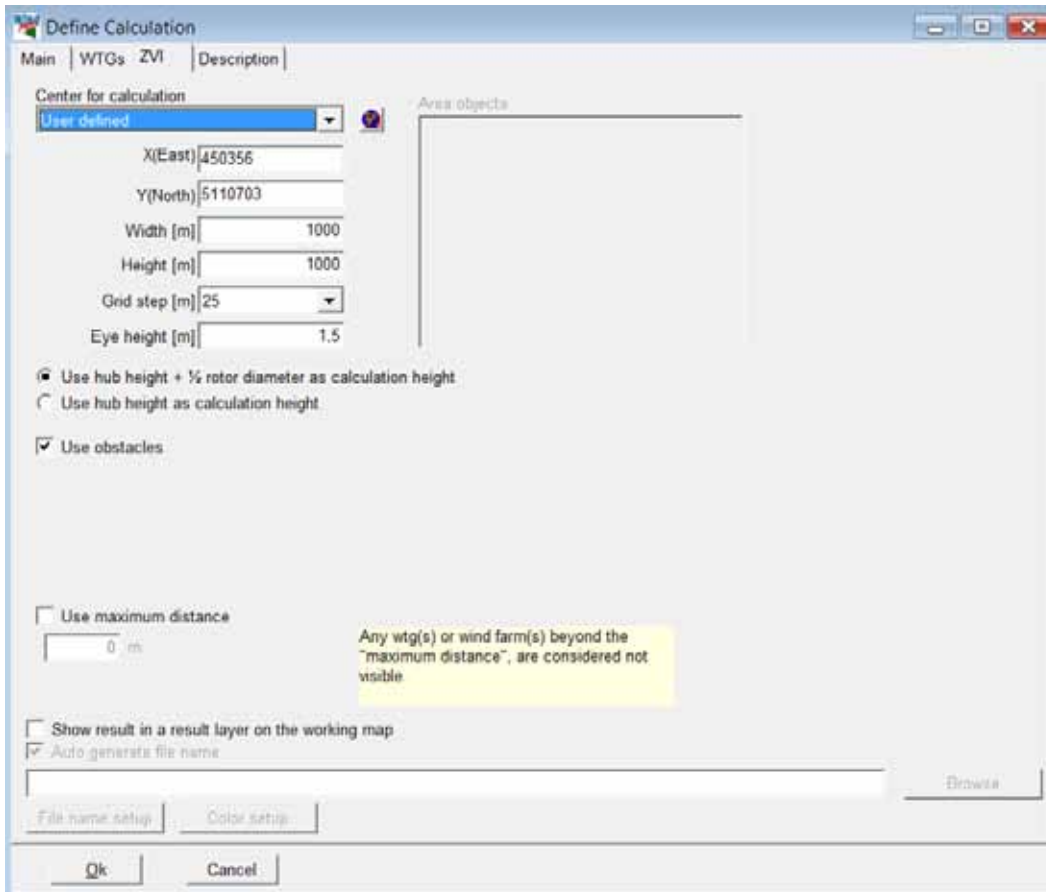
You have the following setup possibilities for a ZVI calculation:

Manual definition of the calculation area: The area selection for the ZVI calculation can be done with a center and an extent for the calculation. Here the site center can be a useful anchor point, but it is also possible to type a coordinate point as the center of the calculation.

Graphical definition of the calculation area: Clicking on the globe icon sends you temporarily back to "Maps and Objects", where you are given a rectangle, with which you can define the extents of the calculation.

It is difficult to give general recommendations for the selection of a relevant area. It could be an area of special environmental interest that you want to protect against the visual impact from too many WTGs or it could cover a whole county to identify the areas where a given number of WTGs would be visible. It could also be the local area around the WTGs for which an impact study is needed. In other words, the area has to be defined in a dialogue between the developer and the relevant authorities.

Grid steps: This sets the grid size/resolution for the calculation. A resolution of 25 m would be a reasonable choice for a smaller area (up to 5 x 5 km) whereas a larger area as a whole county would probably call for a resolution of around 100 m.

