

WindPRO 2.7 User Guide

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Foreword

Welcome to “the World of WindPRO”, which is not only” a calculation tool, but an “expert system” based upon more than 30 years of experience within design, calculation, documentation and evaluation of wind farms.

Our many years of experience within the wind industry have been incorporated in WindPRO, and we continuously try to add new features to the software based on the latest research and development within the area and when new industry demands arise. New features added are based on a selection as not all new developments might be considered relevant or useful for the software user. We use our expertise and “hands-on” experience when choosing the new features we decide will add most value for the users. Furthermore, we test the quality and relevance of new research and development work before we decide to incorporate this in WindPRO.

A major strength of WindPRO is that it is an “all in one” handling tool of wind energy projects through the whole development process, starting from the first idea of a project, when rough data are downloaded and preliminary calculations are performed until the comprehensive and detailed calculations leading to the final approval by both local planning authorities and investors/banks.

Similar to other calculation software, the input data loading and processing in WindPRO is important to obtain correct results. Therefore, we continuously strive to add new intelligent features to the software, which both support the user when evaluating the quality of the input data and assist during the processing of the data.

Enjoy working with the software and help the world to be a better place by designing the right wind farm layouts at the right places.

Per Nielsen, Manager



The manual in brief

Each chapter has its own table of contents. The main chapters are:

- Foreword
- Chapter Overview
- 1 Intro, installation etc.
- 2 BASIS
- 3 ENERGY – MODEL, METEO & PARK
- 4 ENVIRONMENT – DECIBEL, SHADOW, ZVI & IMPACT
- 5 VISUALIZATION - PHOTOMONTAGE, ANIMATION & 3D ANIMATION
- 6 ECONOMY - WINDBANK
- 7 ~~LANDSCAPE AND PLANNING (not included, please see ver. 2.5)~~
- 8 OPTIMIZATION (Energy & Noise)
- 9 ENERGY - CFD interface (Computation Fluid Dynamics interface)
- 10 ELECTRICAL - eGRID
- 11 ENERGY - MCP (Measure Correlate Predict)
- 12 ENERGY – LOSS & UNCERTAINTY

Appendixes are included in chapters where relevant. Further documentation, validation etc. are available at <http://help.emd.dk/WindPRO/>-. Direct link is found in WindPRO HELP menu FAQ (internet), which is continuously updated. In the WindPRO Help the entire manual is available with search options, etc.

In chapter 2 BASIS, all basic functions are described. These are also the basis for using all other modules.

In the beginning of each chapter there will be a STEP-BY-STEP guide, which gives a checklist getting to a calculation result.

Generally, each chapter is divided in a theoretical part describing models and methods, and a part describing how to use the software.

Module descriptions and print examples from the different modules can be found in the separate Module Description. This is also available at <http://www.emd.dk/WindPRO/Modules/>

Chapter 7, module WINDPLAN is no longer included due to low interest for this module. It is still possible to use this module with the former WindPRO ver. 2.5, but this is no longer supported.

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1.0 WindPRO introduction, license conditions, service

1.0.1 Introduction

WindPRO is a Windows /XP/Vista/7 based software suite for the design, development and assessment of wind energy projects. WindPRO consists of a number of modules, each of which has its purpose. The user is free to combine the modules according to their needs and budget. WindPRO is based on more than twenty years of experience in the development of user-friendly software tools for wind energy calculations. The experience gained from this, and from the WindPRO team participating in the development of thousands of projects, is applied in the “expert system” WindPRO. The software suite is offered to everyone dealing with project development, planning, sale and approval of wind energy projects.

System demands

Working with bitmap maps requires fast processors and large memory capacity (RAM), which was a challenge for the PC with the first WindPRO version in 1997, but the development of PCs in recent years has solved many of these problems.

The software requires as minimum a 1GHz processor with a minimum of 1GB RAM and a minimum of 1GB of free space on the hard disk. However, we strongly recommend at least 2GHz processor with 1GB RAM and a minimum of 1GB of free space on the hard disk. For the 3D-Animator module, a 3D-accelerated graphics card is required. For laptops, graphics which shares the main memory may not be sufficient. It is possible in some calculations to take advantage of multiple processors.

The WindPRO Philosophy: Object Orientated Design/strong graphic interface

The WindPRO philosophy is Object Orientated Design. A wind energy project consists of a number of objects among which the turbines (WTGs) are a key element. The program distinguishes between existing and new WTGs and this makes it possible to calculate, for instance, the energy yield or environmental impact from the new WTGs with or without the influence from the existing WTGs.

An object is established on background maps. Any map can be used with the built-in georeference tool or maps from Internet can be downloaded and used with only a few mouse clicks. Similarly, digital elevation models can be established manually with the powerful digitizing tools or simply downloaded from Internet.

Importing, screening and analysis of measured wind data as well as long-term correlation are based on the most comprehensive tools, guiding the user through this very important and complicated task.

Data bases/Online data

The most comprehensive wind turbine database available is probably the one used in WindPRO as it has been updated with all market-relevant turbines since the mid 1980s. The database holds all publicly-available and relevant technical specifications for the most important calculations such as energy yield, noise, visualization, etc. Online data, as mentioned in the previous paragraph gives access to background maps, wind data, elevation data and roughness data.

Google Earth™ export

Having created a wind energy project, a wind resource map or a photomontage in WindPRO, a visual presentation in Google Earth is just one mouse click away. From Google Earth it's easy to e-mail the presentation file to share your project ideas with your business partners or a wider audience.

Languages, versions and report modules

WindPRO in its full language version is available in English, French, Spanish, German, Chinese, Danish and Swedish. Several additional print languages are available. Please see a list of available languages on www.emd.dk Note: manuals are only available in English, German, French and Spanish and on-line help only in English.

Calculation modules and reports

WindPRO generates reports designed to communicate the results clearly and directly to investors, operators or approving authorities as well as background reports with detailed analyses for evaluation purposes.

1.1.2 License Conditions

The independent association Energi- og Miljødata holds all Intellectual Property Rights to the WindPRO software, which is continuously developed by EMD International A/S and distributed worldwide through a network of appointed agents. The manual and other documentation from the WindPRO software are copyrighted and all rights reserved.

Conditions of use: The licensee, who has paid for or by other means legally obtained the right to use the program, is entitled to activate and use a license.

Copyright: The licensee may under no circumstances copy, pass-on, sell or in any other way distribute the program or documentation associated with the program to third parties.

License: The licensee is only allowed to use a single license on one computer at the time, if the licensee has activated a license on two different computers belonging to the same user.

Additional Licenses: The name and address of the licensee, which is printed on all reports from the software, will be the same on each additional license supplied as on the first license supplied.

Duration-Termination: All user rights to the program are withdrawn in case the licensee does not respect the terms of payment in force at EMD International A/S.

Limitation of Liability: The software is provided on an "as is" basis without warranty of any kind. EMD International A/S does not warrant, guarantee or make any representations regarding the functionality of the software, any results obtained by the use of the software and any software support provided by EMD International A/S and their agencies/partners in terms of correctness, accuracy, reliability, usefulness, or otherwise. The licensee is solely responsible for the selection of the software, for the installation of, use of, and results obtained from the software and software support received. Also excluded is any implied warranty by EMD International A/S, such as merchantability, non-infringement and fitness for a particular purpose.

1.1.3 Service and Updates

A valid service agreement with EMD means that the user gets access to the following services:

- Free e-mail or telephone hotline service covering advice and guidance regarding the use of the software.
- The latest version of the software.
- Download access to online data from the EMD-server.

The user pays an annual service fee of 20% of the actual list price for modules covered by his License Agreement.

Software updates are not issued at regular intervals, but typically once a year. It is possible to download improvements and updates from our website www.emd.dk.


For users without a service agreement, or who have cancelled a previous agreement, any future software update charge will be calculated based from the date service expired on the license.

Based on our long experience within wind energy project calculations, WindPRO is designed as an "expert system", both a valuable tool in your daily work, but also a tool, which continuously trains you to develop better projects. Please contact us for further information.



The screenshot shows the WindPRO 2.7.428 Beta software interface. On the left, there is a large logo for 'Wind 2.7 PRO'. Below the logo, it says 'WindPRO 2.7.428 Beta jan 2010'. On the right, there are two text boxes. The top one is titled 'Copyright:' and contains the following information: EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tel: +45 9635 4444, Fax: +45 9635 4446, email: windpro@emd.dk, info: www.emd.dk. The bottom one is titled 'License to:' and contains: EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, +45 9635 4444, 1000, Thomas Sørensen. At the bottom of the screenshot, there are 'Internet links' for email, EMD, WindPRO update page, and FAQ. Below these links, it says 'WindPRO uses Shape Viewer Objects GIS from Ecological Software Solutions ESS'. At the very bottom, there are 'Ok' and 'Details' buttons.

1.2 Installation of WindPRO

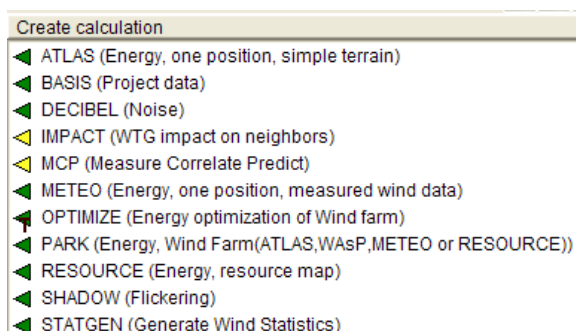
Insert the DVD or USB stick into your computer and click on  AutoStart.exe , you will see the following menu:



Click on Install WindPRO 2.7. Follow all instructions on the screen. The installation process will install the WindPRO software in C:\Program files\EMD\WindPRO2.7\ by default. A WindPRO data folder is also installed. The default path will be in Windows Vista: C:\Users\Username\Documents\WindPRO Data and in Windows XP: C:\Documents and Settings\Username\My Documents\WindPRO Data.

Note that the WindPRO data folder should be placed in a location where all users have both read and write access when running WindPRO. A good place for the WindPRO data folder would be the Windows documents folder shared by all users. It is named differently depending on the Operative system. e.g. in Windows XP:C:\Documents and Settings\All Users\Documents and in Windows Vista: C:\Users\Public\Documents\. Placing the WindPRO data folder on a network drive might affect the performance of WindPRO. For the best performance place the WindPRO data folder on a local hard drive.

The demo DVD or USB stick contains the entire WindPRO package. In demo mode you cannot calculate or print or save a project. However, upon purchase of WindPRO modules, EMD International A/S will provide you with a license file opening the licensed modules. Licensed modules are shown with a green arrow – none licensed with yellow arrow in WindPRO main menu. Arrows marked with “T” mean time-limited license.

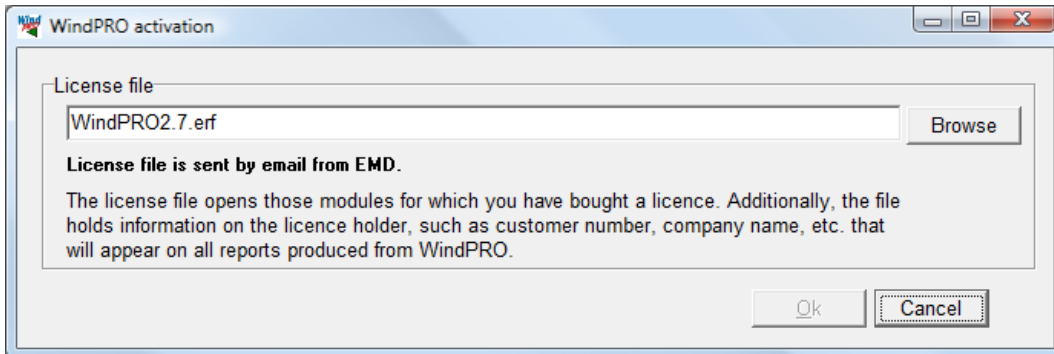


1.3 License activation

A license file will be sent as an attachment to an e-mail. Please contact EMD, if you change your e-mail address or do not get the license file. The license file will be sent to the primary contact that EMD has on record for each company, which holds a current license. If you are in any doubt as to the primary contact details, please contact EMD for information.

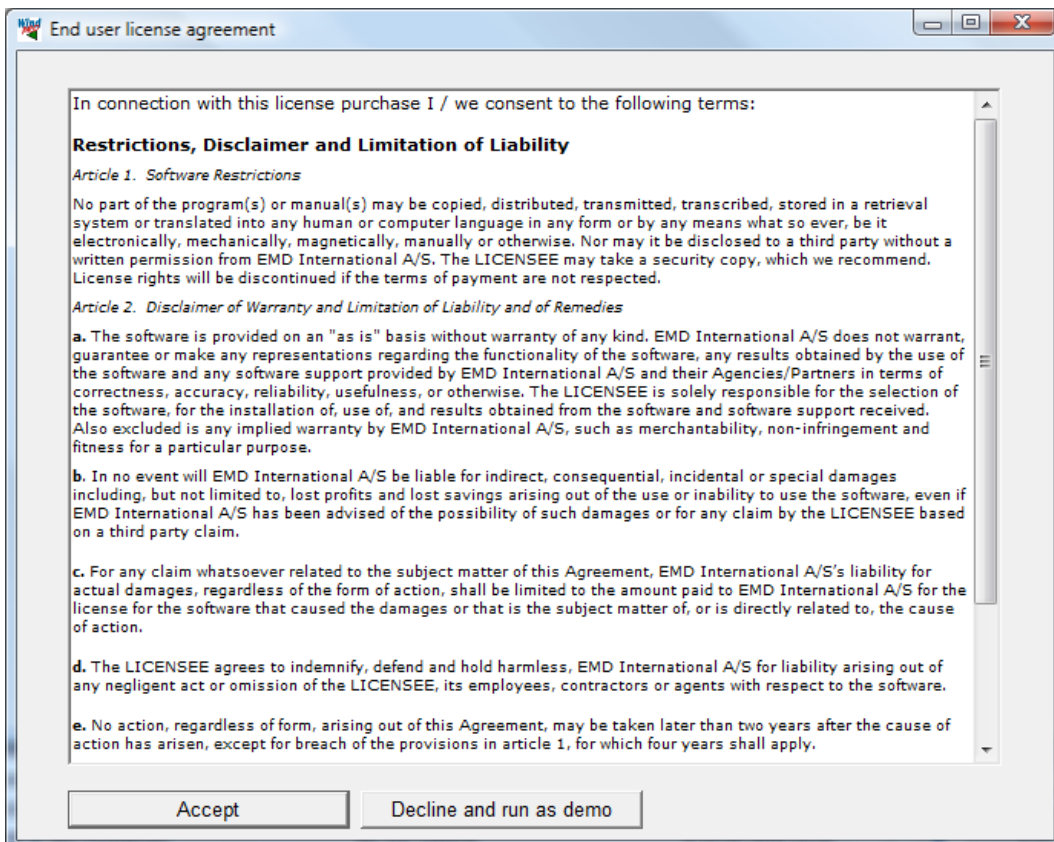
1.3.1 New WindPRO users

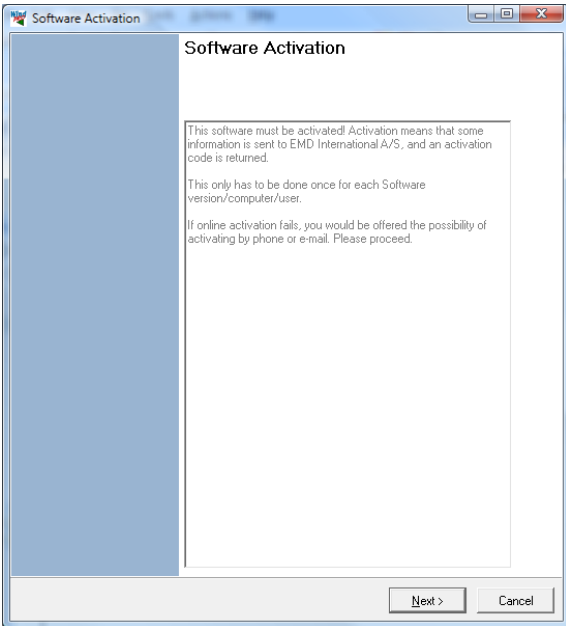
When starting up WindPRO for the first time, the program will automatically ask for a license file.



The license file as received by e-mail should be saved on your computer from your e-mail program and selected using the Browse button from the screen above.

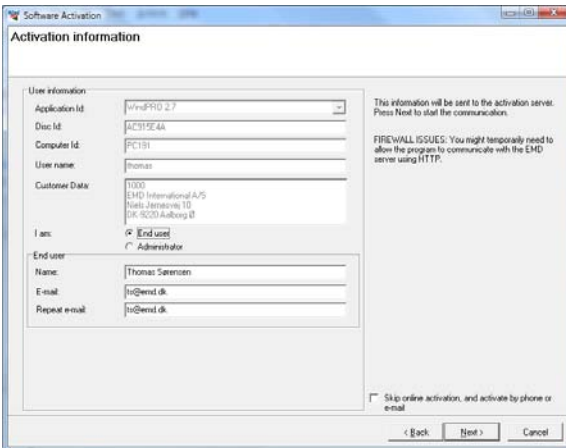
After reading the license file, the *End user license agreement* must be accepted





Each user is identified by email address and each user is allowed two installations, for example an office and a home computer or similar. In order to activate the user must go through the activation procedure.

Press Next to continue the activation process.

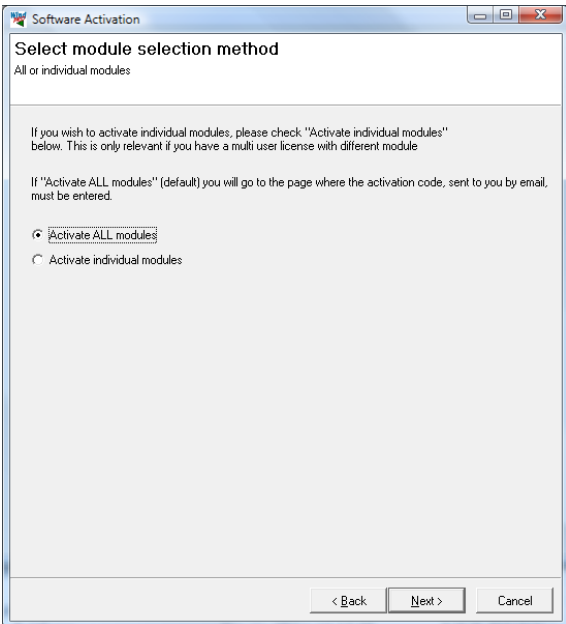


On this screen the data to be sent to the activation server is displayed. The faded texts are read by the software (computer ID, user name etc.).

If you are end-user you fill in your name and email address. A license holder is allowed to use as many email addresses as you have licenses and each email address can be used to activate a license twice.

If you are the administrator you can additionally add your own email address. That will make the activation code come to you instead of the end-user, but the administrator address does not count to the allowed number of licenses.

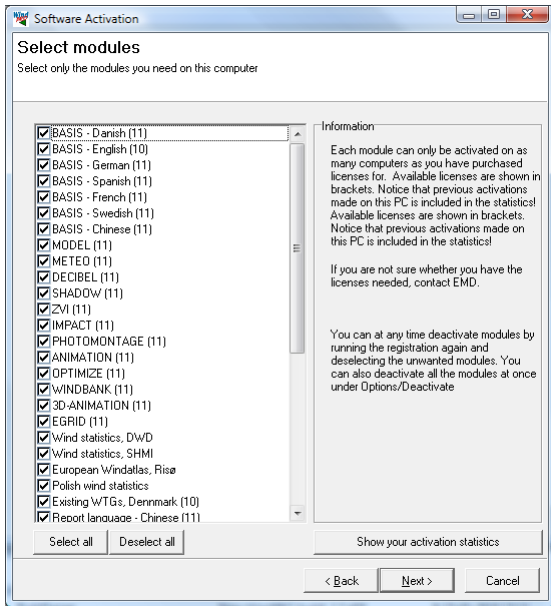
The "Skip online activation..." option is available for users, who do not want to send information via the internet, using FTP. Check this to activate by e-mail or phone.



It is possible to buy a different number of licenses for each module. A user who is only going to make visualizations may not need the energy modules, while his or her colleagues may need energy modules but not visualization modules.

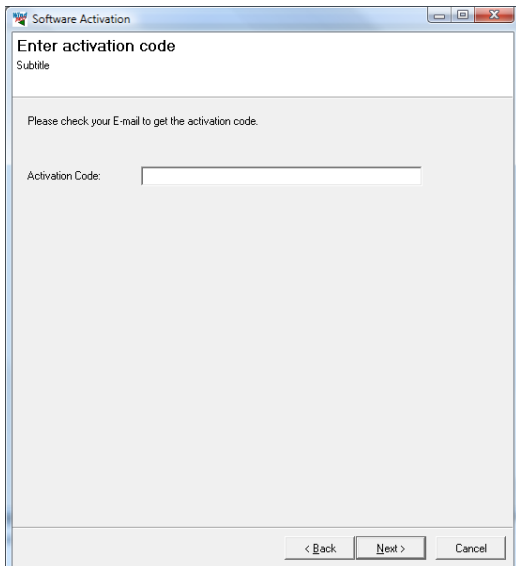
If all modules bought by the user should be activated select Activate all modules.

If instead only a selection of modules should be activated then select Activate individual modules.