Eye height of observer: A height of 2 m would correspond to a "maximum" height of a walking person. For observations from a car, a height of 1 m would be more realistic. A number of 1.5 m seems to be a fair compromise.

Height of WTG: It is possible to choose whether the WTG is visible when you can see just the very top of the WTG blades or if you should be able to at least see the hub. While the top position of a blade tip would cover the full range of visibility, the hub height should be chosen where the zones of significant visibility are searched.

Local obstacles: This enables you to include obstacles with a maximum porosity of 0.3. If a local obstacle is specifically established because of the possible reduction of the visual impact it should be included in the calculation. Obstacles created solely for energy production calculations should not necessarily be included in

the ZVI calculations since the obstacle could, for example, be a row of deciduous trees through which WTGs might be visible during the wintertime.

Area objects: This shows you which area objects are included in the calculation. If there are objects such as forests or villages in the investigated area, they should be digitized into an area object. The areas with a height will be added on top of the height contour lines and thereby provide important information on visibility. Notice that "inside" an area with a height larger than the observer, it is always assumed that all WTGs are invisible. (this might not be true from inside a village). If very detailed calculations are desired, the village must be defined in greater detail, e.g. every house and tree must be defined as local obstacles or small area parts in an area object.

Use maximum distance: Used for excluding WTGs in project at large distances in calculation report.

Save to a result file: Makes it possible to present the results on the map(s) you are working with in WindPRO. Even if the option is not enabled, you can still print out a map with ZVI since the results are stored locally in the computer along with the report.

Auto-generate a result layer: This option automatically inserts a result layer object on the map with the ZVI calculation after it is finished. You can choose color setup before starting the calculations, but it can always be changed later on by selecting "properties" of the result layer object.

4.3.3.2 ZVI - Calculation

When you press OK to accept the calculation definition you can choose to start the calculation or save it for later. The calculation is rather fast and only for very large areas will it take more than a few minutes.

4.3.3.3 ZVI - Printout

When the calculations are completed, a list of available reports that can be printed is shown.
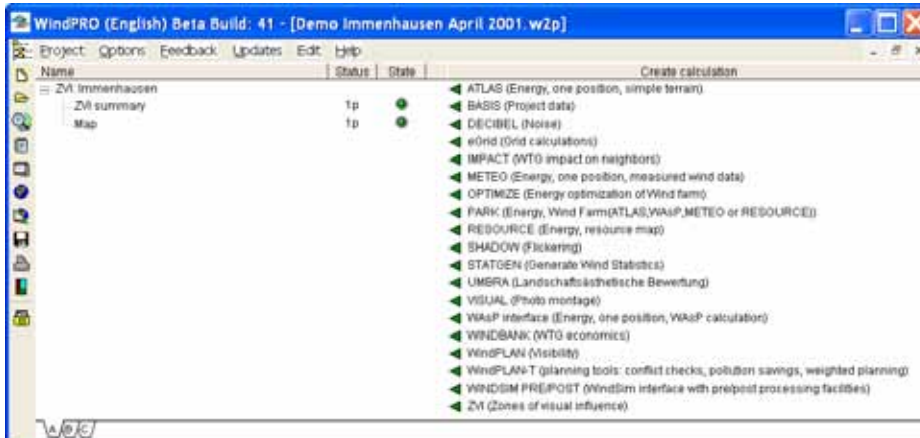
In the ZVI calculation module there are two different reports available:

1. A summary report that gives the assumptions for the calculation together with the resulting areas of visual impact divided into areas of different number of visible WTGs. This information can be useful when assessing the visibility for different micro-siting alternatives.

2. A map with the WTG locations and a raster graphic that shows the impact area and the number of visible WTGs at a given location inside the impact area.

Note: A double-click on a report name automatically shows a preview of the report on the screen.

By right-clicking the calculation header or one of the calculation reports you can either recalculate, change the calculation assumptions, change the printer setup or see a preview of the report on the screen.

By right-clicking the report header you can specify which pages are to be printed as well as the layout. See the general description of "Results - layer object", Chapter 2 in BASIS, Section 10.