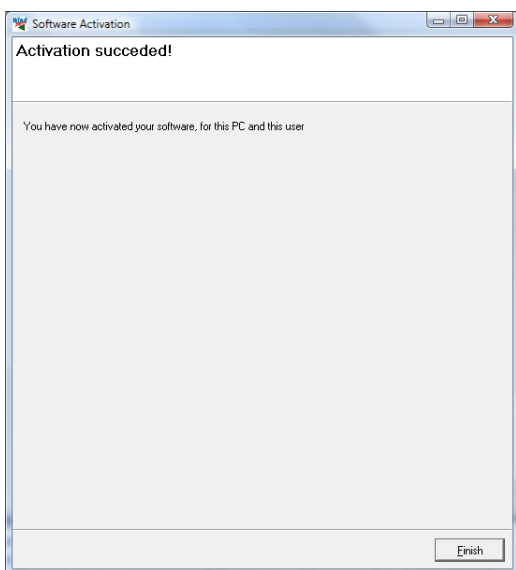


If “individual modules” was selected then you must point out the ones to activate. Note that you always need to activate at least one BASIS module and one Language module in order to run WindPRO in non-demo mode.

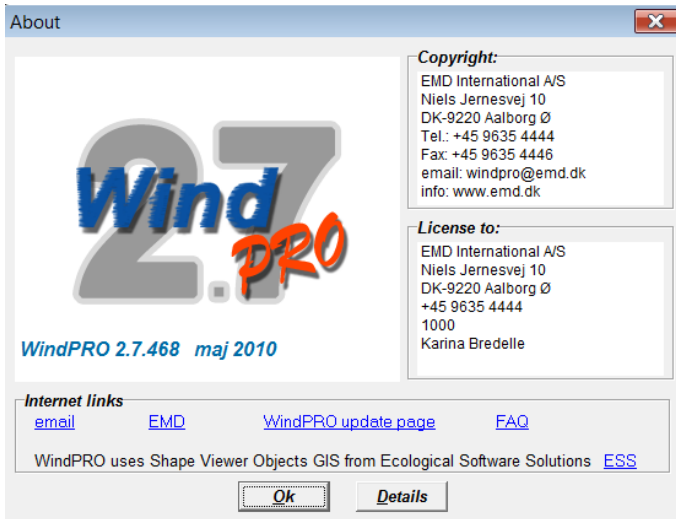
The list will show you all your available modules. If the module you wish to activate is not in the list then you do not have a valid license for it and you may contact EMD. By showing the activation statistics you can see who are currently using the licenses in the company.



Next step is to enter the activation code. At this stage you will have received an activation code in your email inbox. The code was sent to the email address you typed in previously.



Your license has now been successfully activated.

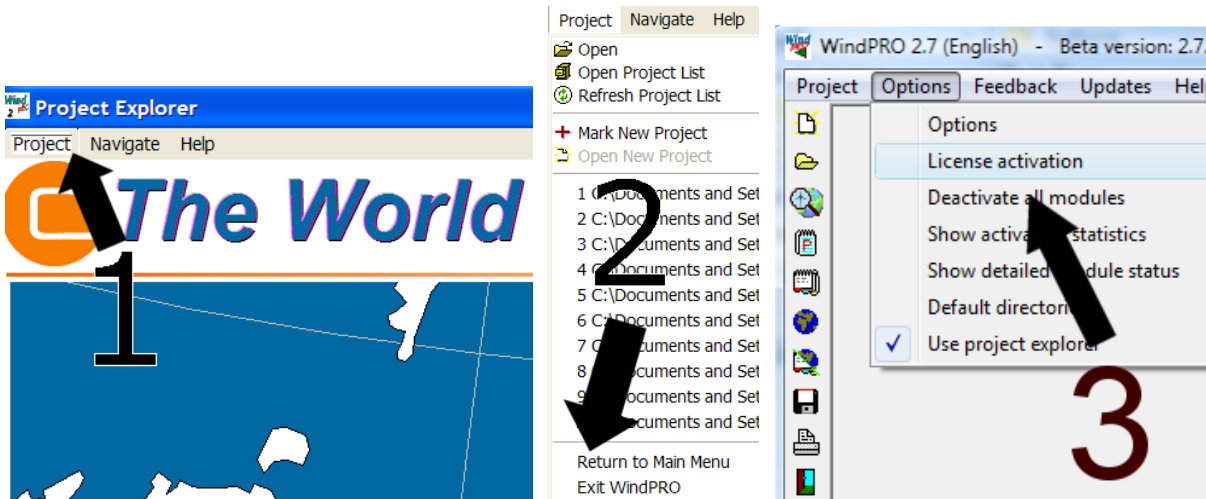


The activation process is concluded by showing you the About window for WindPRO on this computer. Here you can see the license information on your organization. This is the information included on all printouts made with WindPRO. You can also see your current version of WindPRO. If you suspect your version not to be current you can visit the WindPRO update page and check if newer versions are available.

The details button will give you more detailed information about your WindPRO version.

1.3.2 Existing WindPRO users/manual license activation

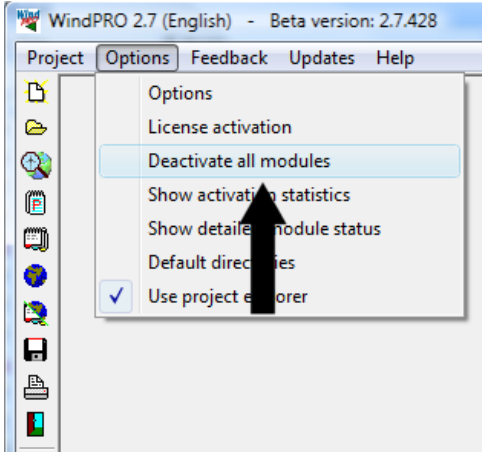
When an additional module is purchased, license holder info is updated or for some other reasons manual activation is required, please start the license activation this way:



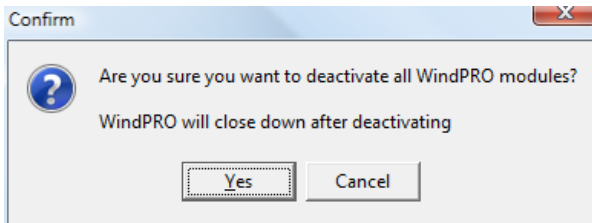
Open WindPRO and click on “Project” and then “Return to Main Menu”.
Click “Options” and then “License Activation”. Follow the procedure as described previously.

1.4 License deactivation

If you need to transfer your license to another computer or another user you will initially need to deactivate your license.

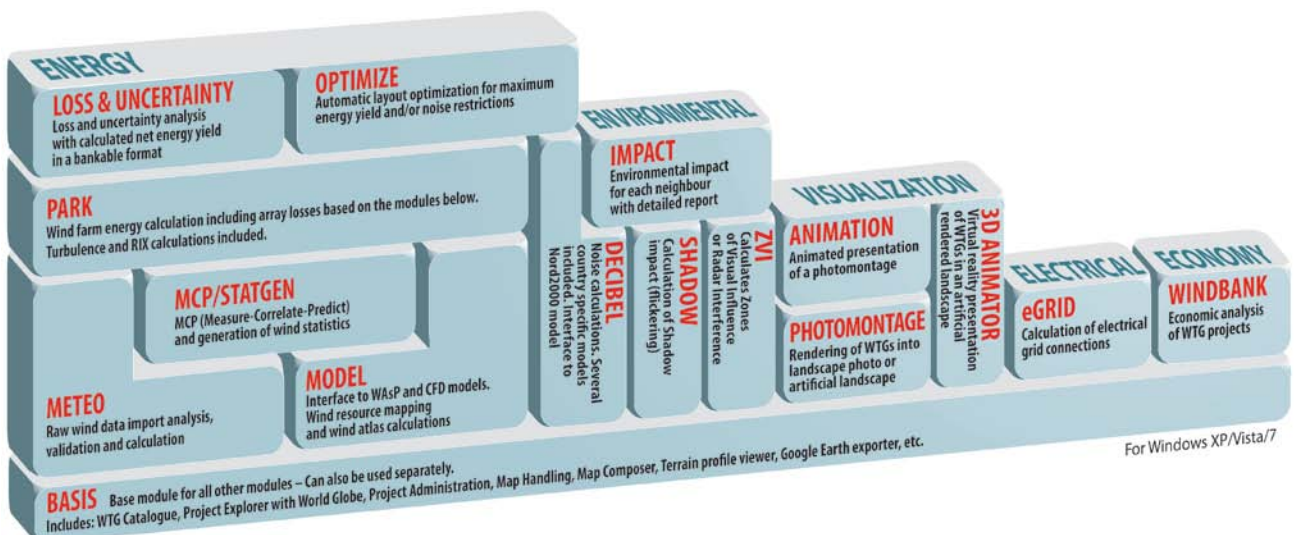


Select Deactivating all modules from the Options menu.



Confirm that you want to deactivate and WindPRO will shut down. The licenses are now released to be used on another computer or by another user.

Note that if you installed on two computers using your e-mail address you need to deactivate both activations before the license is released for another user.



Overview of the WindPRO modules.

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2.0 BASIS – Intro, files, step-by-step guide etc.

2.0.1 Introduction to WindPRO BASIS

The WindPRO BASIS module is, as the name implies, the basis for all WindPRO calculation modules. With BASIS you have access to create a project, which typically consists of background maps and WTGs positioned on the map. Also, most of the other objects such as digital height contour lines, neighbors for noise calculations, etc., can be established from the BASIS module. In addition, the WTG Catalogue is managed through the BASIS module.

Enter all relevant information for a given wind energy project in BASIS, and use the WTG Catalogue to get detailed technical information for most of the wind turbines on the market and for adding new turbines to the Catalogue, e.g. for documentation and comparison purposes.

The calculations you can carry out depend upon which WindPRO calculation modules you have purchased. Non-activated modules can operate in DEMO mode, which means that you can input data, print reports (e.g. from the samples), but not calculate.

In the folder WindPRO Data\samples, some examples are included from which reports can be printed.

2.0.1.1 Conversion of WindPRO-2.5 or previous projects – new 2.6 data structure

If you have old projects saved from WindPRO 2.5 version or previous, these will be converted from .w2p to .w3p project files. please contact EMD.

The data management system is going through a comprehensive revision.

The first step of a long-term revision plan is taken in v2.6. The main idea is to use a more modularized structure, improving program efficiency. At a later stage, this modularization will make it possible for other software to interface to any part of the WindPRO project data.

When fully implemented, this will allow the creation of a RESTORE function (e.g. in the case of a power failure or “crash”), which is already partly implemented (mainly for the Meteo data object). Finally, the new structure will open up new features in upcoming updates like “revision history”, an undo function etc.

For now, the user will see following:

When opening a v2.5 project (.w2p) first time, it will take a little longer – especially if there are a lot of Meteo data objects - these must be converted into a new format.

When saving, the file format will automatically be w3p, meaning that you do not overwrite your v2.5 project from v2.6.

With the “Save As” option on the Main Menu | Project Menu, users can decide to save a project as .w2p (v2.0 – v2.5 format) in case they are sending the project file to someone running an older version of WindPRO.

If users choose to export the project, the exported project will be in the new .w3e format, BUT, if you first “Save As” .w2p, and THEN export; it will be in .w2e format. Exporting or saving to w2p/w2e formats will not include Meteo data objects due to the complete change in the Meteo object data structure. To save as .w2p the user must add the .w2p extension manually to the filename – it does not appear as a drop-down option.

2.0.1.2 File type overview

The WindPRO-2 data files:

In the folder \WindPRO Data\Projects\...

*.w3p – WindPRO-2.6 and later project file – holds data stored in objects, plus calculation reports and links to files. For objects with larger data amounts, the data is stored in separate files to speed up the data handling and keep the project file size down. The user wont “see” these files.

*.~w3p – backup of WindPRO-2.6 a later project file – is made when you save an opened project and is a backup of the opened project. This gives you the opportunity to revert to the original project file if you make

serious mistakes (delete or change data) or if your PC or software should "break down" during the saving process and damage your project file.

*.w2p – WindPRO-2.0 – 2.5 project file – holds all data stored in objects, plus calculation reports and links to files.

*.~w2p – backup of WindPRO-2 project file – is made when you save an opened project and is a backup of the opened project. This gives you the opportunity to revert to the original project file if you make serious mistakes (delete or change data) or if your PC or software should "break down" during the saving process and damage your project file.

*.wpe – WindPRO-1 export file – during export you can select which data to be included in the file (e.g. bitmap maps).

*.w2e – WindPRO-2.0 – 2.5 export file - during export you can select which data to be included in the file (e.g. bitmap maps).

*.w3e – WindPRO-2.6 and later export file - during export you can select which data to be included in the file (e.g. bitmap maps).

*.bmi - Binary map info. Coordinate settings for user-defined maps. When a local coordinate system is used, it can be imported to another project from a BMI file.

*.bx Bitmap maps with coordinates defined in a BMI file. In the current version the files are saved in a PCX format but this can be changed later. "x" is the file number, starting with "0" for the first one.

*.wpo – Digitized lines from Line Object – holds height contour or roughness lines plus a digital elevation model (Triangular Irregular Network (TIN)).

*.w2r – WindPRO regions – digitized polygons from Area Objects.

*.lty - Landscape types for WindPRO Area Object. (The landscape types are included in the .w2r files, but the .lty files makes it possible to exchange the definitions with other .w2r objects).

External file types (data from other sources), used with WindPRO:

*.map – WAsP map file format for digitized height contour and/or roughness lines

*.rsf – WAsP Wind Resource Map

In the folder \WindPRO Data\Standards

*.wmi – meteo import filter .

*.wbs – WINDBANK input file (template or complete input data file for economy calculation).

*.wsh – Solar and/or wind distribution for SHADOW calculation.

*.wpc – WindPRO color setting.

*.lty – Landscape types – can be used from Area Object to import/export predefined landscape types from one Area Object to another.

*.wti – Wind Time variation file to use for time varying AEP calculations and loss calculations. There will be some example files included that can be used.

In the folder \WindPRO Data\Windstatistics

*.wws – WindPRO Wind Statistics. Binary equivalent to LIB files, in addition to the Wind Statistics information, it contains information about country, coordinates, creation time, source, elevation, height and other info on the basis for the wind statistic. Also user comments written when the wind statistic is saved are included. File type can be locked so a license key is required to use the file (see Chapter 3).

*.LIB – Wind Statistics in Risoe's WAsP format (when saved from WindPRO, coordinate information is included) (see Chapter 3).

In the folder C:\WindPRO Data\WTG data

*.wtg – Wind turbine file – holds all relevant data of a specific WTG type, defined from manufacturer, type-designation, kW_{nom} - kW_{small} , Rotor diameter and Tower type. A typical name: **VESTAS V66 1650-300 66.0 IO!.wtg**, Where "IO!" means tubular tower and "I#" means lattice tower and "I3!" mean 3-leg tower and lastly "I-!" means unknown or other tower type. All information is integrated in a file, which is flexible to hold more different sets of e.g. power curves, noise data etc. In the .wtg files from EMD, the power curves etc. are integrated in the .wtg file. If the user adds some data, these will be placed in a separate file so an update from EMD can update previous data without destroying the user added data.

*.uwt – User-defined wind turbine file, which holds additional data to the .wtg file, added by the user. Note: The .uwt file only works together with a .wtg file with exactly the same name. If you want to send wtg data to another user, BOTH files must be copied.

Other relevant file formats:

*.shp – Shape file (from Arc View GIS software) – polygons, which can be used as an overlay map in the Project Explorer and later on imported in the Area Object or added as background map. Samples can be found in **C:\WindPRO Data\Globe**

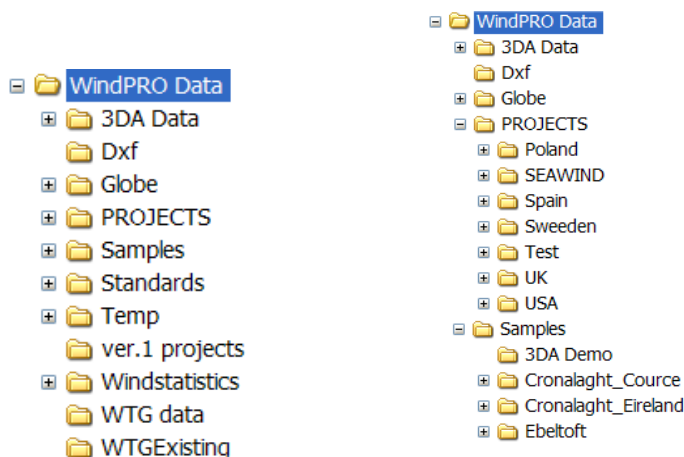
*.dxf – Auto desk exchange file format (Auto Cad) – can be digitized height contour lines, which can be imported in the Line Object or drawings of e.g. high voltage mast or lattice WTG-towers, which can be used for visualization purposes.

*.ntf – From the UK Ordnance Survey, digitized height contour lines can be imported in the Line Object.

2.0.1.3 Proposed way to organize data

We recommend that you create a folder in \WindPRO Data\projects\ for each new project (or group of projects in same region). In this folder, the project file (*.w2p) is stored as well as the local bitmap maps, digitized files, e.g. height contour maps, measured wind data, generated Wind Statistics, photos for visualization, site specific WTG-types etc. Hereafter it's always possible to have all data in the same folder, which makes backup of a complete project or handing over a complete project to other WindPRO-2 users easy.

Below on the left, the structure of default sub-folders to WindPRO Data is shown. To the right, the sub folder PROJECTS is expanded with an example grouping project sub-folders by country. If you only work in one country, other substructures might be better, depending upon how many projects you expect to handle. If only a few, each project should just have a folder with the project name.



For Wind Statistics and WTG-types that you might use for other projects, it's recommended to store a copy in the folders:

\WindPRO Data\WTG Data
 \WindPRO Data\Windstatistics

If you are connected to a server and need to have files there for sharing of data with other employees, you simply create a folder on the server and add this folder to your Project Browser (and WTG and Wind Statistics

Browsers). This folder should have exactly the same structure as the one described above, which makes it easier, e.g. when you want to move projects from the server to your local PC or Laptop for travelling.

Note: In the WindPRO project file (*.w3p), all files, which cannot be found in the original folder will be searched for and, when found, replaced automatically in the actual project folder or sub-folder to this (working directory).

The mentioned rules of addressing files means that links to data (for example folders with WTG Data or wind statistics) will be replaced with links on the new PC if project files are moved from one PC to another.

If you always want to use WTG Data from a common server, make sure that only a search path for this is specified in the WTG Explorer.

To be completely sure that you are working with exactly the same files as your colleague, but from another PC, make an export file (from menu files|export) with all files included and open them from your own PC, or work directly with the project files placed on a common server version.

2.0.2 Recommended auxiliary hardware and software

HARDWARE

PC	Min.: 1 GHz Pentium, 1 GB RAM, 2 GB HD free space. Recommended: minimum: 2 GHz processor, 4 GB RAM, 5 GB HD free space. 3D accelerated graphic card required for the 3D-Animator
Scanner	If you don't have access to digital map sources, you will need a scanner to integrate background maps in WindPRO. An average to high quality scanner is recommended, as in low-cost solutions, deformations are likely to occur. For scanning large paper maps an A1-A0 drum scanner is ultimate, but if seldom used it will be cheaper to get this as external service.
Digital camera	For photomontages or just in general for documentation of the site a digital camera is a must. 2 Mpixel or more is preferable for visualization of WTGs. Knowledge of the exact focal length of the lens in 35 mm film equivalent is important – if the camera has zoom lens, it is an advantage to use the known min/max zoom, which then not should be too extreme. E.g. 35 – 70 mm (35mm equivalent) can be used in most tasks. Round 45 mm is closest to the human eye's "focal length" and preferred by many as "fixed lens". Most digital cameras stores EXIF info in the picture files, which is very usefully for photomontage use. The Camera object in WindPRO reads this information and you thereby get like date-time and focal length automatically loaded from photo. Some of the latest cameras store GPS coordinates for the photo position and even the direction the photo is taken. This makes it even easier to make a photomontage with WindPRO.
GPS	A useful device for acquiring coordinates of objects (e.g. Existing WTGs, Measuring mast positions, Photographers' positions) in fieldwork. Expensive models can offer increased accuracy (0.1m), but might need additional references (differential GPS) where "standard models" has round 10m, which in most cases are sufficient. Cable to transfer data to PC is very useful if many GPS points are logged in field.

SOFTWARE

WASP version 4 or 5 (DOS); or from ver. 6 and higher (Windows)	Energy calculation engine used by WindPRO for calculations on complex terrain – so far the only real difference in WASP versions used from WindPRO is the calculation speed and the size of digital contour data they can handle (last one is very limited in WASP 4). The DOS versions are
--	---

	no longer recommended while they require some complicated installations via DOS-BOX to run in later Windows versions (XP, Vista, Win7). There are some differences from WAsP 9 to later versions, see separate notes on this topic at EMD Helpdesk. The page can be opened from WindPRO menu "Help – FAQ (Internet)".
Paint Shop Pro (preferably version 5.01 or newer)	Very powerful graphic tool for preparing scanned maps or digital photos for use in WindPRO. You can, e.g., use Paint Shop Pro (PSP) to delete already existing WTGs on photos, if you wish to repower an existing project (use the "Clone" function to copy the landscape on top of the existing WTGs).
Adobe Reader / Adobe Acrobat	To be able to read/view "PDF-files" it is a must on any PC to-day, this requires the free downloadable Adobe Reader – WindPRO also can save reports as .pdf. But being able to manipulate .pdf files like merging more files, have pdf as a standard printer etc. requires the extended version called Adobe Acrobat. But there are many different products within this field to-day, so search the web to find your needs. Installing a PDF printer is extremely convenient, while you then can print all reports as .pdf documents. There are free tools available for this purpose.

For some purposes, additional software will be required such as the WAsP software for energy calculation in complex terrain.

2.0.4 Getting started – language selection, etc.

To start WindPRO, click on the START button and then find "All Programs" and then the EMD subdirectory (if defaults are used when installing) and then WindPRO-2.x language selection.

WindPRO 2.x – let you select language when starting (if more language modules are purchased). To start with a specific language, just click on the flag.



2.0.4.1 Printing language

From WindPRO version 2.4 a new feature is available, printing reports in another language than you are working in. To use this feature it requires a Print Language module. See in the start menu (shown above) which languages are available.

2.0.5 Step-by-step Guide for creating a basic project

Ensure that you have relevant maps scanned in a proper resolution (or have them as digital files) and read which coordinate system the maps are drawn with. If the system is unknown by WindPRO, you might design an approximate system or work with local coordinates. **Alternative/supplement to scanned maps is the maps you can get from the On-line data service.**

Create a new project, typically from the Project Manager, by marking the approximate site location on globe. Fill in project properties with a relevant coordinate system and attach maps (define maps from "MAPDEF" button if maps are not yet set with coordinates.) EXIT project properties with "OK".

Push Map-button from the main menu and load relevant maps from the map buttons.

Start (typically) by entering height contour information using the Line Object.

Create relevant objects depending on which calculations you wish to perform. Read the relevant parts of the manual for a specific calculation. Follow the step-by-step guide for the desired calculation.

Go to the calculation menu, when the necessary objects have been established.

Perform the calculation and print the reports.

2.0.6 Auto save / recovery and save as older versions

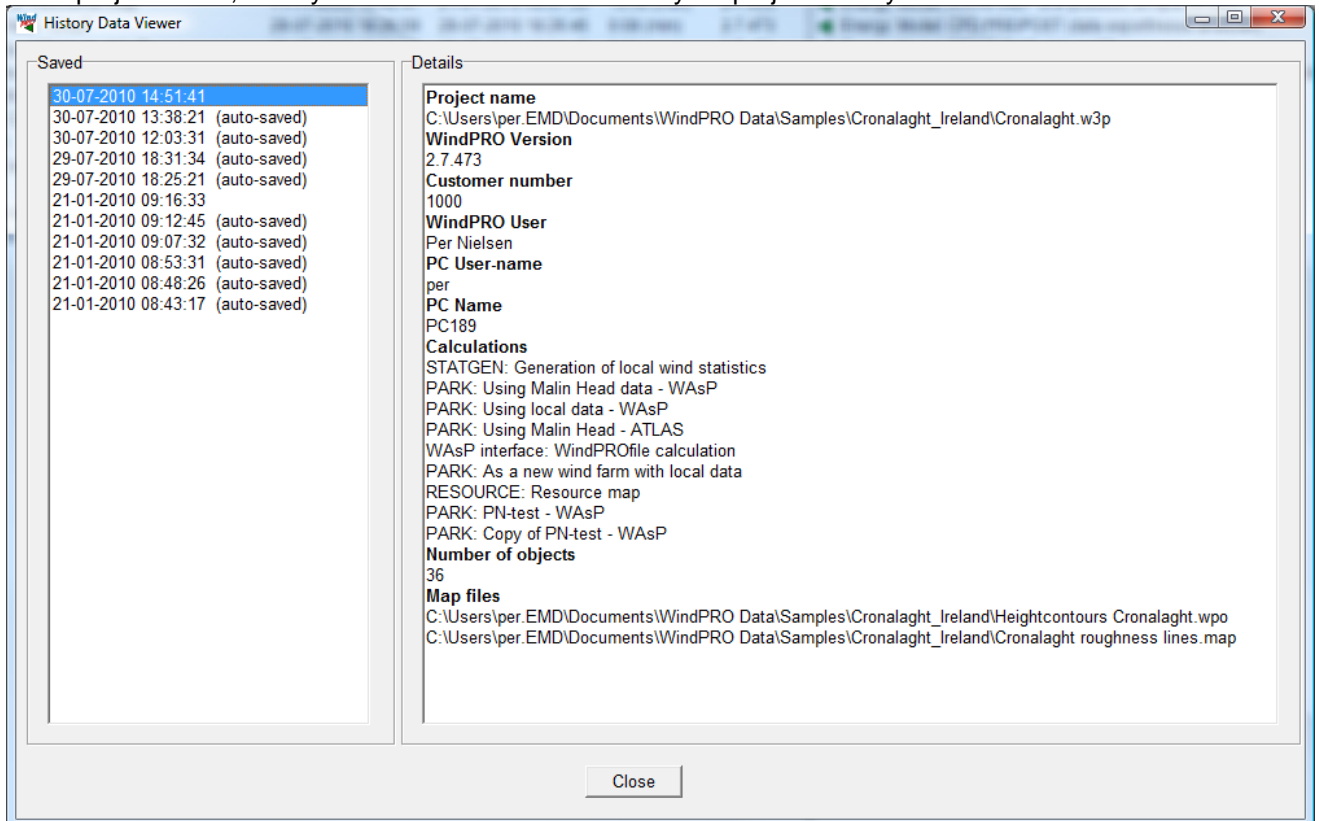
There is an automatic auto save feature. This runs each time a calculation is performed and by several other events. It is "intelligent" so it check how long time last auto save did run, if less than 3 minutes it won't run and

thereby it disturb as little as possible. If the software or the PC crashes, a restart of WindPRO will start asking if you want to open the recover file.

You can from the “save as” choose to save as version 2.5 or later – this makes it possible to open a project in older versions if needed. Simply chose the file format in the “save as type” drop down box in the save as dialogue.

2.0.7 The WindPRO history log

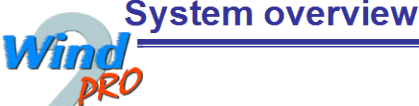
In the project menu, history show different information of your project history.



This can be used to identify which changes/calculations you made when.

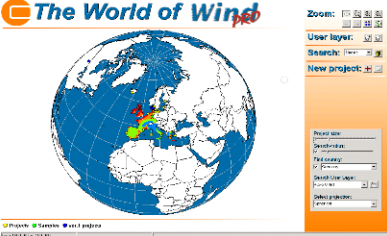
2.1 BASIS - The structure of WindPRO

2.1.1 WindPRO structure – System overview

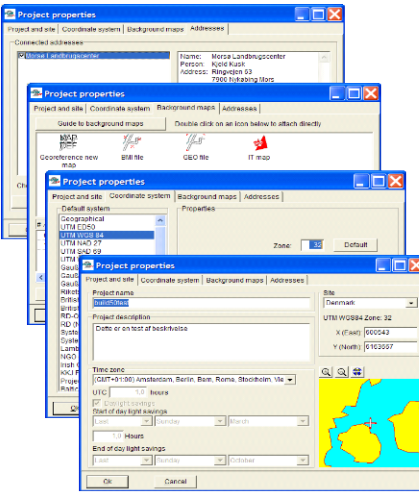


System overview

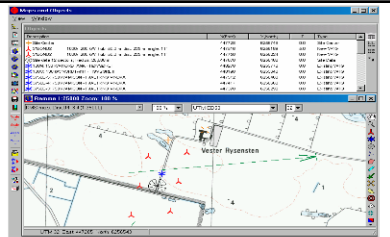
Project explorer
(Globe and list with advanced sorting)



Project Properties
Basic settings: Customer, coordinate system, Maps!



Maps and Objects
(Working space)



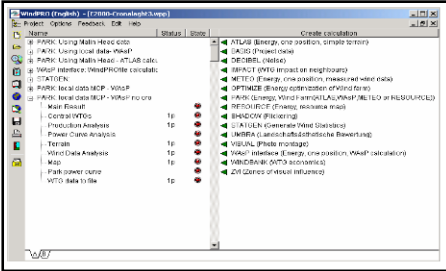
WindPRO data:

- WTG Data
- Windstatistics
- Predefined Standards

Objects:

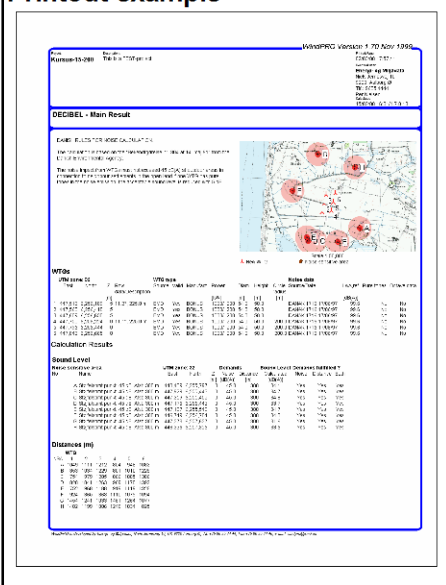
- > New WTG
- > Existing WTG
- > Park Layout (Only with Optimize)
- > Site data (energy)
- > Meteo data (energy)
- > Noise Sens. Area (decibel)
- > Obstacle (energy)
- > Camera (visual)
- > Control mark (visual)
- > Shadow receptor (flicker)
- > Line object (height/roughness)
- > 3D-object (visual)
- > Area object (ZVI, roughness etc.)
- > Result layer (Resource map etc.)
- > WTG area (optimize, WindPlan)
- > Text
- > Virtual Reality (3D Animation)
- > Measure tool
- > Shape tool (Also for Gridlines on map)

Calculation modules
(Main menu)



Reports - ready for customer.

Printout example








Input to the program is given in the following menu items:

Project Properties, where the general project information is entered (name, client, coordinate system and any associated maps).

Maps and Objects, where the specific conditions for the project are entered (wind turbine positions, wind turbine type, information on calculation of wind conditions, noise conditions, etc., depending upon the type of calculation desired).

Calculation modules. When a calculation module is activated you can restrict the calculation to selected objects from the object/map list. You are also given various choices, e.g. which calculation module to select when more than one calculation module can be used.

The five icons shown below indicate the shortcuts to input of information:

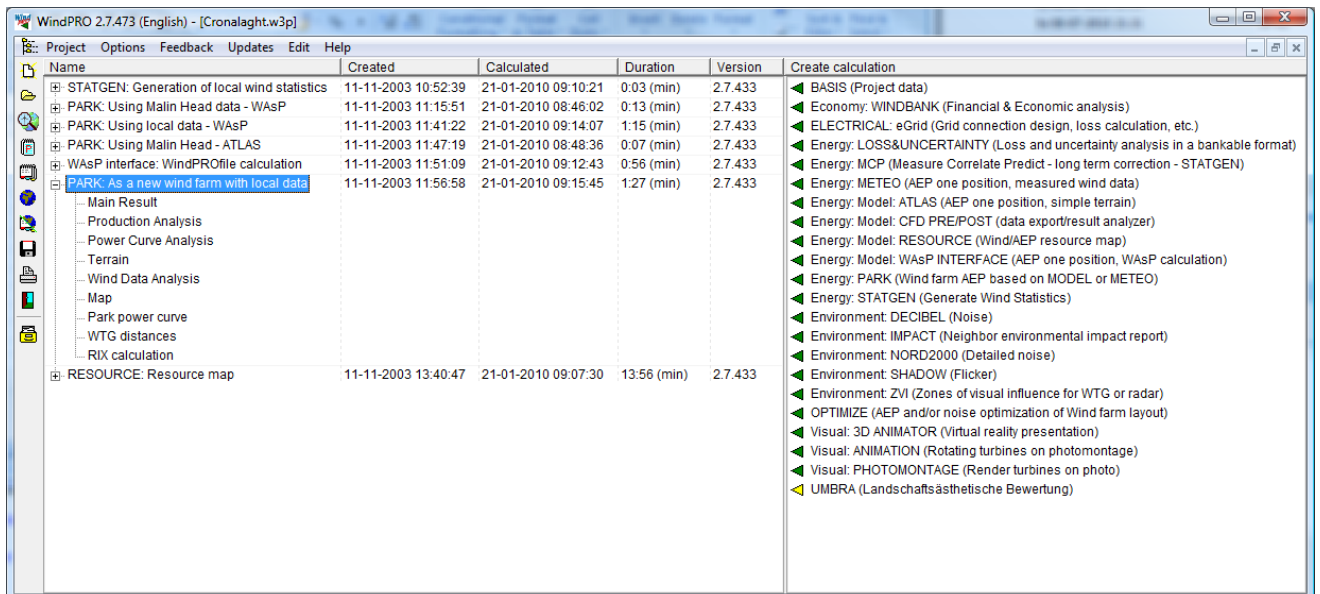
-  Project Properties
-  Objects (coordinates and object description, e.g. for the wind turbines)
-  Maps (graphic viewing of background map and entering of objects)
-  Maps and Objects (both the map and Object Lists are shown on screen)
-  Calculation (menu with calculation modules)

Calculations and outputs are carried out in the last item.

2.1.2 WindPRO structure – Calculation and report window

Calculation output (in the form of reports) is stored in WindPRO. If a printout of an earlier calculation is needed, you just have to open the project in question and print out the needed reports without having to rerun the calculations.

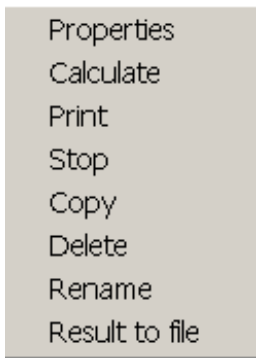
The output is arranged in a tree structure similar to the Windows Explorer. It gives you a good overview of the calculations carried out. This tree structure is shown on the calculation icon button.



When a calculation has finished, the window shown above will appear, listing the available reports that can be printed.

There will be info columns telling when calculation was created, last calculated, the duration and with which version.

A sub-level report will automatically pop up on the screen if you double-click on a sub-level report name. The sub-level report has its own right-click options, where you can define report details. When you right-click on the calculation header or on one of the calculation reports, you get access to this menu:



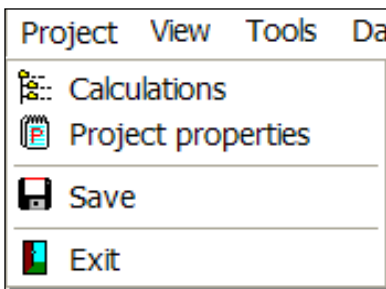
Choosing “print” gives access to setup all report features that can be modified.

The Result to file allow for saving some results in other formats, e.g. copy to clipboard and then paste to excel or save results as text files. Some graphic outputs, like iso noise lines, can be saved as shape files.

2.1.3 WindPRO structure – Menus in maps and objects

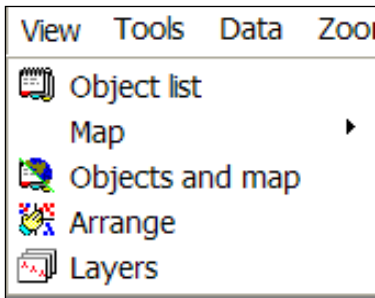
In this section, an overview of the menus is given. Note that by pressing the <Alt> key (if activated in your windows setup), all menus can be activated from the keyboard by pressing the underlined letter when the <Alt> key is held down.

2.1.3.1 Project



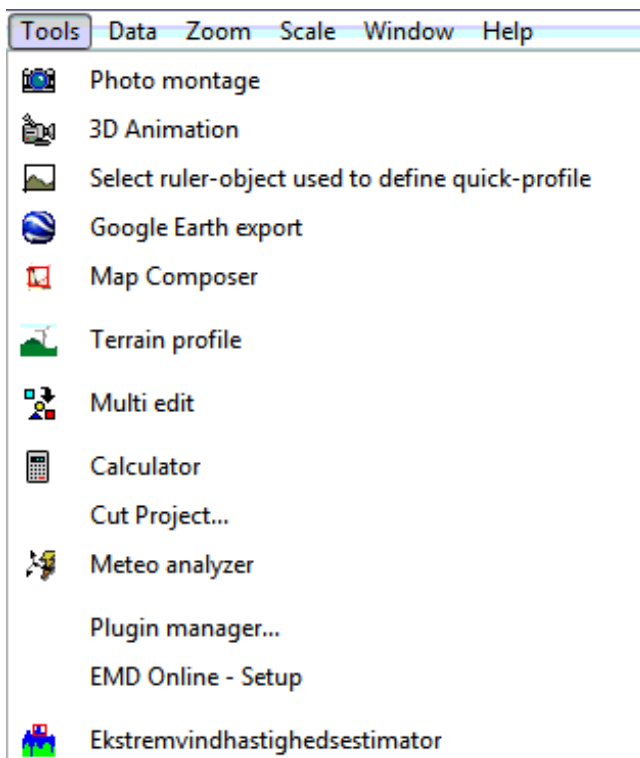
Direct links to the main functions – note that the “Save as” function is only available from the WindPRO main menu.

2.1.3.2 View



The Layer structure is very useful for organizing your objects. You can save a preferred layer structure and load it in other projects by right-click at the layer form. The layer form can be docked into the main window.

2.1.3.3 Tools



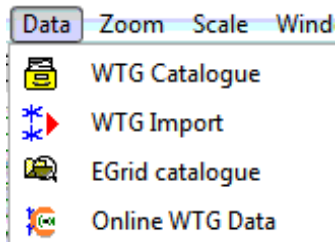
The first 2 tools (Photomontage and 3D Animation) require a license for full use.

The “Cut project” tool makes it possible to delete all data outside a given area. If you import a large amount of GIS data or height data from other sources and only wish to work on a limited part, this is an easy way to get rid of many different types of unwanted data in one operation.

The Plugin manager is more an “internal tool” that can be used to disable some services if unexpected errors occurs.

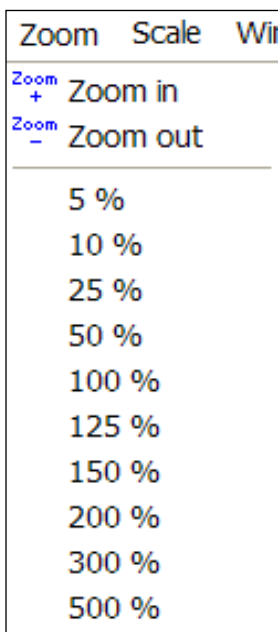
The other tools are explained in other parts of the manual.

2.1.3.4 Data



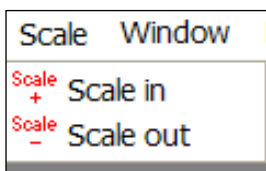
“WTG import” is for importing existing WTGs from a file prepared for this purpose. This file can be purchased for Denmark with all WTGs in Denmark, including estimated long-term production figures for each WTG. This feature are from version 2.7 replaced with Online WTG data, and the WTG import will be removed from ver. 2.8. Only by accessing via the online option give access to updated data.

2.1.3.5 Zoom



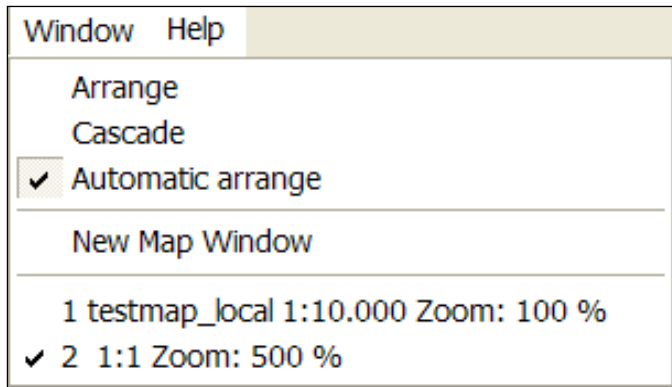
By right-clicking on map and choosing “Map-> Set zoom and scale” full free definition of the zoom factor can be chosen.

2.1.3.6 Scale



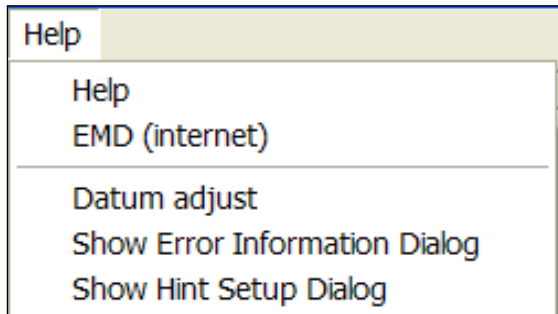
“Scale in” and “Scale out” only work with the .it map (Denmark) format holding more map scales in one file structure. More formats might be supported in future.

2.1.3.7 Window



Standard Windows-arrange functions

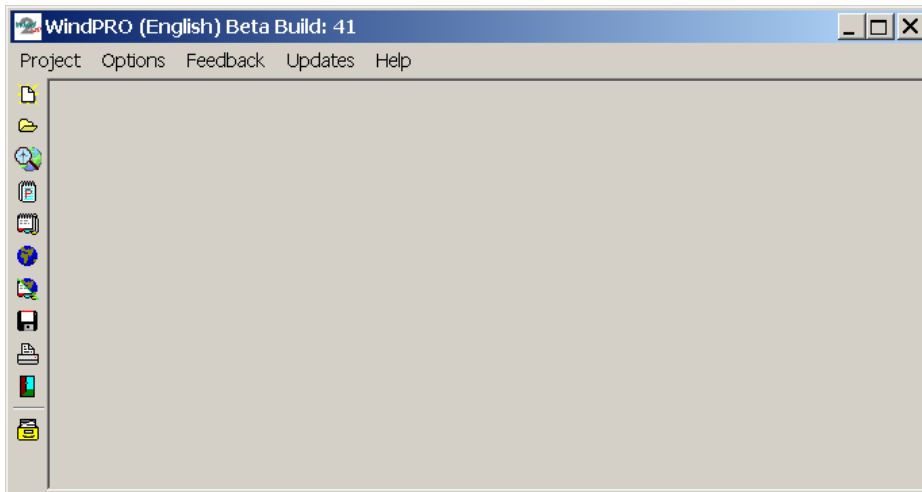
2.1.3.8 Help



“Datum adjust” is used for correcting errors in map datums (mainly caused by reopening old WindPRO project versions).