4.3.3.4 ZVI presentation in the result layer

It is possible to display the resulting ZVI map in Maps and Objects using the result layer. In this case the resulting .ear file must be selected in the browser of the Result layer. See Chapter 2 Section 2.10.

4.3.4 Cumulative ZVI

The cumulative ZVI can be used to compare the visual impact of a number of windfarms located in the same area. This may be the case if a new project is planned next to an existing one or if several projects are competing in the same area.

The cumulative ZVI calculation is performed on the wind farm(s) as a whole, not on the individual turbines within the wind farm(s) (i.e. the result is a quantification of whether any turbine from a project can be seen at the given grid node rather than the number of turbines visible).

4.3.4.1 Cumulative ZVI - Setup

Each wind farm has to be defined on a separate layer, where the name of the layer becomes the name of the wind farm. By default the wind turbines on one layer are considered as one wind farm for the purposes of cumulative impact.

Although it is theoretically possible to do the calculation with a large number of wind farms and this may make sense for special calculation tasks (see last paragraph), the calculation will generally be easier to interpret so long as there are no more than three wind farms chosen. If you have more wind farms in the area, it may be necessary to group wind farms onto layers so that you only have three layers with which to perform the calculation.

In ZVI calculation, the ZVI for "Wind farms visibility (Cumulative)" should be selected.

4.3.4.2 Cumulative ZVI – Printout

The output is the map result showing the zone of visibility of the different wind farms.

Compared to a standard ZVI calculation, the legend of the map is not showing the *number* of visible wind turbines but *which* wind farms are visible. For example it can be shown the areas of visibility of a wind farm A alone, then the areas of visibility of the wind farms A and B or A and C, etc…

The legend categories show all possible combinations of the different wind farms visibility. For n number of wind farms, the number of combination is then 2^n, i.e. for three wind farms, there would be eight categories in the legend.
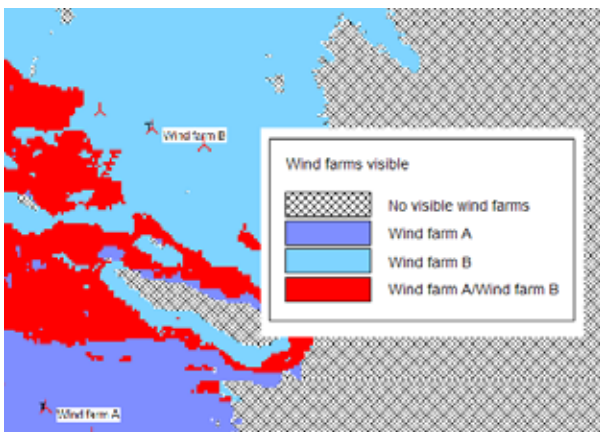

In addition, the display can be manipulated to add or remove colours from any of the legend entries. If you want to see only those areas where wind farm A adds to the visibility of wind farms in the area, then you can

set all other colours to white (i.e. not shown on the map) and you will be left with only those areas you wanted to display. Similarly, if you want to show only the areas where all wind farms are visible, then you can set all legend combinations to white apart from the last one.