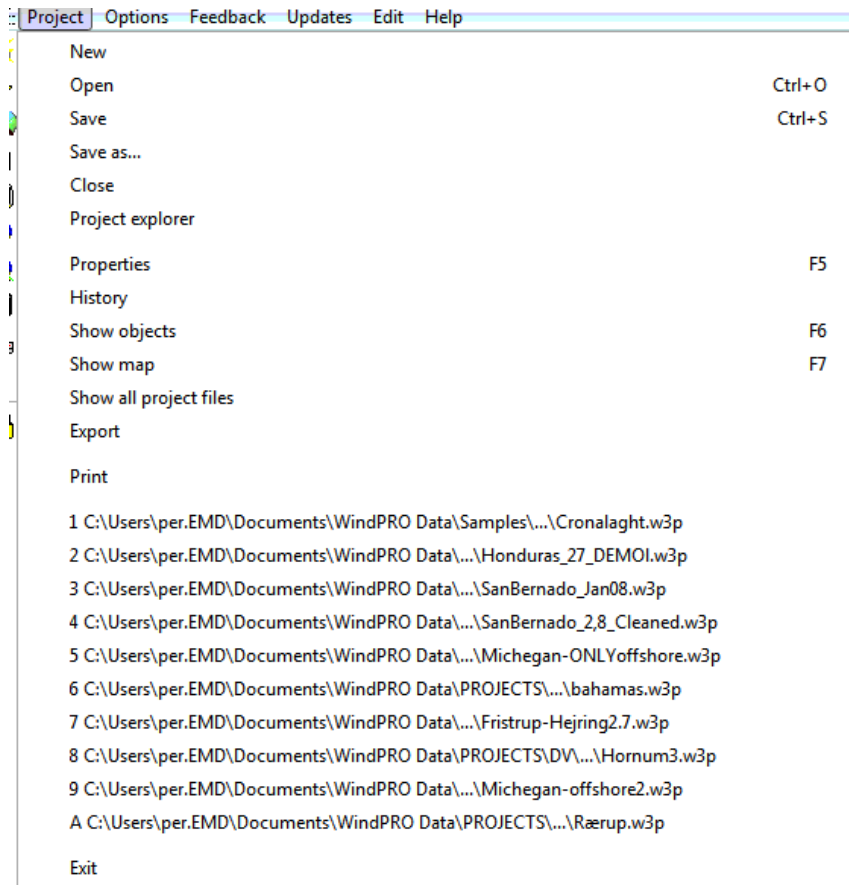
2.2 BASIS - General functions, setup and help

2.2.0 Introduction to general functions and setup



Below you will find a description of the main features, which can be found in the menu boxes under Project, Options, Feedback and Help, shown in the top menu bar shown above. In addition, you can work with the "Project Explorer", which is described in the next Section 2.3, and which will appear as the start screen unless you have deselected this option.

2.2.1 Project menu



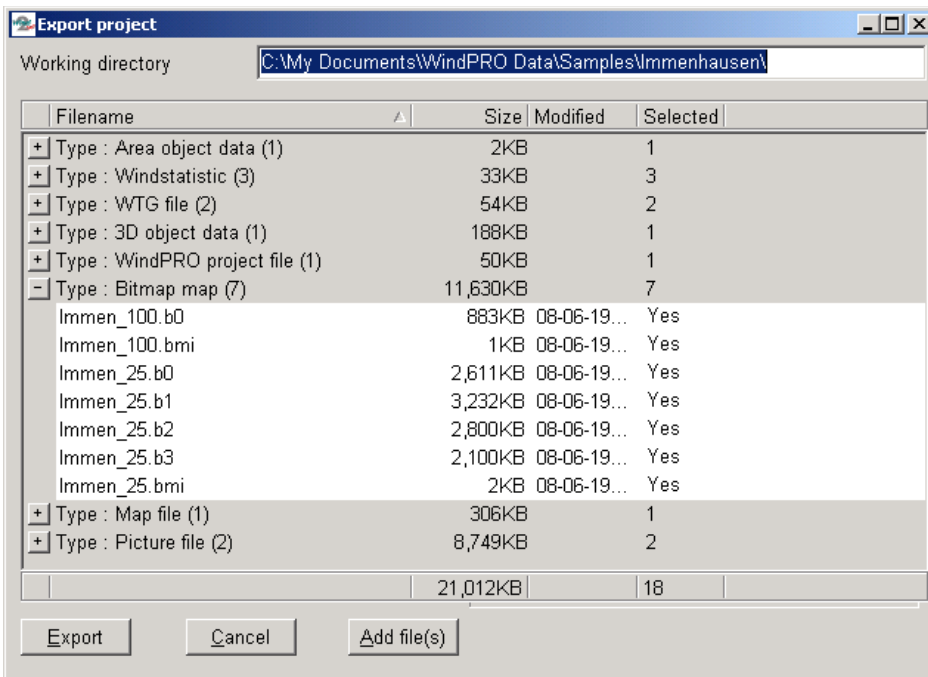
The project menu is used for "normal" navigation purposes known from other Windows software products. Below some details are explained.

2.2.1.1 Show all project files

Creates a list with all files used in current project and their locations.

2.2.1.2 Exporting WindPRO data

The export function is used when you want to copy project information from one PC to another or create complete backup packages. Since the data is structured in files, a "normal" copy with the Explorer can be used, but then you will have to make sure that all files needed by the receiver are included and that the files are placed in same folder structure. Otherwise, you have to re-link bitmap maps, Line Object files, etc. With the export function, you can let WindPRO organize what should be included, and all data will be packed into one file ready to be opened from another WindPRO-2 application with updated links.



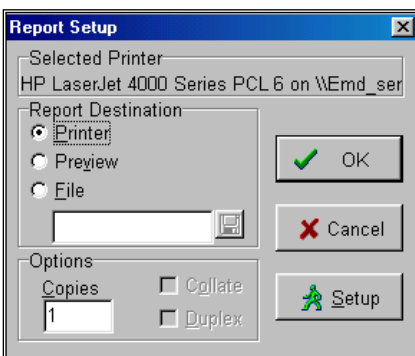
In the window shown above you can see how WindPRO lists all the relevant files for the export file. At this point, files can be deselected in order to reduce the export file size or to exclude information from the export file.

Simply expand the type of data and double-click on the file you want to select or deselect. Then click on "Export".

In addition to those files suggested by WindPRO, you can also add files into the export from the "Add file(s)" button (before exporting).

2.2.1.3 Printer Setup

By selecting the Print option you gain access to changing the printer settings, including the printer type. When defining the printer setup, the configuration will be stored as the default printer in WindPRO. However, you can always change the printer setup during printing by clicking on the Setup button. Printing functions will not be enabled for all parts of the program.



Note, that if you have Adobe Writer, and installed the PDF writer, you can let WindPRO print a complete report directly to a PDF file, ready to attach to an email or presentation on your web site. A PDF file can also be made directly from the WindPRO preview page from the "Save as" option.

2.2.2 Options

Options Feedback Updates Edit

- Options
- License activation
- Deactivate all modules
- Show activation statistics
- Show detailed module status
- Default directories
- Use project explorer

The menu item “Options” gives access to defining or changing a range of settings, which typically need to be set only once. This menu item is continuously updated as new functions are added.

If you don’t want to use the Project Explorer (see Section 2.3.1), you can deselect here.

2.2.2.1 Options – User Reference in printouts

Options

User | WAsP | Maps | Modules | Misc. | File dialogs | Report logo

Licensed to:
EMD International A/S
Niels Jernesvej 10
DK-9220 Aalborg Ø
+45 9635 4444

User name / E-mail address / Custom user ID	Show in reports
Per Nielsen *	<input checked="" type="checkbox"/>
pn@emd.dk *	<input checked="" type="checkbox"/>
Testing	<input type="checkbox"/>

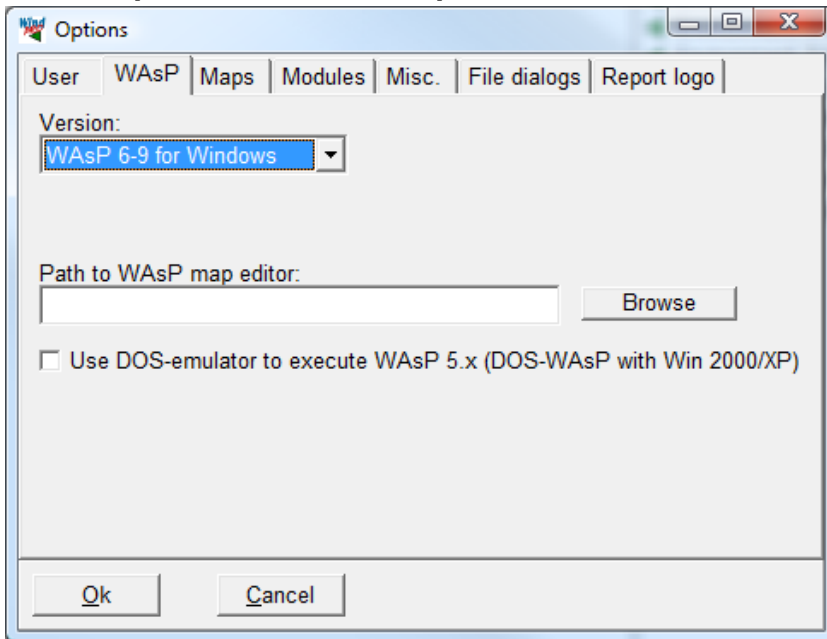
*) Read only, taken from the activation

Preview

Ok Cancel

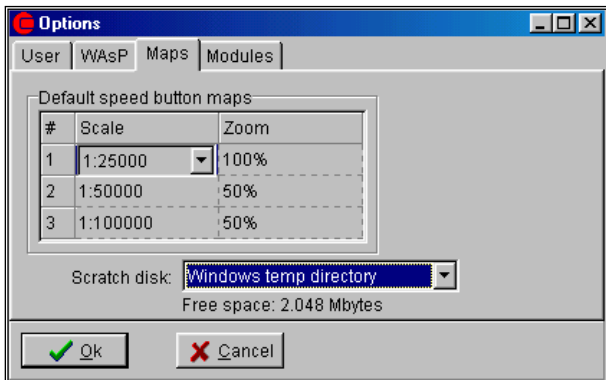
Here the name of the person and email address are from the activation (License) – it can be checked which lines shall be shown in reports. An additional line is available for e.g. department name.

2.2.2.2 Options – WAsP Setup



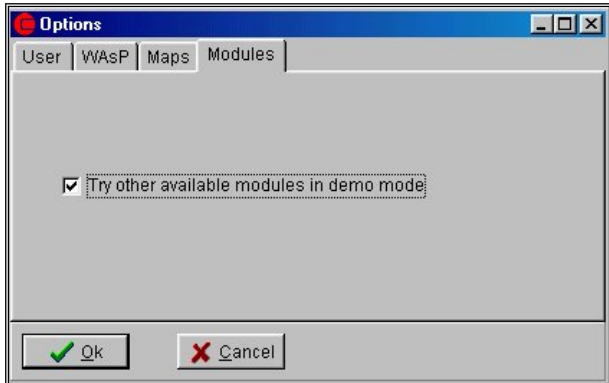
If the WAsP program from RISOE is used by one of the energy calculation modules, the version of the program and, if using the DOS version, also the path to the WAsP program, must be entered here. Note also that the WAsP Map editor (WAsP 7) can be configured for use (this is no longer relevant since the EMD editor now provides most of the functions available in the WAsP MAP editor and much more). In order to make sure that you have the correct interface between WindPRO and WAsP, see new releases on our web site www.emd.dk. New from version 2.5, is the DOS emulator that makes it possible to run DOS WAsP version 5 from Windows 2000 or XP.

2.2.2.3 Options – Maps



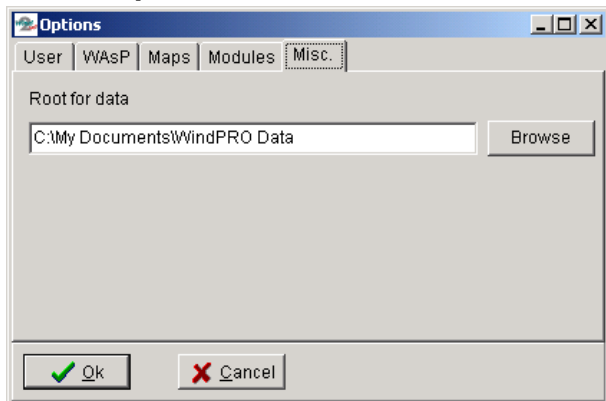
The default settings for the three map-reader shortcut icons are entered. This item is especially relevant when using maps from a CD-ROM, containing maps with different scales. The setup is also relevant with regard to the systematic use of .BMI files. The "#" symbol refers to the icon number. A click on icon #1 in the settings (shown above) will render the map in a scale of 1:25,000 with zoom 100%. A click on icon #2 will render the same area in a scale of 1:50,000 with zoom 50%, etc.

2.2.2.4 Options – Non-licensed modules in DEMO mode



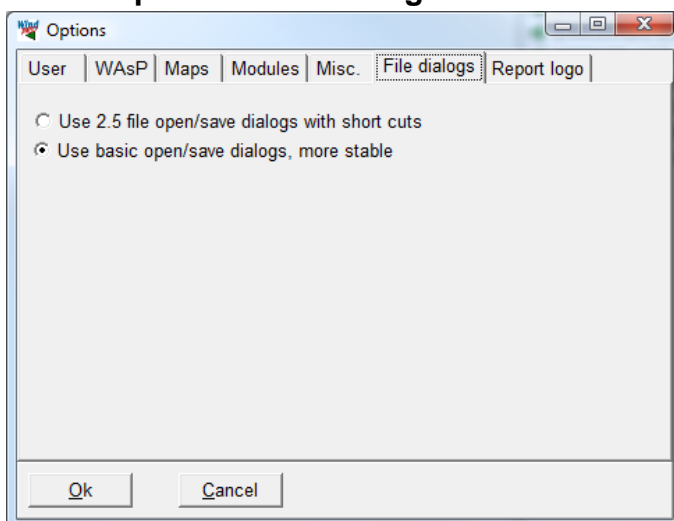
You can choose whether you wish to work with only those modules for which you have purchased a license, or if you wish also to have access to the DEMO versions of the other modules. The option of deselecting the DEMO modules has been included in order for you to get a better overview of your licensed modules when using WindPRO for specific purposes only, e.g. visualizations.

2.2.2.5 Options – Misc. Path for WindPRO Data



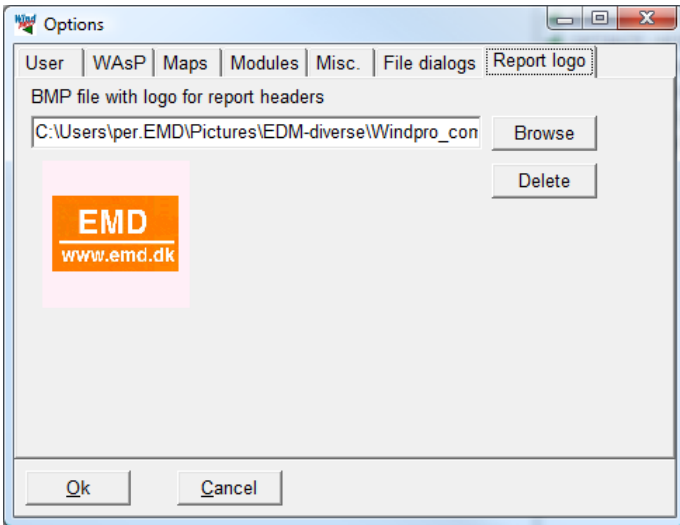
The root for your WindPRO data gives WindPRO information on where the default file location is for storing new projects, and where to search for projects, data etc.

2.2.2.6 Options – File dialogs



Older version had a more refined open/save dialog control, but with the more recent versions of Windows the needs for this seem no longer relevant, then it is better to get used to the Windows dialogue controls.

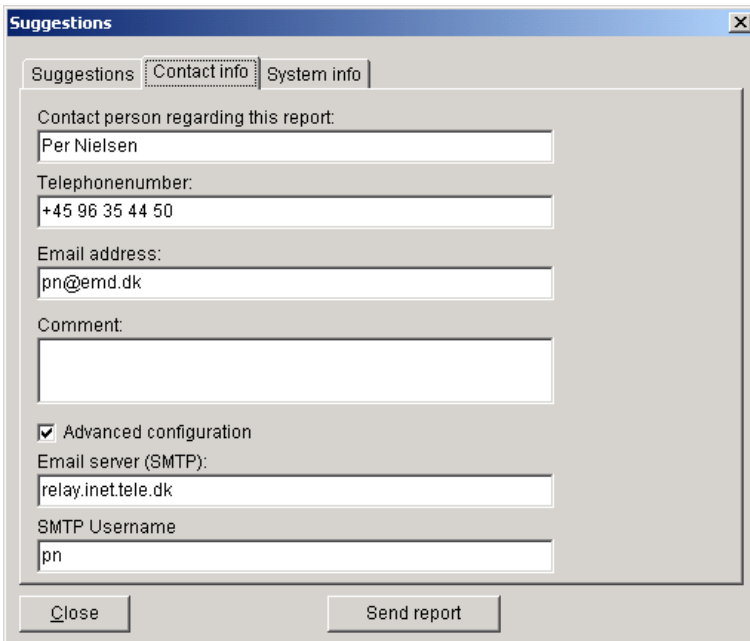
2.2.2.7 Options – Report logo



A company logo can be included which will appear on all reports.

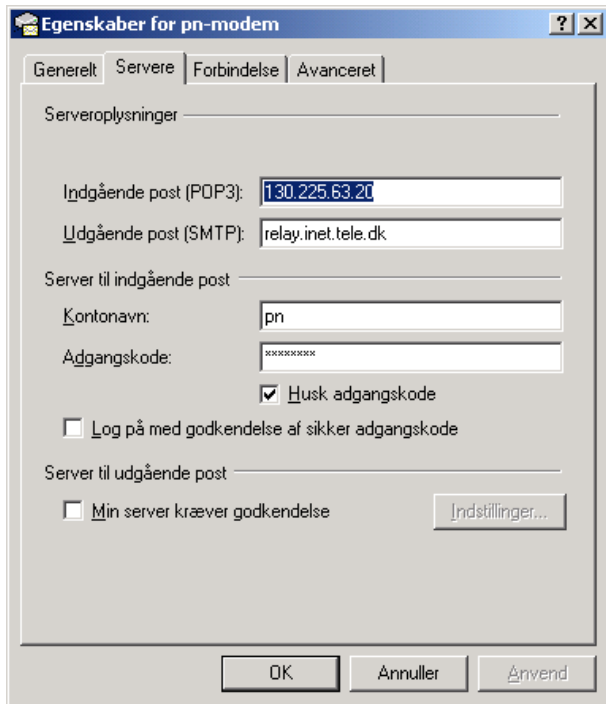
2.2.3 Feedback

The feedback option, gives us the chance to make WindPRO even better.



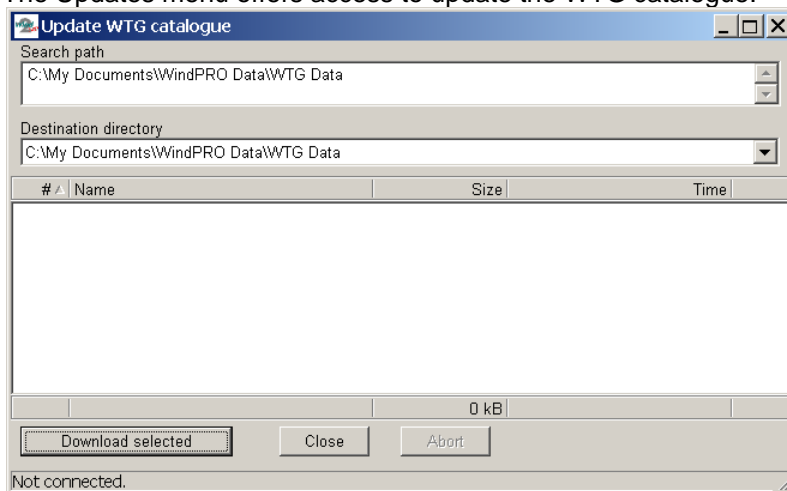
You can send suggestions as well as error reports. In both cases, when sending by email, you have to set up your server connection. This is done in the "Advanced configuration", where you have to find your email server (outgoing). This is found in your email software, e.g. in Outlook, in "Tools|Services" (or accounts in older Outlook versions). You find the server in "properties" (see the below example).

Note: If you don't have a permanent connection you have to connect before emailing.



2.2.4 Updates

The Updates menu offers access to update the WTG catalogue.

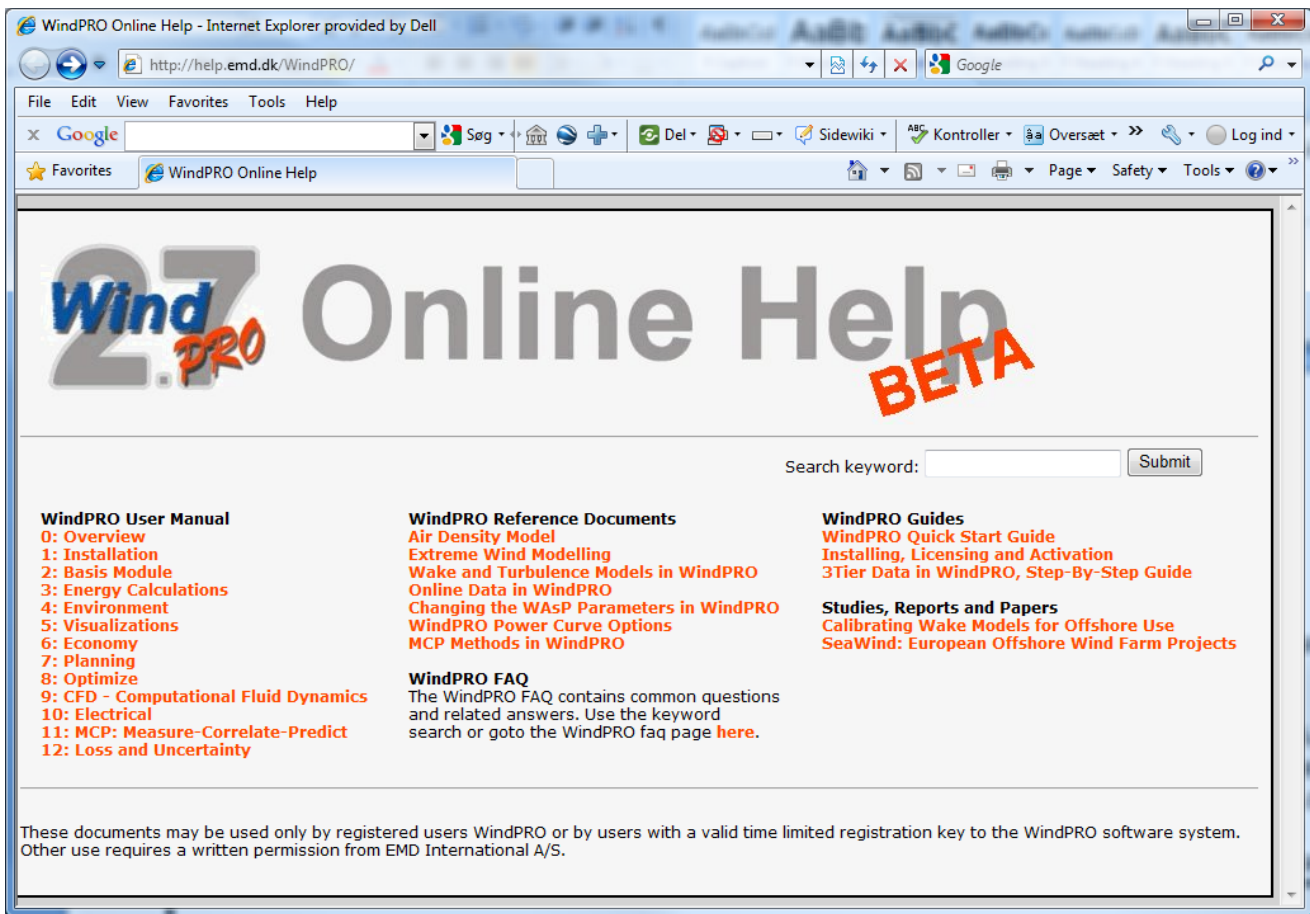


Specify the path for the WTG Data, normally directly below the WindPRO Data directory. Both the search path for existing data and destination directory can be set. Based upon the search path, WindPRO determines which new or updated WTGs will be available. The specific WTGs to be downloaded can be selected by pressing the “Download selected” button.

2.2.5 Help

The help system works like most other Windows help systems. Important to know is that by pressing the <F1> key from a specific menu, you should get the relevant help features for that specific menu/window (Context sensitive help). The build in help system is basically this manual for WindPRO.

The WindPRO Online help page, where typically the more advanced features are frequently updated based on latest research. The page can be opened from WindPRO menu “Help – FAQ (Internet)”:



A knowledge base is continuously expanded.

The “FAQ Internet” can only be accessed from the help menu in the WindPRO main screen. The two below mentioned can only be accessed from the help menu in Maps & Objects.

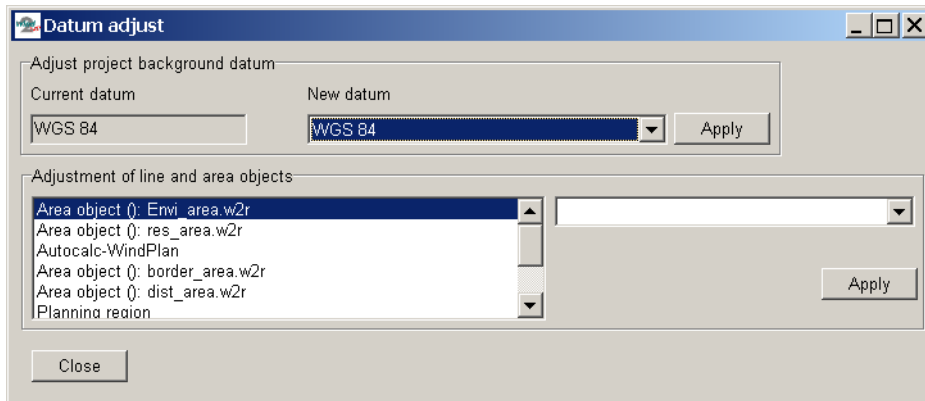
2.2.5.1 Error information dialogue

From the Help menu, you can recall the error information dialogue, which holds all recent error messages and warnings. This allows you to refer back to an error message you may have closed without reading.

2.2.5.2 Datum adjust

The Datum contains information about how the coordinate system “unfolds” the earth’s curvature. The formula for “unfolding” the earth onto a flat sheet is different at different places on the earth, partly due to differences in curvature, but also due to historical reasons, where different map makers preferred different formulas than the neighboring country, even though they may not necessarily have been better.

If you have worked with WindPRO and digitized your own contour lines, or areas, or imported them while working in one Datum, and later you realize that this Datum was incorrect, the Datum adjust menu provides you a way to change your line or area data to another datum (see menu below).

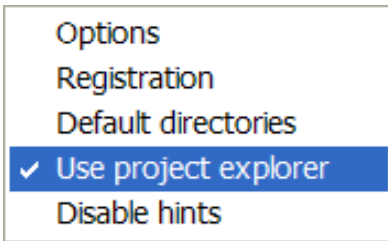


The first line is the complete project background datum you can adjust. In the lower part, you can individually adjust Datum for specific line or area data.

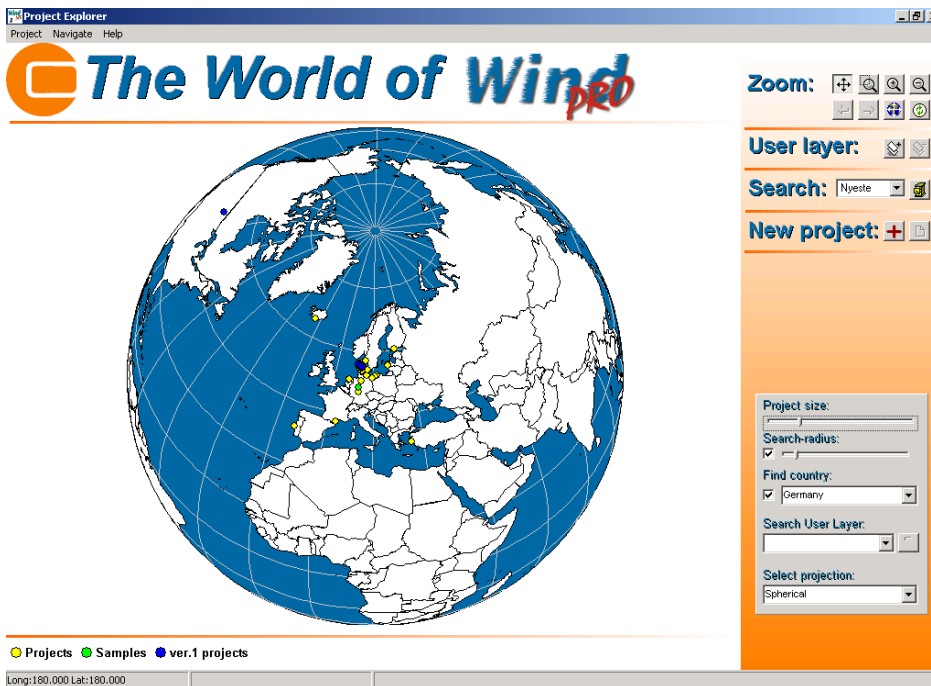
2.3 BASIS- Project Manager (Project Explorer)

2.3.1 Project Explorer – map and globe navigation

By default, the Project Explorer is enabled. From the WindPRO main menu, you can disable this feature if you prefer the ordinary Windows Explorer method of locating your projects. This is done from the main menu in options, see below. Here you can also enable the use of the Project Explorer.



Projects are opened from the Project Explorer by hovering” over a spot on the map, and then double-clicking on the relevant project in the drop down list, which will appear containing all projects located within the user-defined search radius.



The above figure shows the start-up desktop for WindPRO if the use of the Project Explorer is not deselected. The colored dots on the globe are the projects, which are in the search paths and accepted by possible filter settings (search profiles). At the bottom of the map, the actual search paths are shown. It is possible to assign different colors to each search path in order to better organize the project view.

Navigation on the map/globe is fairly intuitive; however, a detailed description of the tools is as follows:



The Zoom buttons



Click on the button in order to move the map/globe when holding down the left mouse button.



Click on the button in order to drag a square that is then zoomed.



The buttons zoom in given steps.



Back and forward. Remembers your "zoom history", so you can quickly return to a previous zoom.



Zoom to full extend gives you the entire globe.

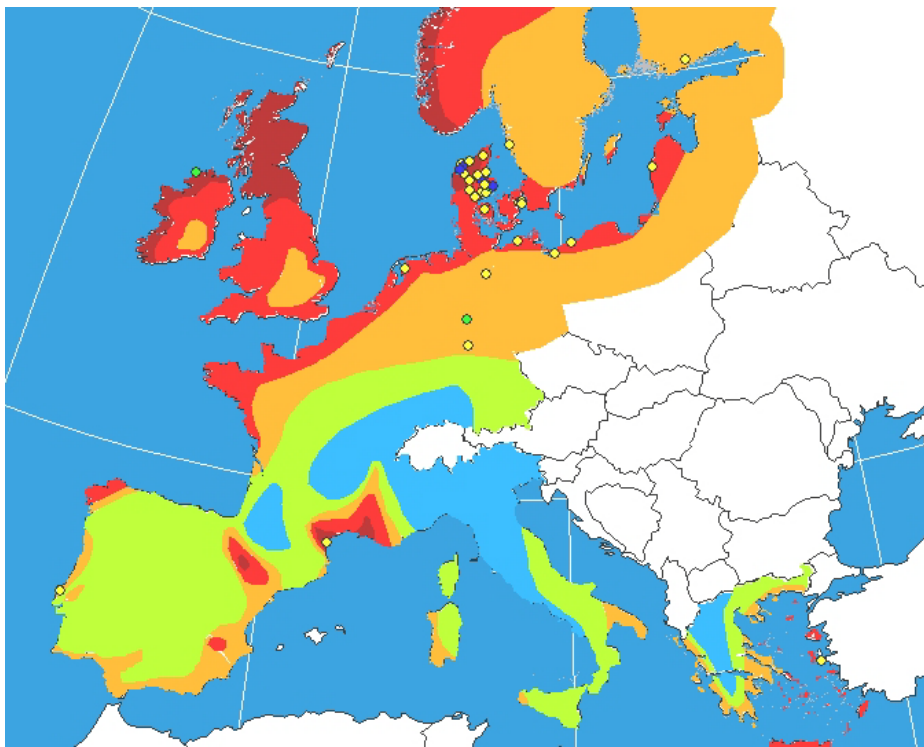


The refresh button refreshes your project list (colored dots on the map), if you e.g. copied some projects with the Windows Explorer into your Project Explorer search path or if connected to a server with additional projects.

User layer:



The "User layer" feature makes it possible to add a layer on top of the map/globe, which gives additional information e.g. roads or local administrative borders. The user layer must be a shape file (from Arc View GIS-system) where the coordinates are a geographic system (latitude/longitude). Some examples are enclosed in WindPRO Data\Globe\ and can be opened. These can provide a more precise background map and e.g. the State borders for the USA, the wind resource map from "European Wind Atlas" (see figure below), a detailed Wind Resource Map for Denmark, etc. See \WindPRO Data\Globe\ or add your own. NOTE: It's possible to search on data in the user layer (covered later).



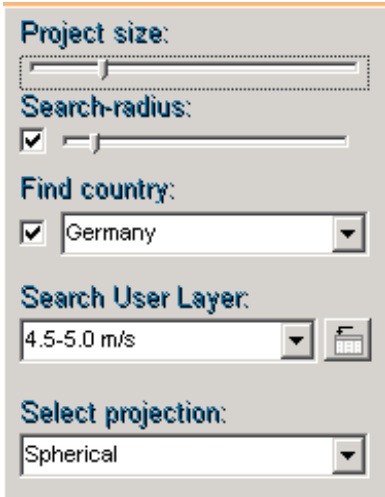
Search:



The search option gives access to the Project Explorer list, where search paths can be added (covered later), e.g. to show only projects within a given search path. An example could be "Changed during year 2001". When this search path is selected in a drop down box, only the projects fulfilling the search path criteria will be shown on the map.

New project:

With a click on the “New Project” cross hair, you will be able to mark a specific place for creating a new project. Coordinates and country will then be transferred to Project Properties (see later), when clicking on the right button “New Project”.



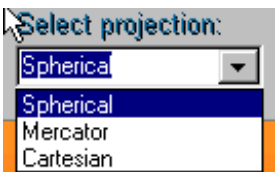
Project size adjusts the size of project dots on the map.

Search radius specifies the radius within which projects are found when "hovering" with the cursor over an area on the map.

Find country interacts with the map/globe. Click on a country that is shown in the list, and it's then highlighted on the map. You really have a brilliant tool for learning country geography as an extra benefit.

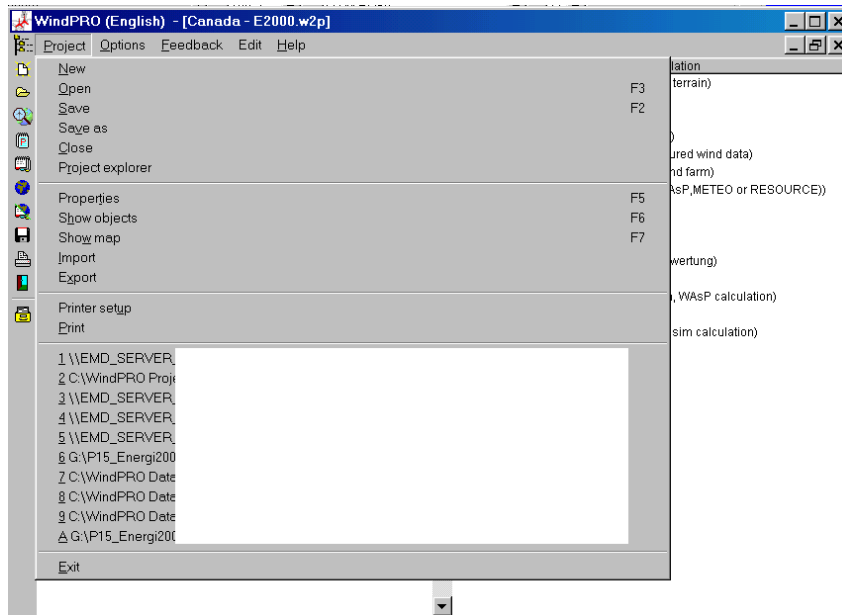
Search user layer gives the opportunity to search/show a user parameter from the user layer (shape file), if there is a database linked to the user layer (a .dbf file). The "data field button" to the right, gives access to select which field from the database to be shown in the “Search User Layer” field.

Projection – shows a map as a "round globe" or flattened out, see possibilities below.



The check boxes next to the search radius and country make it possible to disconnect these functions.

The upper left menu bar, also gives access to the project list and the same functions as in the tool panel in the right part of the screen. The last 10 opened projects can also be reopened from here.



2.3.2 WindPRO Explorer List

The WindPRO Explorer List will appear in following places:

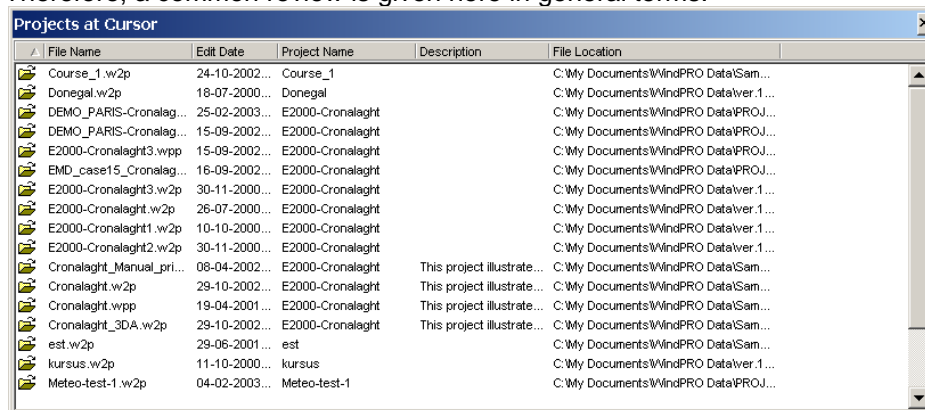
Project Explorer

WTG Catalogue

Wind Statistics

Address list (in a reduced form without search profiles and same search path as the Project Explorer).

Therefore, a common review is given here in general terms.



The WindPRO Explorer List consists of 2 important elements:

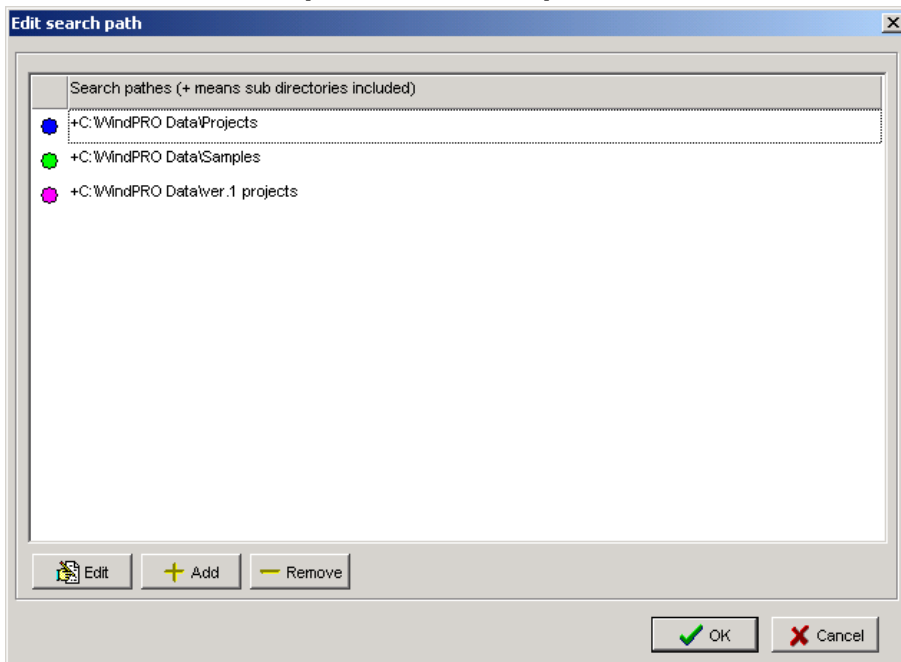
The search path setup - which specifies where to search for relevant files. This makes searching faster and makes it possible to organize projects in different ways, e.g. partly on a local disc and partly on a server version

The search profile - which is a filter to give a conditional view of files in order to find relevant files faster.

Different information on the files is shown in the list. The list can be sorted by clicking on the appropriate column heading.

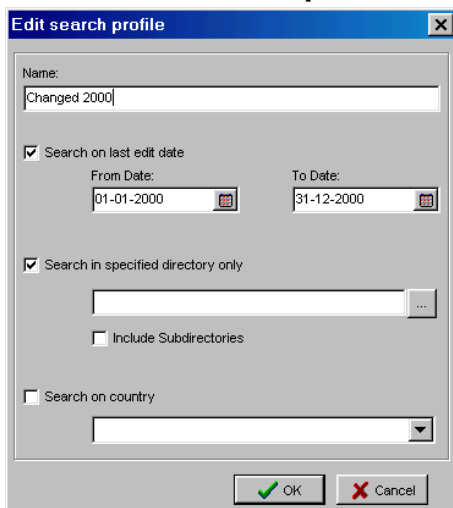
Double-clicking on a file in the list will open the project.