4.3.5 Radar ZVI

Two types of Radar ZVI calculations can be performed. The first one "Turbines visibility" calculates whether the WTGs are visible from one or more defined radar(s). The clearance height which is the distance between the intersection of the line of sight of the radar and the tip height (cf below) is also calculated. The second calculation "Planning map" calculates a map showing the areas where a WTG with specific dimensions could be installed and would not be seen by the radar(s). In the areas where the WTG is seen, the maximum clearance height is also given by the map.
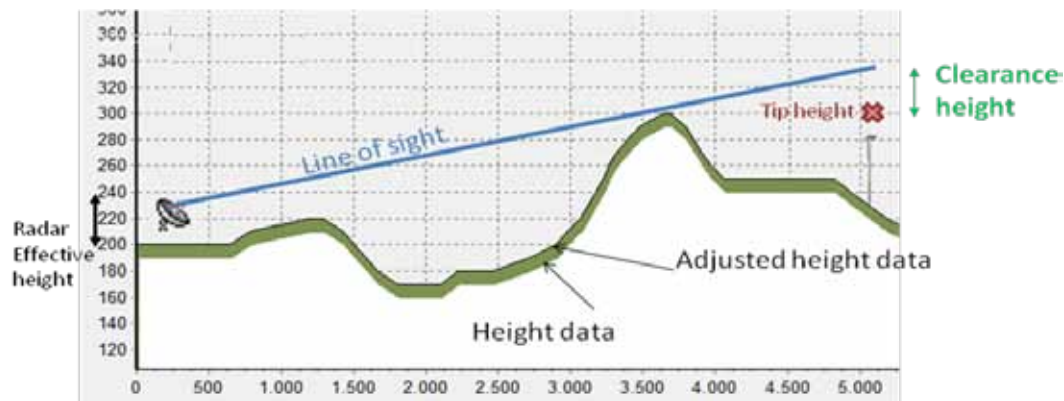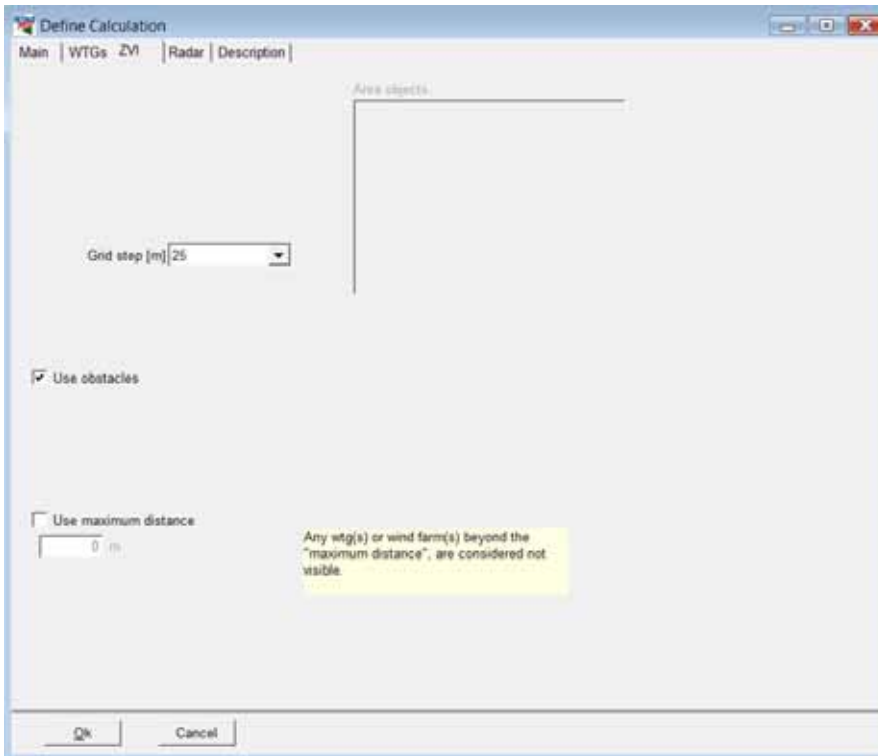

Definition of the clearance height in a Radar ZVI calculation
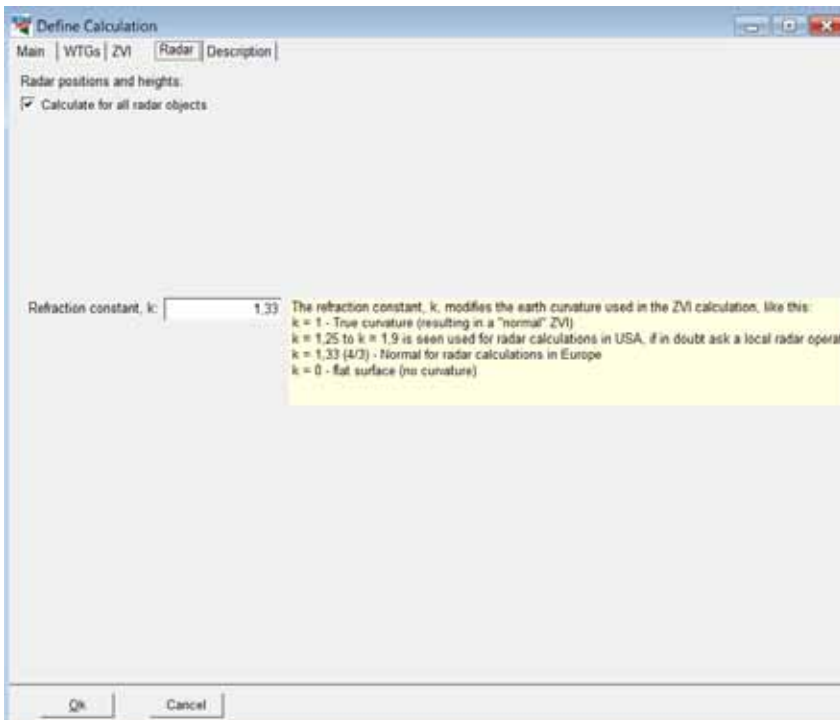
4.3.5.1 Radar ZVI - Setup

Turbines visibility calculation

In the Radar ZVI calculation, "Turbines visibility" should be selected.
For the input of wind turbines and radar(s) see Section 4.3.2.
The option "Grid step" sets the grid size/resolution for the calculation.

On the Radar tab, the radar(s) to be considered can be selected.

The Refraction Constant k modifies the Earth Curvature used in the ZVI calculation.
Variations in the atmosphere cause bending of radar signals, which as a result extends the effective radar range beyond the visible horizon. This is commonly compensated for by using a larger effective Earth Curvature in the calculations (i.e. flattening the Earth). This compensation allows radar signals to be treated as straight lines. The Earth Radius is multiplied by a refraction constant k to give an increased effective Earth curvature. The standard figure used for k is 1.33 (4/3). In the USA k is between 1.25 and 1.90.


Planning map calculation

In the Radar ZVI calculation, "Planning Map" should be selected.

For the input of wind turbines and radar(s) see Chapter 4.3.2.

Definition of the calculation area: the area can be selected for the ZVI calculation with a center and an extent for the calculation. Here the site center can be a useful anchor point, but it is also possible to type a coordinate point as the center of the calculation. For a graphical definition of the calculation area: clicking on the globe icon sends you temporarily back to "Maps and Objects", where you are given a rectangle, with which you can define the extents of the calculation.

The option Grid steps sets the grid size/resolution for the calculation.
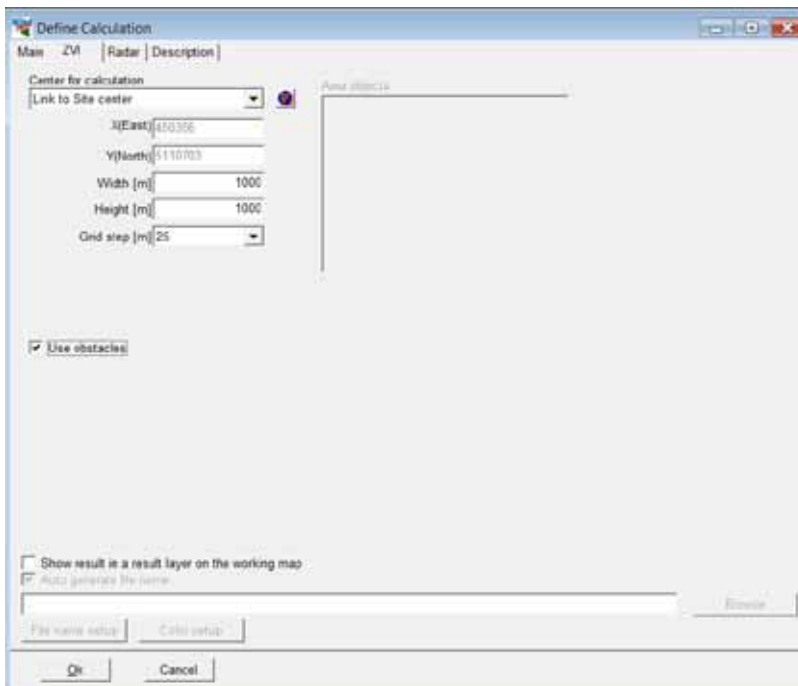
The WTG type is selected on the Radar tab.