2.3.2.1 WindPRO Explorer – search path



Adding locations on the local disk(s) or network neighborhood gives access to the project you may want to see or work on, without searching through Giga bytes of files every time you open the software. When adding a new search path, a color can be specified which will determine how the file is shown on the map/globe.

2.3.2.2 WindPRO Explorer – search profile




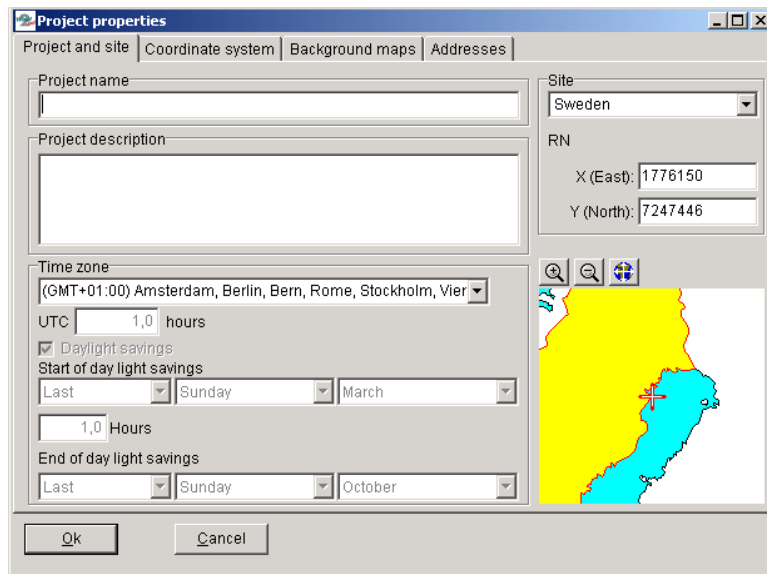
The search profile is individually designed depending on where in WindPRO the Explorer is used. The search profiles are a filter, which allows the user to limit the number of files to the ones fulfilling specific criteria in order to get an easy and fast search result of files, or to give an overview for certain presentations, e.g. sales meetings.

2.4 BASIS - Project Properties and attachment of Maps

2.4.0 Introduction to Project Properties (PP)

The term "Project Properties" is a generic term covering all information regarding site description, coordinate system, maps and addresses.

If you select "Project Properties", or if you click on the shortcut icon  or create a new project, the window for input of project information will pop up. Please see below:



2.4.1 PP Tab Sheet: Project and site

2.4.1.1 Project name and site description

A project name and a description of the project site and other information, which will appear on printouts, can be entered. Please note, that for each calculation performed, additional text relevant to the calculation can be entered. This means that the site description is the overall description of the site or general assumptions.

2.4.1.2 Site coordinates

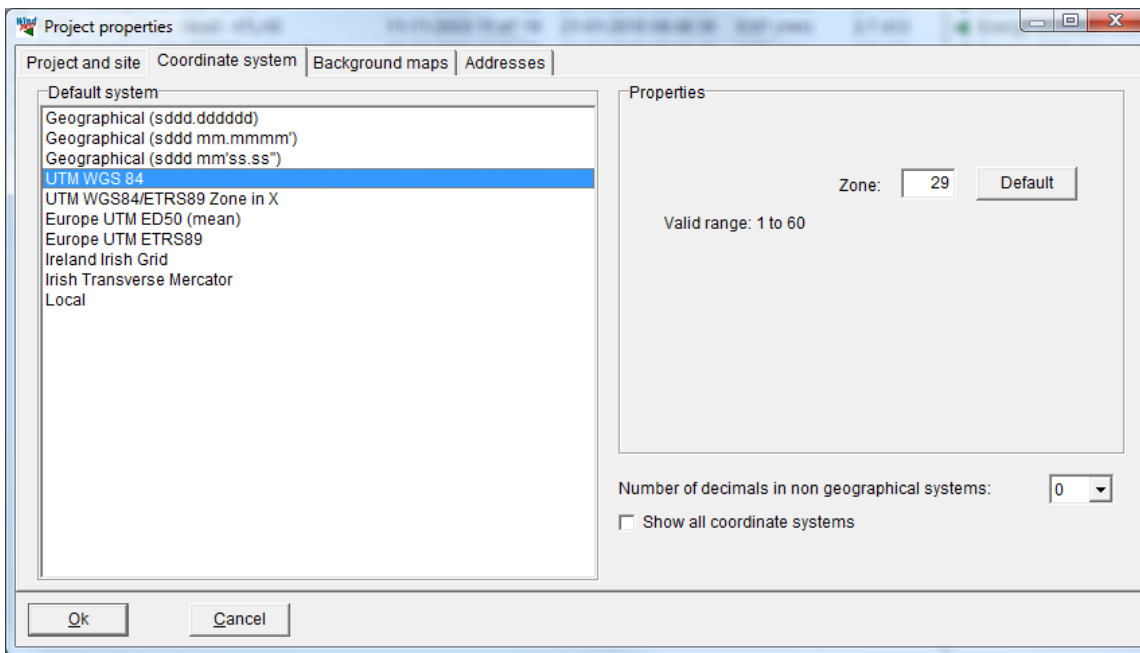
The preliminary site coordinates are entered here. If you have created a new project from the Project Explorer, site coordinates will already be filled in with approximate coordinates. The site coordinates (site center) will later appear on the map as an orange crosshair and can be adjusted. The site center will be centered on the screen when opening maps later in the project design phase.

2.4.1.3 Time zone

Selecting the correct time zone is important in order to perform a correct shadow flicker calculation or photo-montage. WindPRO will aid you in the right choice showing major cities in the different time zones.

2.4.2 PP Tab Sheet: Coordinate System

Move on to the Tab Sheet with coordinate system information by clicking on the relevant tab sheet.



On this page you can select which coordinate system you wish to work with. If you have created a new project from the Project Explorer (see Section 2.3.1), a default coordinate system and zone will automatically be provided, based on the country and the location. It's important that you select the system which matches the scanned maps you will be using.

On standard maps (paper) the coordinate system used is printed. Almost all maps will contain a latitude - longitude (lat/long) grid. Therefore this system can always be used. However, the system (degrees, minutes and seconds) is inconvenient to work with and makes measurements, conversions, checks, etc. a tiresome task. If the information is also available in a metric system, this system should be used.

Number of decimals on coordinates can be chosen to 0, 1 or 2.

The coordinate systems shown can be filtered, so only the most relevant ones for the project country are shown – or you can check “show all coordinate systems”.

2.4.2.1 The UTM System

The UTM system is used worldwide, and is often printed on the map material.

The earth is divided into 60 zones as defined in the figures below. Each UTM zone has an east-west width of 6 degrees. The median line of a 6 degree section has, by definition, the value of 500,000 meters. The widest part of a section (approximately 667 000 m) is at the Equator, (the Earth's circumference of 40,000,000 m / 60 sections). The x-coordinate value (Easting) thus lies between 167,000 and 834,000 meters, and is always positive.

In the northern hemisphere, the y-coordinate (Northing) equals the distance to the Equator. In the southern hemisphere, the y-coordinate equals 20,000,000 meters minus the distance to the Equator. This means that 1 km south of equator, the y-coordinate is 19,999,000.

The UTM South system is used more commonly, where the y-coordinate is 10,000,000 minus the distance to the Equator. In this case, 1 km south of the Equator, the y-coordinate is 9,999,000.

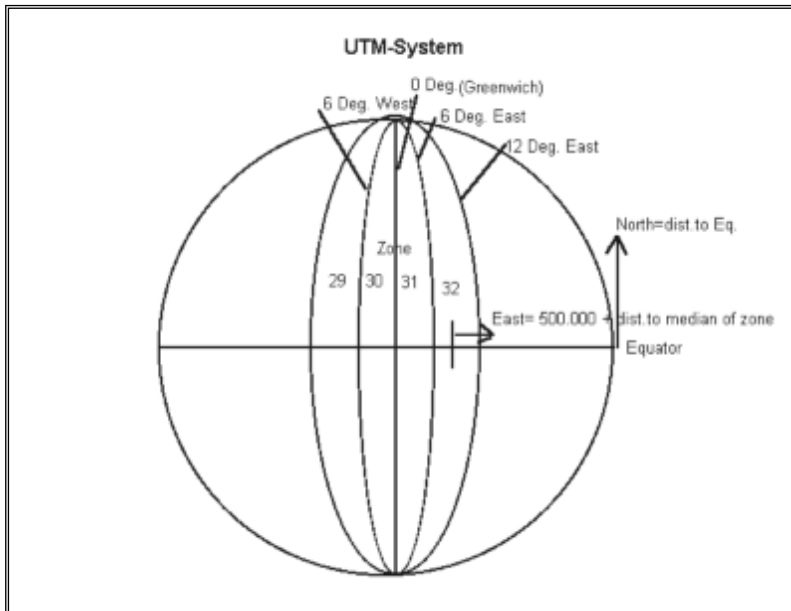
The DATUM of the UTM system indicates how much the globe differs from being exactly round (the Datum refers to the set of “unfolding” algorithms used to change the curved surface of the globe into a flat map, often referred to as the Ellipsoid). Several different DATUM'S are used in different parts of the world, but more and more countries are changing to the WGS 84 also named euref 84 in the EU.

Common Datum's used with UTM coordinate system:

WGS 84 = World Geographic System, the "New" world standard since 1984.
 ED 50 = European Datum since 1950 = Hayfort
 NAD = North American Datum (More variants)
 SAD = South American Datum

Overview of Longitudes and UTM-zones

Western longitude (West of Greenwich)			Eastern longitude (East of Greenwich)		
From	To	UTM-Zone	From	To	UTM-Zone
180	174	1	0	6	31
174	168	2	6	12	32
168	162	3	12	18	33
162	156	4	18	24	34
156	150	5	24	30	35
150	144	6	30	36	36
144	138	7	36	42	37
138	132	8	42	48	38
132	126	9	48	54	39
126	120	10	54	60	40
120	114	11	60	66	41
114	108	12	66	72	42
108	102	13	72	78	43
102	96	14	78	84	44
96	90	15	84	90	45
90	84	16	90	96	46
84	78	17	96	102	47
78	72	18	102	108	48
72	66	19	108	114	49
66	60	20	114	120	50
60	54	21	120	126	51
54	48	22	126	132	52
48	42	23	132	138	53
42	36	24	138	144	54
36	30	25	144	150	55
30	24	26	150	156	56
24	18	27	156	162	57
18	12	28	162	168	58
12	6	29	168	174	59
6	0	30	174	180	60



2.4.2.2 Other metric systems

Also, many countries have defined their own systems, which are being used instead of the UTM system. In Denmark, the System 34 is used. In Germany it's the Gauss Krüger system, and in Great Britain it's the British National Grid that is used. The list of which coordinate systems WindPRO recognizes will be updated continuously.

The British National Grid calculates with two different Ellipsoids (Datums); the AIRY and the GRS80. The British Ordnance Survey has informed us that all British maps use the AIRY Ellipsoid. The British National Grid has its origin at Lat. 49 N and Long. 2 W.

If the system you are currently working with is not included in the WindPRO list, you can define your own local system, and indicate (0,0) as the bottom left corner of the project area.

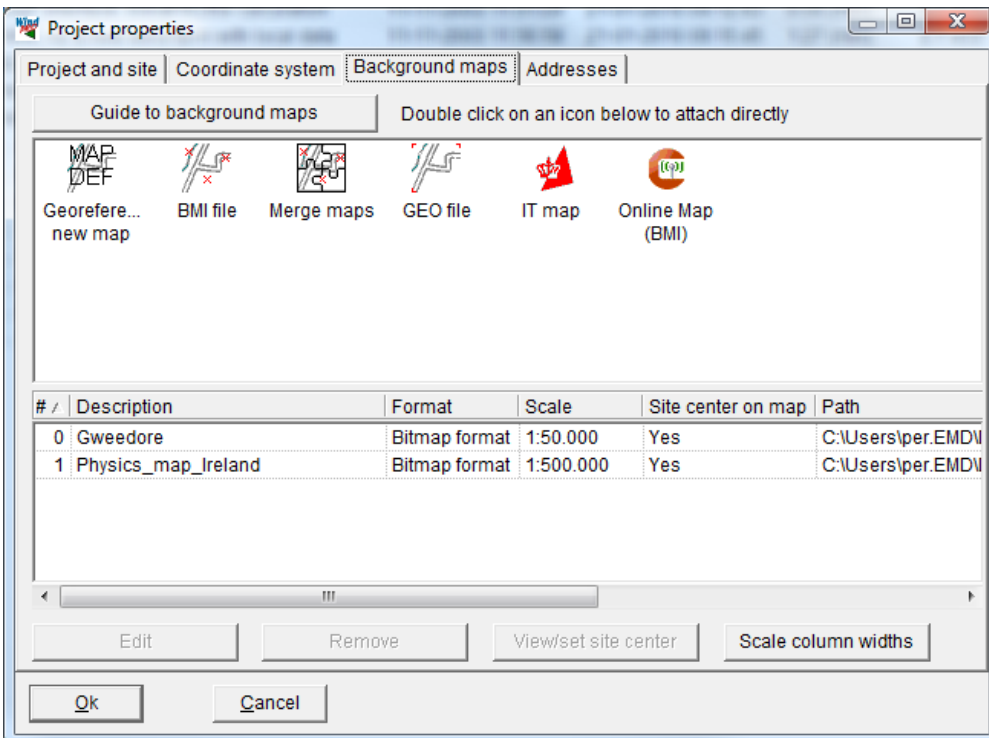
If the "Local System" is selected, you have to enter 1-3 reference points for the local system, in a coordinate system which is recognized by WindPRO in order for it to be able to calculate the exact geographic position. Several of the calculation modules and most printouts use the geographic position. Lastly, you can enter deviation data if the system used calculates with an angular deviation to geographic (true) north. This deviation is often indicated on the map material (if only at one fixed point).

One of the advantages of using a local system is that you can work with small coordinate values instead of the 6 and 7 digit coordinate values used by other systems. Another advantage is that you can continue to work with client information when you receive information from a client in his local system which he would like to see applied, e.g. in layouts.

Please notice, that your choice of coordinate system determines the system in which you can enter coordinate information. However, you can always change the system during your work and let WindPRO handle the conversion. Coordinates already entered will automatically be converted to the new system, as all coordinates are stored internally as latitude/longitude degree values. This means, that you can enter different information in different coordinate systems, e.g. wind turbine positions in the UTM system from GPS measurements and information from local authorities regarding existing populated areas (for noise calculation) in the latitude/longitude system.

2.4.3 PP Tab Sheet: Background maps

In the Tab Sheet "Background maps", link to maps and the preliminary site coordinates (site center) can be entered. This data can be adjusted later on during the project design work.



There are more ways to attach background maps:

Use MAPDEF for defining scanned maps from scratch or for stitching additional maps that already contain coordinate information (GEO Tiff maps).

BMI files (WindPRO's internal background map format), that holds information on geo-referencing and coordinate system.

Merge maps is a function where you can open a number of .bmi files and the software will automatically merge these into one map in the screen view. Note: all maps must have same resolution (pixels/m).

IT map format (DK only so far)

GEO refers to geo-referenced "world file format" which is two files, an image file and a coordinate specification file, like .JPG and .JWG files or .TIF and .TWF files can be attached just by pointing out the location of the formatted map file(s).

Online maps is a new service (from WindPRO 2.6) giving the user access to download background maps from EMD server.

2.4.3.1 Relevant background maps

As previously mentioned, maps make the project design work much easier. The maps used in WindPRO are primarily bitmap background maps, which show populated areas, roads, forests and other objects that you need to take into consideration when planning the project layout. Digital orography maps (Height Contour Lines) or roughness maps are described in Chapter 8, Line Object.

You choose the maps according to your kind of work. As a guideline, the following map scales are recommended:

1:10,000 For very accurate positioning of turbines and measuring distances for noise calculations. Possibly with landowner boundaries for planning consent work

1:25,000 Normal scale for positioning of turbines, definition of local obstacles, input of orography, measuring distances for noise calculations and entering check points for visualization.

1:50,000 Suitable for roughness classification within the nearest 5-10 km of the site.

1:100,000 Used for roughness classification between 10-20 km from the site.

If you scan the maps yourself, a combination of 1:25,000 and 1:100,000 will probably be a reasonable compromise between time consumption and usefulness.

The link to the maps function is an option - not a requirement for carrying out calculations under WindPRO. However, this option should be used whenever possible, as it's this function, which makes WindPRO unique, compared with other software - including the earlier calculation tools from EMD.

You can connect a map to WindPRO in more different ways, where new options will appear in future. The present ones in version 2.4 are:

A CD-ROM map in a format, which is recognized by WindPRO

Maps, which are bitmap graphics, scanned or cut from a CD-ROM and subsequently defined with 3, coordinate points in WindPRO

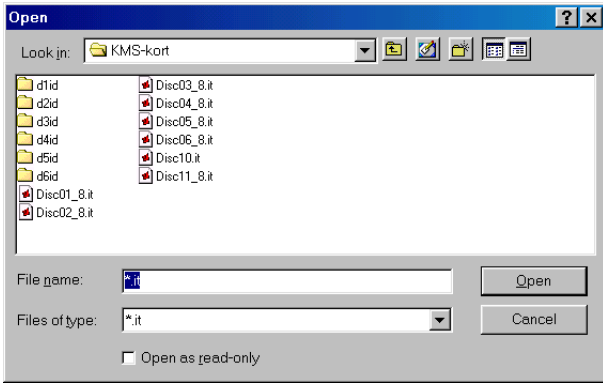
Geo-TIFF maps which mean that they consist of a graphic/bitmap *.TIF file + a *.TFW file, having the coordinate information

2.4.3.2 CD-ROM maps recognized by WindPRO

This option is the easiest one as the coordinates are already associated to the map and a complete reader for this format is included.



Double-click on the icon above and point out the location of your *.IT maps. The IT format is the format used by the Danish Kort- og Matrikelstyrelsen (the Danish Ordinance Survey).



If the IT format is selected, a click on the file list button [Browse] will invoke the Windows standard file browser. Here, you can browse to find the needed file (refer to the Windows manual for help regarding the use of the file browser), click on the needed file and then choose "Open" (or double-click on the file name) to attach the map to the project.

It's optional to enter an individual description of the map file, but it may be of great help to you when having to relocate the map file on a CD-ROM when you are editing a project at a later stage.

It's now possible to select the site center from the attached IT map. Click on the attached map and then on the View/set site center button just below. This will invoke the following map:



You can move the map around on the screen by holding down the left mouse button. A click with the left button on the map creates a red cross. If the position is wrong, you simply click on a new position. Please notice, that you must not move the mouse when you are going to mark a position. If the mouse is moving when you click it, the program will interpret it as a command to move the map around instead. In the above example, a preliminary position has been marked at the port of Ebeltoft.

Now click the "Scale+" icon in the upper left corner. Depending on which CD-ROM you is linked to, a more detailed map appears.

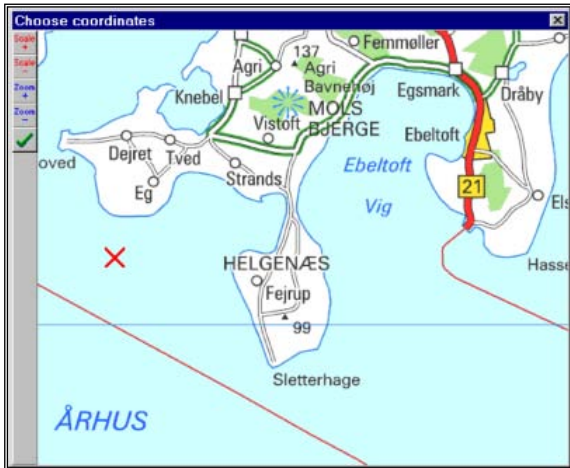


Figure 1 Increase the resolution of the site coordinates by using a smaller map scale.

The new map shows that the initial position was not marked on the exact site center. A new "cross" is therefore marked with a click. You can still drag the map around to get the correct area inside the window frame.

You can continue to zoom to more detailed map scales (depends on the present map material) if a further refinement of your preliminary site coordinates is needed. The coordinates chosen will be used to define the site center on all of the detailed maps you are going to use later on during the project design work.

More maps can be added, e.g. a scanned map with landowner boundaries. However, such map would need to be calibrated and have coordinates attached (see the next chapter).



Click on the "OK" bitmap button to exit the map. Now, all the general project information is entered and the project design work can begin.

2.4.3.3 Calibration of bitmap maps with MAPDEF

Bitmap files can be scanned or digital images of maps, where you subsequently have to make a coordinate calibration. MAPDEF is used for the Geo TIFF maps, where the TFW file holds the coordinate information. It's also used for stitching additional maps together, rotating, cutting etc.



Double-click on the icon MAPDEF in order to start processing one or more new maps for the project.

How to process (Geo-reference, cut, rotate etc.) a bitmap map in WindPRO is explained below. Apart from the main items described here, a range of other functions are available, e.g. adjustment of brightness and colors. Also the color resolution or map size can be reduced so that it occupies less space on the hard disk and is faster to use (requires less RAM). It should be noted however, that the quality (sharpness) of the map is reduced as well.

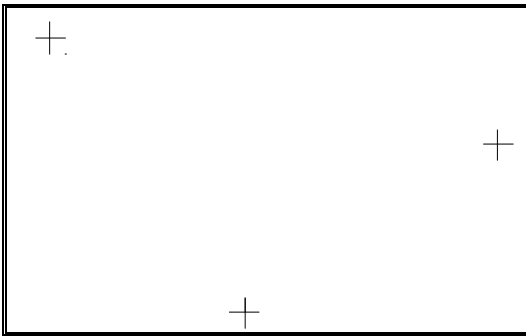
Using a bitmap image without coordinate information

Scan the needed map sections, or cut from a CD-ROM.

Select the bitmap map containing the map sections.

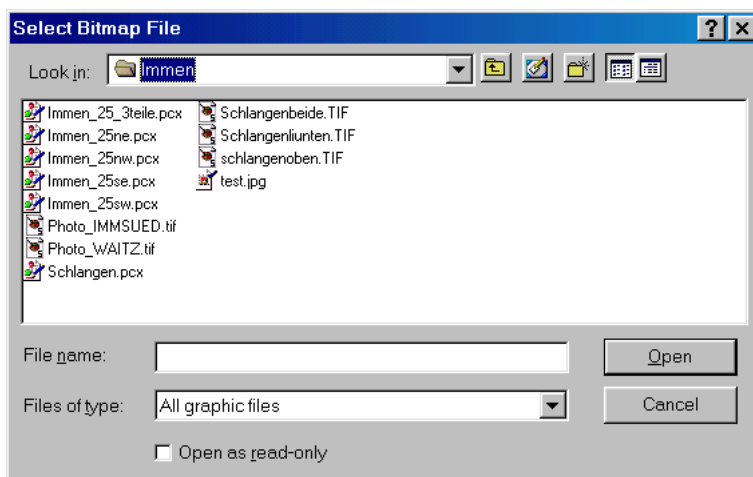
Rotate the map so that it's aligned with north (pointing up).

Mark three points and enter their coordinates. An example of positioning of the points you use for the calibration of a bitmap to a .BMI file is shown on the below sketch.

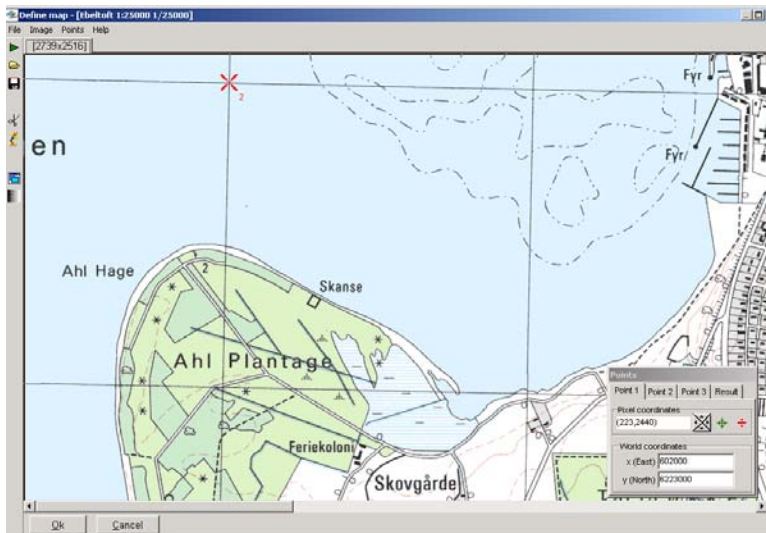


Repeat step 1-4 until three coordinates have defined each map section.
 Orient the maps so they are correctly rotated for merging (combining the maps).
 Cut eventually the edges of the map sections. Note map 1 (first attached) is at the bottom, which means that no cutting is needed for this one.
 Save the .BMI map.

Use a scanner resolution of 100-150 dpi and 256 colors. The preferred bitmap format is .PCX, although most other formats will also work. Make sure to include the edges of the maps in the scanning process, as they usually hold the grid coordinates. Please notice that the user has the full responsibility of not violating any copyrights! Save the maps in folders that you use for this purpose only, or in the WindPRO project folder with the local project.



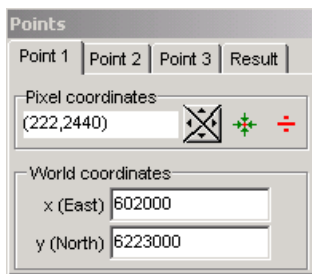
When "MAPDEF" is called, you have to select which map file(s) to add (more than one map can be added at a time). The file browser is used for this.



Once the first map segment has been scanned, the map is aligned with north and any necessary adjustments of colors and size are made. Note from ver 2.5 a color adjustment proposal will appear by default. This gives different reduction options with a preview option so you can decide which choices don't distort the map colors (which depends on the graphic image format). Hereafter, the definition of positions is made.

Try to avoid rotating the maps in steps other than $\pm 90^\circ$ and 180° . If the maps are rotated in other steps, the appearance on the screen will become distorted - text especially appears very unclear. The program will always keep track of north - providing that the coordinates have been entered correctly. BUT, if more maps are stitched together, a full horizontal or vertical edge might be needed in order to stitch without blank triangles.

The positions are marked by clicking on the positions on the map where coordinates can be read or obtained. Make sure to place the three defining coordinate sets as far away from each other as possible in order to be able to maximize the accuracy of the definition. When you mark the first point, you have to tell the program which coordinate system you are going to use. The coordinate system is usually printed on the map.



The four arrows indicate a fine adjustment of the pixel coordinates if e.g. an intersection between two gridlines hasn't been pointed out precisely enough.



The menu for entering positions enables you to center the map around the actual point (or to get it inside the area which is rendered on the screen).



If a position is incorrect (or too poorly positioned) it can be deleted.

The last Tab Sheet to the right in the menu box for entering positions is "Result". This window indicates the correlation between the entered coordinates and the pixel coordinates. One position is calculated based on the two other positions and the deviation is checked. The deviation is categorized into:

Fine

Not precise, but acceptable

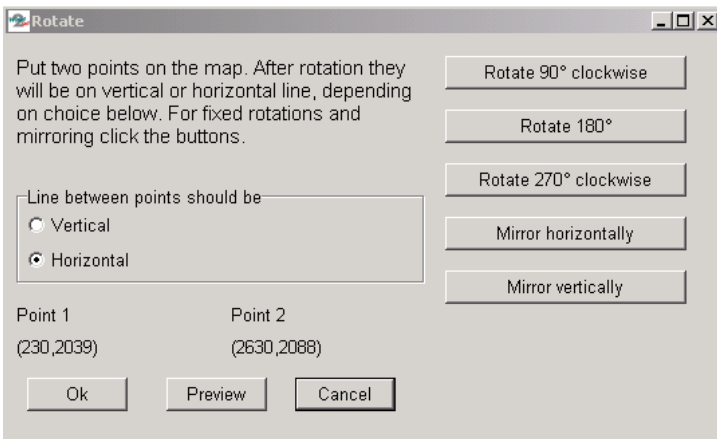
Not acceptable

The third category result indicates that you have to look for possible errors or redo the definition. Note: The levels of acceptance can be defined manually in the “points | options” menu.

You add more maps by clicking on the green arrow in the upper left corner of the window (repeat the previous actions 1-4). Please notice that this menu item is used to add maps that are to be merged to the previous map(s). Different map scales or map types are created as new maps.



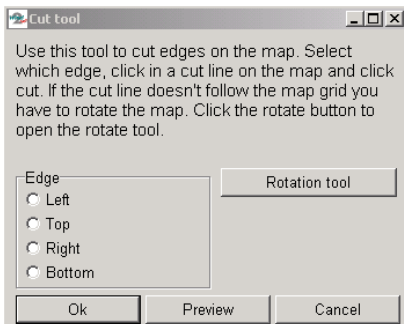
You align two maps by clicking on the icon with the two rotating maps.



When you click on the icon, the dialogue box shown above will appear. On the first map you can define a certain line as the horizontal or vertical line by clicking on two points on the map (e.g. two points on a grid line) or perform fixed rotations. The program rotates all the additional maps so they are aligned with the first map - this function is based purely on the coordinate definitions, which you have entered. After having created new maps, the individual maps should be checked visually for possible errors, i.e. incorrect orientation. A misaligned map holds incorrect coordinate definitions, which must be corrected. Then the map should be realigned.



Map collars, borders, etc. can be removed by using the cutting tool. When you click on the scissors the dialogue box shown below will appear.



Choose which side of the map to cut then click on the map to indicate where you want the cut line to be and then click on “OK”. It’s also possible to mark cuts off of all four sides before clicking on “OK”.

You save the map by clicking on the “OK” button. When you save the map it’s added to the list of maps that WindPRO can use in the actual project. The map is saved as a .BMI file which holds the coordinate information



and file names for the new adjusted graphic files which are saved as .PXC files designated as .B0, .B1, .B2, etc. At this point, the original graphic files can be deleted to save disk space.

Once the .BMI file has been defined and linked to the project, you can define the site center coordinates on the map (for details see section 2.4.3.5 describing “view/set site center”).

2.4.3.4 GEO “world file” maps.

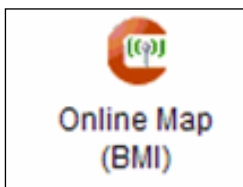


Double-click on GEO file to add one or more georeferenced world files, that can be .JPG and .JWG files or .TIF and TFW files. Simply select the file(s) in the list. Only the image files (.JPG or .TIF) files will be shown in the browser by default.

	O46096G6.TIF	2.500 KB	ACDSee TIF Image
	O46096G7.TFW	1 KB	TFW File

A small .TFW file holding the coordinate information must be available together with the main .TIF file holding the bitmap. WindPRO performs geo-referencing based on the .TFW file and the number of horizontal and vertical pixels in the .TIF file (so don't change the pixel size of the .TIF file without changing the info in the .TFW file!) However, it can be a good solution to change both the .TIF file and the .TFW file if the .TIF file is very large and far too detailed). Make sure that the .TFW file is stored in same folder as the .TIFF file. Please notice that the .TFW file does not hold any information on coordinate system or datum. This must be known and given as input.

2.4.3.5 EMD Online maps



Online maps are a new service that gives the user access to download background maps from EMD server. It will automatically be detected which map sources that are available for the site location. EMD will develop the service continuously and add more and more sources.

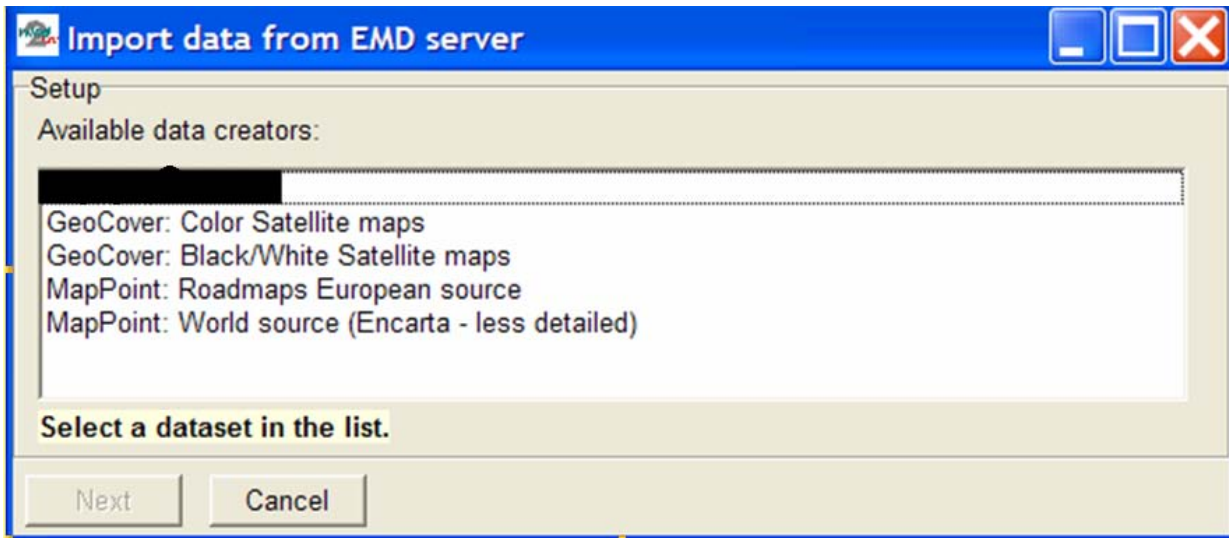


Figure 2 The online service detects which maps there are available around the location of the specified project site.

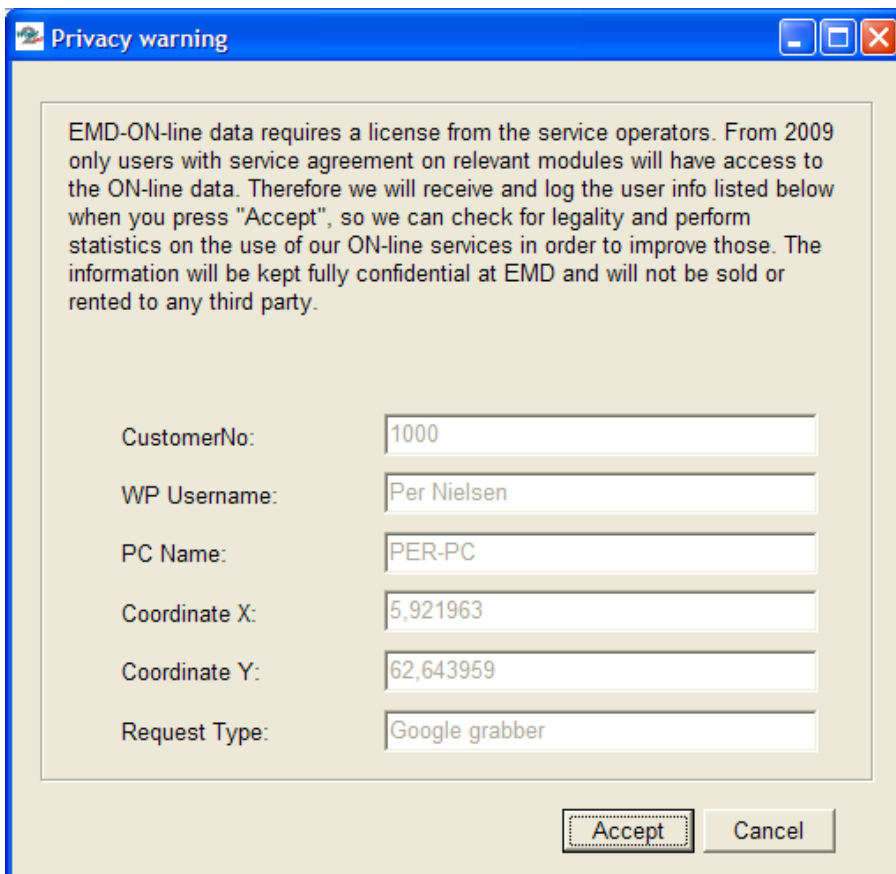


Figure 3 The service requires you to accept this "privacy warning".

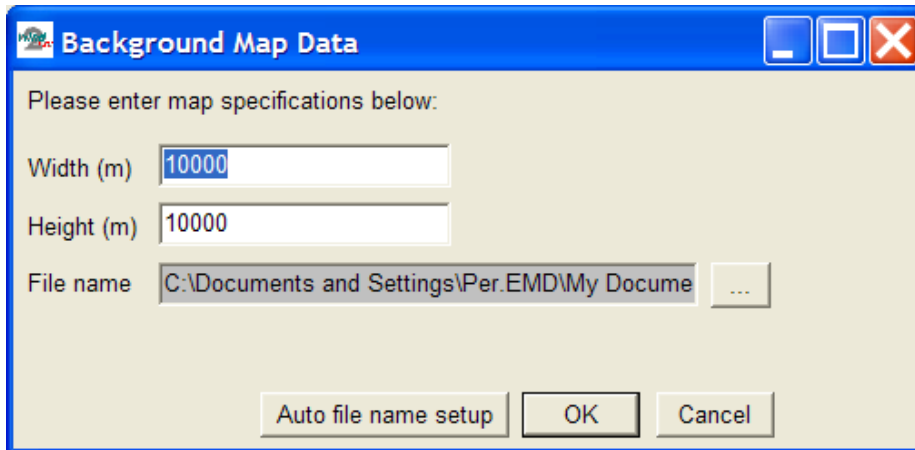


Figure 4 After selecting the source, you can specify width and height of map. The resolution will typically be automatically set to give a reasonably small file size that can be downloaded immediately, usually within a minute or so, depending on the speed of your internet connection. For some data sources you can choose resolution.

The ON-line map is added to the list as .BMI files, the internal WindPRO background map format.

2.4.3.6 View and set site center

When you click on one of the attached maps and then on the View/set site center button shown below,

#	Description	Format	Scale	Site center on map	Path
0	Ebeltoft 1:25000	Bitmap format	1:25.000	Yes	C:\WindPRO Data\Sar
1	Ebeltoft 1:500.000	Bitmap format	1:500.000	Yes	C:\WindPRO Data\Sar
2	Bitmap map: Ebe50k...	Bitmap format	1:50.000	Yes	C:\WindPRO Data\Sar

Buttons: Edit, Remove, View/set site center, Scale column widths

either the map will appear, or a square on the globe showing you that your site center is outside of the defined map (see below). If the site center is outside the defined map, either move site center or redo the geo-reference.

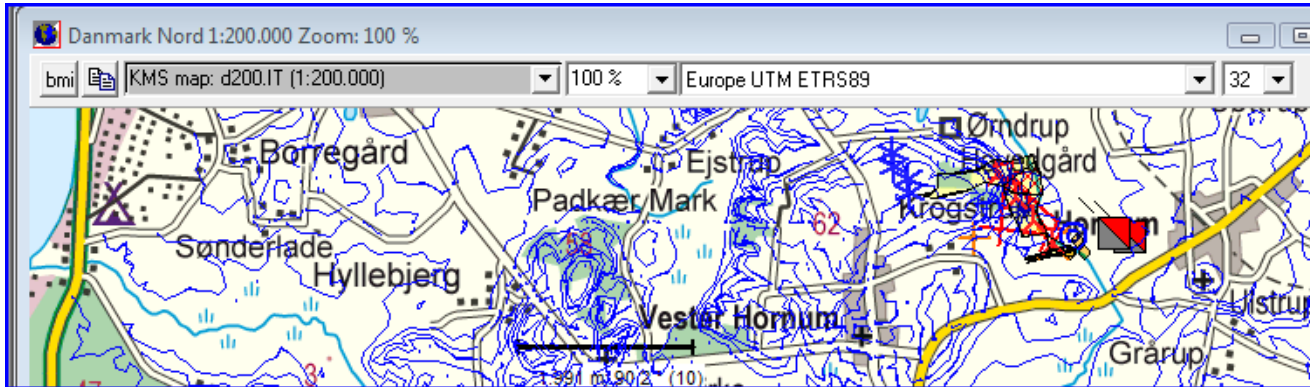


In the example shown above, the squares show the locations of the attached maps on the globe and the red cross shows the present location of the site center. The red line points to the center of the map that you are currently trying to view. To move site center inside the map, simply click inside the red square.

2.4.3.7 Blank map

If no maps are available, you can still enter objects graphically by using a blank map, which is simply a white background that is automatically scaled to your project design area. A blank map appears automatically if there are no other maps defined.

2.4.3.8 Some map window features



In the top bar of the map window, you'll find two buttons to the left.

First one creates a .bmi file (WindPRO's native background map format). This .BMI file is then including "what you see" on the map, like objects etc. The map is immediate loaded after pressing the button. If you have a large wind resource map file or detailed water depth map, that takes long time to render, it can be efficient to have a "hard copy" where you save the render waiting time.

Second one simply copy the map to clipboard, for pasting into like Word for documentation reports.

The zoom as well as the coordinate system and coordinate zone can at any time be changed by the drop down boxes. Zoom can also be changed by scroll button on mouse. Coordinate system choices can be limited to the country relevant ones to "reduce confusion". EMD maintain a list that pairs countries and coordinate systems.

2.4.3.9 Where to find other maps on the Internet?

In the USA, maps can be downloaded as zipped *.DRG files. They are either free or can be purchased for a relatively small fee.

Try these Internet locations:

www.mapmart.com

<http://data.geocomm.com/dem/demdownload.html>

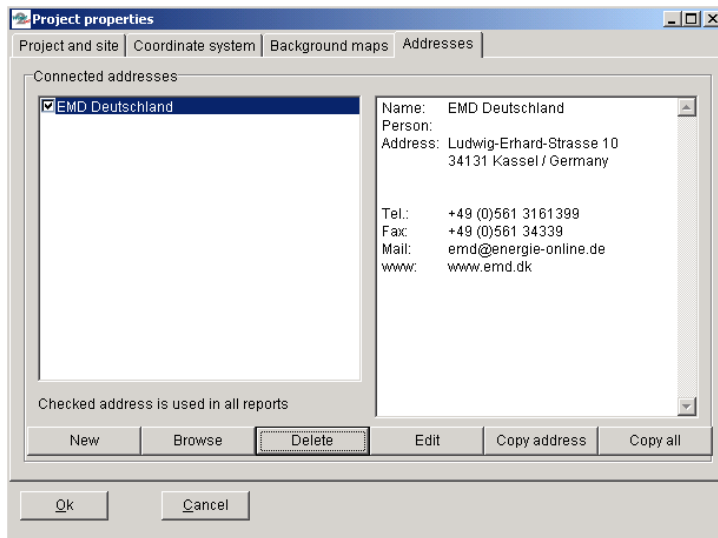
After downloading, the unzipped files can be attached to the WindPRO project as described in section 2.4.3.4. Please notice that the world map files already are georeferenced and thereby easier to use.