With a WTG height of 0m, the clearance height corresponds to the maximum height of a wind turbine that can be planned without been seen by the radar(s).
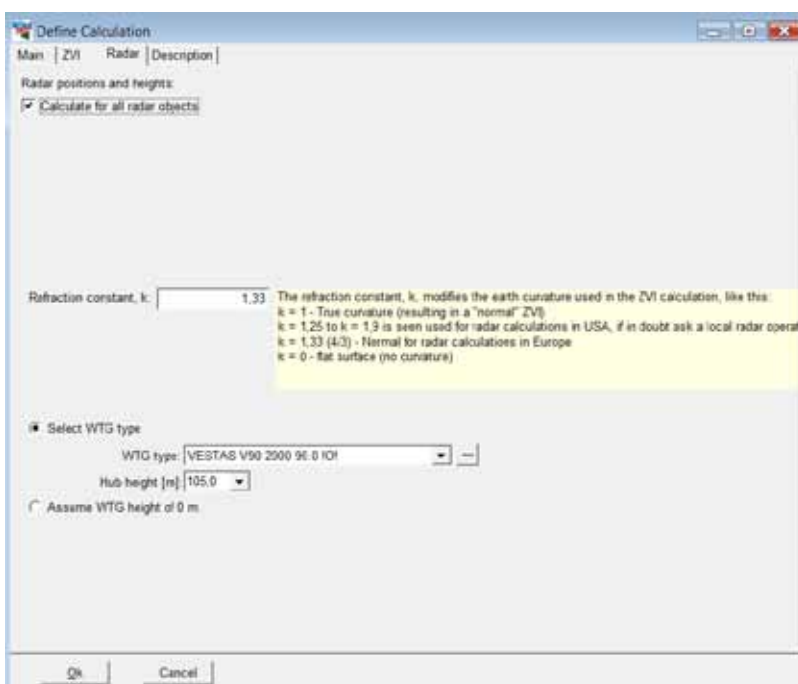
4.3.5.2 Radar ZVI - Printout

Turbines visibility calculation

The clearance height between each wind turbine and radar is given in a table. The clearance height specifies the space between the WTG and the line of site of a radar; negative value indicates that the height of the WTG is above the limit.

		Clearance height [m] R1
wtg1	GE WIND ENERGY 2500 kW (182)	-121,3
wtg2	GE WIND ENERGY 2500 kW (183)	-76,1
wtg3	GE WIND ENERGY 2500 kW (184)	-131,7
wtg4	GE WIND ENERGY 2500 kW (185)	-114,3
wtg5	GE WIND ENERGY 2500 kW (186)	-66,2
wtg6	GE WIND ENERGY 2500 kW (187)	-92,0
wtg7	GE WIND ENERGY 2500 kW (188)	-120,4
wtg8	GE WIND ENERGY 2500 kW (189)	-135,0
wtg9	GE WIND ENERGY 2500 kW (190)	-68,1
wtg10	GE WIND ENERGY 2500 kW (191)	-7,6
wtg11	GE WIND ENERGY 2500 kW (192)	-54,2
wtg12	GE WIND ENERGY 2500 kW (193)	-127,0

Clearance height table

Planning map calculation

The output shows the distribution of clearance height values over the area of calculation in a table and on a map.
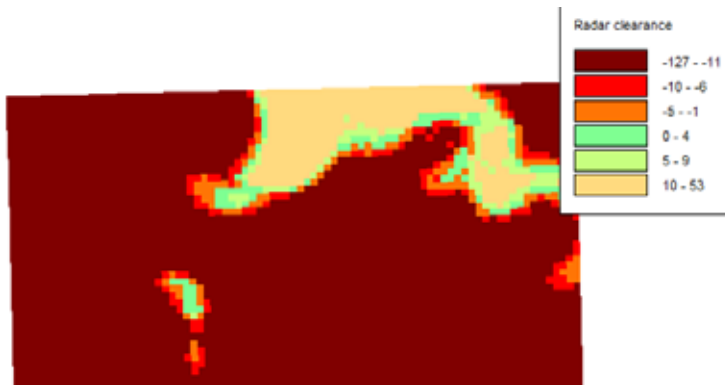
Map of clearance height for a 125m high turbine (total height)

4.4. IMPACT - Calculation of Neighbor Nuisance

4.4.0 IMPACT - Introduction

Impact is the name of the calculation of the aggregated environmental impact at each neighbor in a planned wind energy project.

The following can be calculated:

- · Noise
- · Shadow flicker
- · Zones of Visual Influence (ZVI)

A bitmap photo can also be inserted, typically a photo of the premises on the side facing the WTGs.

Apart from the calculation results the printout will also include an explanation of the individual types of impact (effect) and governing limits where legislation is in force.

4.4.1 IMPACT - Calculation method and setup

The calculation follows the descriptions found in Sections 4.1 (Decibel), 4.2 (Shadow) and 4.3 (ZVI) of this chapter.

What is unique about this calculation module is that all environmental impact calculation results are included on one single printout per neighbor.

Both the noise and the shadow calculation setup are the same as for the DECIBEL and SHADOW calculation

In the ZVI calculation, the same point is used as for the noise calculation.
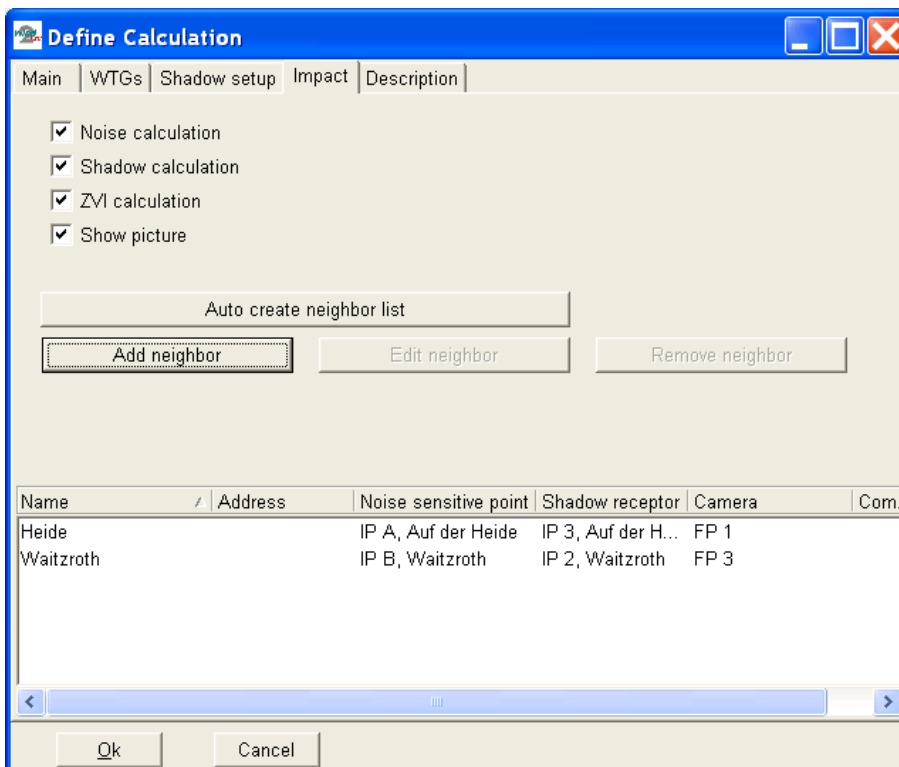
The only "special" operation in this calculation is the pairing of objects for each neighbor. This is done in the window shown below. If you have assigned the same object name (typically a neighbor address or name) to a noise-sensitive area, a shadow receptor and a camera, the "Auto create neighbor list" button will pair these automatically. Alternatively, neighbors can be added individually and paired manually using the form shown below. Here it is also possible to write a caption for the picture and a comment for the page. This could be your evaluation of the total environmental impact for the neighbor.

The calculation provides a page for each neighbor included and a map showing the positions of the WTGs, the neighbors and the cameras.

An example of the printout can be seen in the Module Description.