In Europe, a site with links (mainly for commercial map products) is:

<http://www.eurogeographics.org/gddd/INDEX.HTM>

2.4.4 PP Tab Sheet: Addresses

In the Address Tab Sheet shown below, you enter the address of the relevant customer, the electricity company, the county, etc. You can check one of the addresses, which means that this address will be printed on all printouts.



The buttons are as follow:

New: Create a new address.

Browse: Look in the list of addresses used in previous projects in order to use a previously typed address. See section 2.4.4.1 for further details.

Delete: Remove the highlighted address from the project.

Edit: Edit the highlighted address.

Copy address: Copy name, person and address to the clipboard in order to paste them into a text document e.g. a letter, a fax or an address label to send with the calculation reports.

Copy all: Copy all fields in the address record to clipboard

Besides the fields shown in the above screen, you have some additional "user-fields" in which you can add project status, costumer number referring to other costumer databank, more telephone numbers, contact persons, etc. All fields are shown below. The field lengths are practically unlimited, but remember that if you wish to use them in other databases, there might be a limited field length.

2.4.4.1 Address list browser

When you browse for addresses, you will get a list of all addresses in previous projects which are included in the project browser search path.

Filename	Name	Person	Address1	Address2	Address3	Address4	Telephone	Fax
C:\WindPRO Data\ver.1 projects\W...	NEG-Micon		Alsvej 21	8900 Randers			8710 5000	8710 5001
C:\WindPRO Data\ver.1 projects\W...	Anders Bundgård	Rørholtvej 76	9370 Hals				9825 4001	
C:\WindPRO Data\ver.1 projects\W...	Test			lyestvej 2				
C:\WindPRO Data\ver.1 projects\W...	NEG-Micon		Alsvej 21	8900 Randers			8710 5000	8710 5001
C:\WindPRO Data\ver.1 projects\W...	Banestyrelsen, ...	Morten Stender ...	Salvgade 40 opg...	1349 København K			331 40 400	3391 1285
C:\WindPRO Data\ver.1 projects\W...	IS Nordjyllandsv...	Jørgen Saxov	Postboks 51	9310 Vodskov			9954 5454	9954 5455
C:\WindPRO Data\ver.1 projects\W...	NEG-Micon		Alsvej 21	8900 Randers			8710 5000	8710 5001
C:\WindPRO Data\ver.1 projects\W...	VINDKRAFT PRO...	Endre Dingsør	Postbox: 30	Sandslørke 63	5049 SANDSLØ		+47 55997242	+47 55997241
C:\WindPRO Data\ver.1 projects\W...	IS Nordjyllandsv...	Jørgen Saxov	Postboks 51	9310 Vodskov			9954 5454	9954 5455
C:\WindPRO Data\ver.1 projects\W...	VINDKRAFT PRO...	Endre Dingsør	Postbox: 30	Sandslørke 63	5049 SANDSLØ		+47 55997242	+47 55997241
C:\WindPRO Data\ver.1 projects\W...	NEG-Micon		Alsvej 21	8900 Randers			8710 5000	8710 5001
C:\WindPRO Data\ver.1 projects\W...	NEG-Micon		Alsvej 21	8900 Randers			8710 5000	8710 5001
C:\WindPRO Data\ver.1 projects\W...	NEG-Micon		Alsvej 21	8900 Randers			8710 5000	8710 5001
C:\WindPRO Data\ver.1 projects\W...	Bonus Energy A/S		Fabriksvej 4	7330 Brande			9718 1122	9718 3086
C:\WindPRO Data\ver.1 projects\W...	NEG-Micon		Alsvej 21	8900 Randers			8710 5000	8710 5001
C:\WindPRO Data\ver.1 projects\W...	NEG-Micon		Alsvej 21	8900 Randers			8710 5000	8710 5001
C:\WindPRO Data\ver.1 projects\W...	Peder Villadsen	Holmevej 3	8305 Samsø				8659 0761	
C:\WindPRO Data\ver.1 projects\W...	Banestyrelsen, ...	Morten Stender ...	Salvgade 40 opg...	1349 København K			331 40 400	3391 1285

When opened with the browse button from Project Properties; if you double-click on an address, WindPRO will return the selected address. You can also return the address by highlighting and clicking on OK.

The address list can also be copied to other programs simply by making your selection the same as you would in the Windows Explorer (with the <Shift> key and/or the <Ctrl> key held down when clicking), then right-click and select "Copy". The entire address list with all fields can then be pasted into a spreadsheet. This can be useful when making status reports on all projects or transferring addresses to other software programs as general customer databases.

2.5 BASIS – Project design, import/export, calculation, print

2.5.1 Introduction to establishing a project

When the project properties have been entered, the actual project design work can begin. In this chapter we will describe how WTGs or other objects are entered and how general object editing, copying and import/export work. Other object inputs will depend upon the calculations you wish to perform. These other object inputs are described in the relevant chapters.

2.5.1.1 Map

WTGs and other Objects must be entered via the maps. Click on the map button to open the map window.



If one or more maps have been linked to the project, these maps can be invoked by clicking on the 5 map buttons.



Please notice that when you enter objects via maps, if you hold the <shift> key down while selecting a tool, this tool will become a default. This makes it possible to enter several objects with the same object properties, e.g. a series of noise objects with the same distance and dB requirements, or a number of parallel rows of WTGs.

You can insert bookmarks on the maps by <Ctrl+k> <1> for marking the first of up to 10 bookmarks, then <Ctrl + 1> for GOTO bookmark 1, etc. This makes it possible to move quickly between different “sweet spots” on your map.

2.5.1.2 Object List



The Object List can be opened parallel to the map. This is very useful to interact between the map view and the Object List view. In the Object List view, objects are marked with a red x if there are errors associated with the object (typically missing data that the object links to, or missing height information (TIN) where the object is placed). The latter error shows a red x in the Z-value column, only if the object is set to get its Z-value from the Digital Height Model (DHM), which in this case means the calculated Triangular Irregular Network (TIN) (see Section 2.8.2.2).

Objects							
	Description	Locked	X(East)	Y(North)	Z	Type	Result (most recent)
	Noise sensitive point: Danish 200...	No	523.166	6.299.656	26,1	Noise Sensitive Area	14 42,9 dBA @ 6 m/s; 43,8 dBA @ 8 m/s
	Noise sensitive point: Danish 200...	No	523.316	6.299.242	24,6	Noise Sensitive Area	15 41,0 dBA @ 6 m/s; 41,8 dBA @ 8 m/s
	Noise sensitive point: Danish 200...	No	523.765	6.298.879	23,6	Noise Sensitive Area	16 39,8 dBA @ 6 m/s; 40,6 dBA @ 8 m/s
	Noise sensitive point: Danish 200...	No	524.062	6.298.904	25,0	Noise Sensitive Area	17 40,4 dBA @ 6 m/s; 41,2 dBA @ 8 m/s
	Noise sensitive point: Danish 200...	No	524.297	6.298.877	26,2	Noise Sensitive Area	18 39,3 dBA @ 6 m/s; 40,1 dBA @ 8 m/s
	Noise sensitive point: Danish 200...	No	524.382	6.298.944	29,1	Noise Sensitive Area	19 39,5 dBA @ 6 m/s; 40,3 dBA @ 8 m/s
	Noise sensitive point: Danish 200...	No	524.732	6.299.134	20,0	Noise Sensitive Area	20 38,3 dBA @ 6 m/s; 39,1 dBA @ 8 m/s
	Noise sensitive point: Danish 200...	No	525.060	6.299.984	20,0	Noise Sensitive Area	21 36,5 dBA @ 6 m/s; 37,3 dBA @ 8 m/s
	4*Siemens SWT-3-115_Visual 30...	No	523.427	6.300.324	34,5	New WTG	74 11.528 MWh/y; 3202 h; 36,5 % CF; 7,0 m/s; Wake eff. 97,6 %
	Control Point: Uncertainty horiz: ±0 ...	No	540.685	6.290.143		Control Point	121

In the Object List you can select several objects in the same way you would in Windows Explorer. The selection will then work on the map also. For example you can then move all the selected objects in one operation by dragging them to a new location on the map. Note also the right-click features available for selected objects in Object List, such as Delete, Edit, Copy or import/export (described in details later).

Note the feature “Results”, which show the most recent main calculation results for some selected objects like Noise Sensitive Areas or WTGs. These results can also be shown as labels on the map, and they can be copied to clipboard – a very efficient way when analyzing a special case where many different smaller adjustments are performed.

A special feature for line or Area Objects is the ability to center the object at the point where the linked data is on the map. This may help you find where the imported data in line or Area Objects are located and then possibly locate import errors.

2.5.2 Entering, moving, snapping, and selecting WTGs (and other objects)

WTGs can be created as individual WTGs or as rows with fixed in-row distance and WTG type. It's always possible to turn a row into individual WTGs (with a right-click) and still be able to edit the coordinates and WTG type individually afterwards. The WTG type must be listed in the WTG Catalogue and so, must first be created in the Catalogue if not already listed in it. In energy production calculations for single WTGs (WIND ATLAS), the hub height can be changed during the calculations without having to create all the possible hub heights in the WTG Catalogue.

After you have entered WTGs via a map, you can position it at the correct location by clicking on the WTG mark and dragging it to the desired location on the map. You can fine tune the position by holding down the <Ctrl> key and moving the selected object with the arrow keys. You can also link an object to another by holding down the <Ctrl> key when moving one object towards another object. A hook appears to illustrate the activation of this “snap” feature.

To select an object when a number of objects are positioned close together, you can move the cursor over the group of objects to get a drop-down list of the objects. You can then select the one you wish to move or enter properties for.

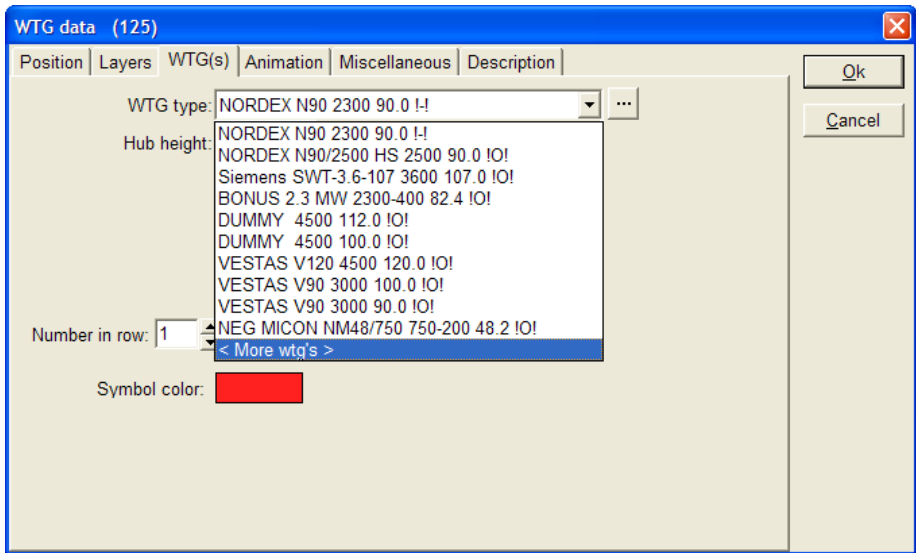
For rows of WTGs the following rule applies:

Place the cross hair inside the center mark, left-click and drag to move the row parallel to its original position. Place the cross hair inside an outer mark to rotate the row around the opposite outer mark. Hold down the <shift> key while dragging an outer mark to change the in-row distance.

2.5.2.1 WTG Object Tab Sheet: WTG(s)



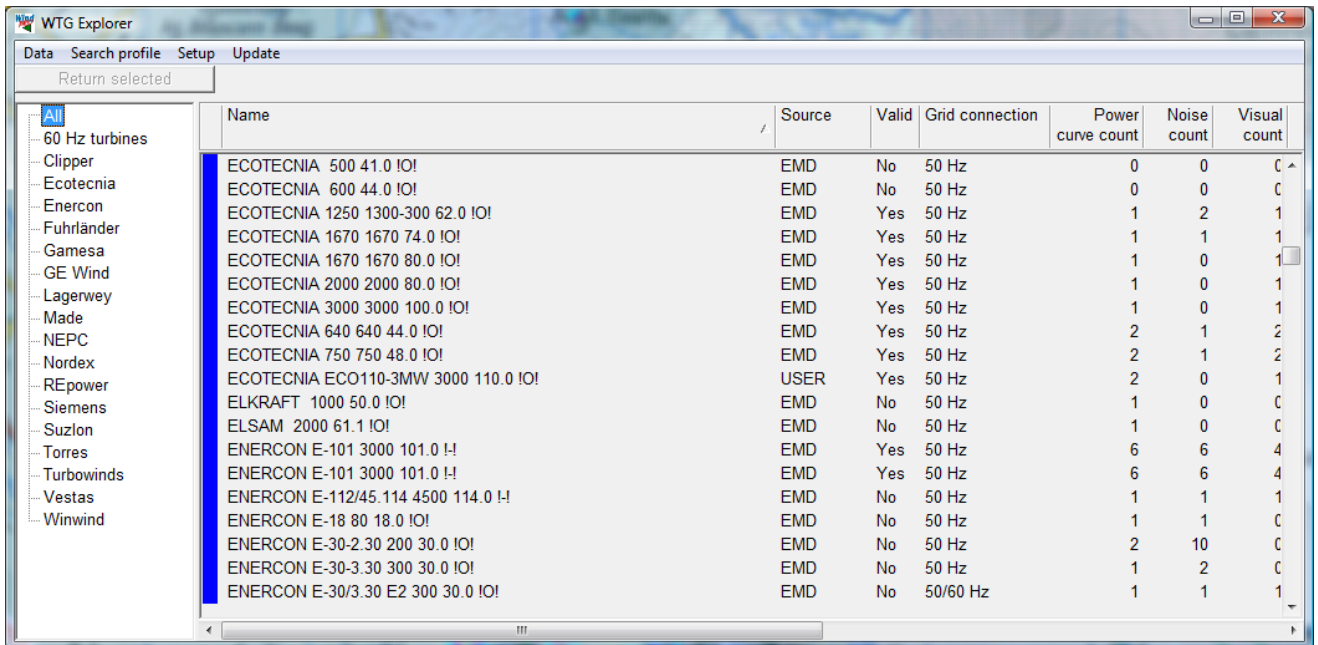
Activating the "new WTG" icon creates new WTGs by clicking on the desired position on the map. The following window will appear.



Entering new WTGs:

With the "Number in row" it's possible to create not only one WTG at a time, but also a row of WTGs with same in-row distance and on a straight line.

The WTG type is selected from the WTG Catalogue via the drop-down list, which holds the last 10 WTGs used. Select <more WTGs> to access the WTG Explorer (see figure below), where you can build different search profiles and select these in the WTG Explorer. This makes the searching and selecting of a specific WTG type easier and faster. Note from the Setup you can edit the search path, and thereby decide where to browse for turbines (in which folders). By default you browse in the WindPRO Data\WTG folder and the current project folder.



In the list you can sort by the different columns by clicking in the top of the column.

After having selected a WTG, it's possible to look for different power curves, noise data etc. by deselecting "Always use default" (see below).

Here 5 different sets of noise levels appear, and corresponding power curves will be selectable. It's the users' responsibility to select matching power curves and noise data, if these are coupled as for the WTG above. The "Adv." (Advanced) checkbox will be explained later.

After having entered the WTGs on a map it's easy to move them:

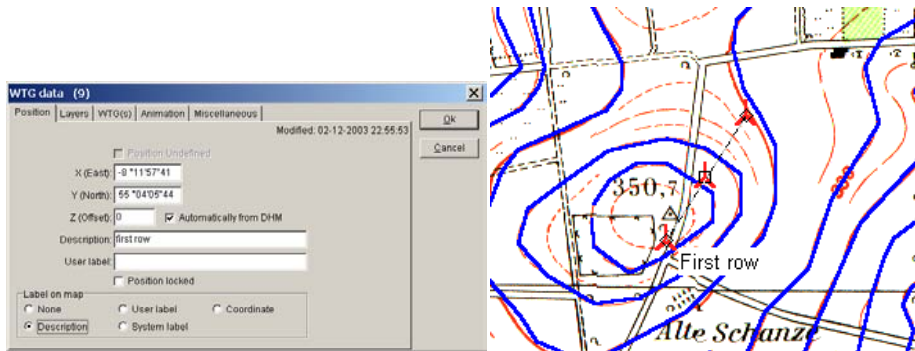
Click once on a WTG row to select it. Activate the center selection mark and drag the object sideways. Activate and drag an outer selection mark to rotate the row. Activate an outer selection mark while holding down the <Shift> key in order to change the in-row distance between the WTGs.

2.5.2.2 Object Tab Sheet: Position

By a right-click and selecting properties, the input window for a WTG or any other object will appear, and more details can be entered. The Tab Sheet "Position" is common for all objects. Here you can enter the exact coordinates. The Z-coordinate can be entered or read automatically from a Digital Terrain Model calculated on the BASIS of a Line Object (Height Contour Map), but then the object has to be inside the TIN radius, see Line Object. A description can be entered and used as label on map. It's shown in the Object List and will be shown on printouts too. You can also enter a "user label". The software automatically gives a "system label", where the first created object gets no. 1, the second no.2 etc. These system labels can never be changed. Therefore you have the opportunity to assign your own user label to objects, e.g. for a special numbering order in your WTGs or other objects. Later on (in "Printing Reports"), you can choose to sort the WTGs by user label instead of system label and thereby obtain full control. If you use letters in the user label, normal alphabetic sorting will be used.

On the map following labels can be visible next to the object:

- Description,
- User label,
- System label
- Coordinates or
- None

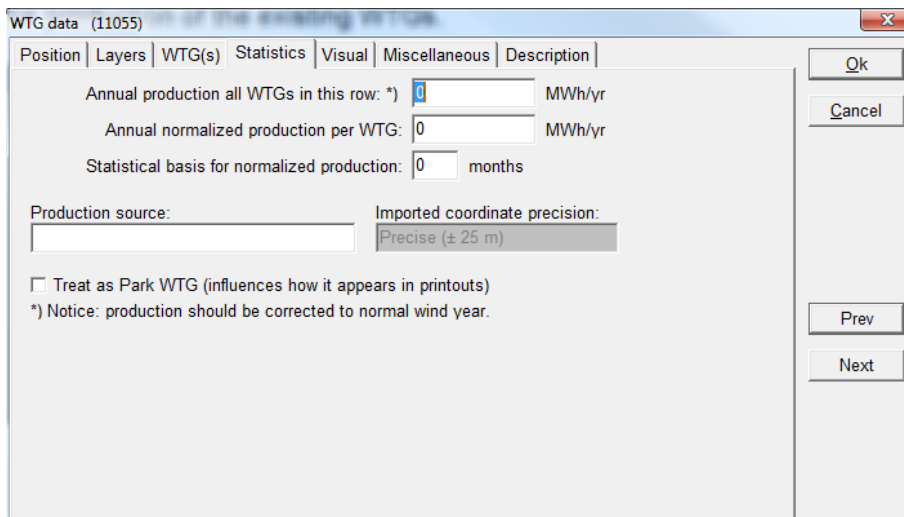


Under the Tab Sheet "Position" you can enter the exact coordinates. The Z-coordinate can be entered manually or read automatically from a Digital Terrain Model calculated on the basis of a Height Contour Map. Description can be entered and used as label on map.

2.5.2.3 Existing WTGs Tab Sheet: Statistics



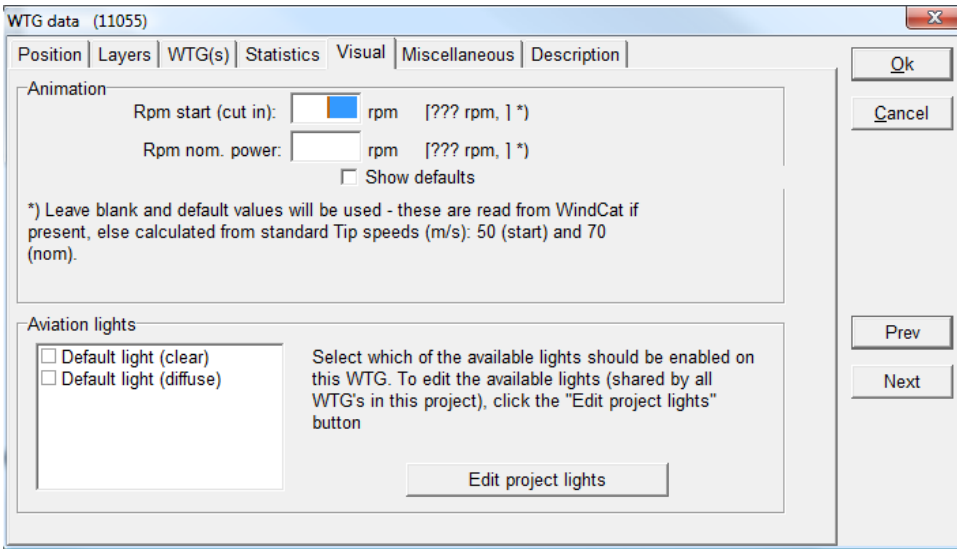
Existing WTGs are created the same way as the new WTGs. The only difference is that it's possible to input statistical data, i.e. actual production data, for the existing WTGs and thereby compare the energy production calculations. In a PARK calculation the results will be grouped in new and existing WTGs respectively, including information on the impact of the new WTGs on the production of the existing WTGs.



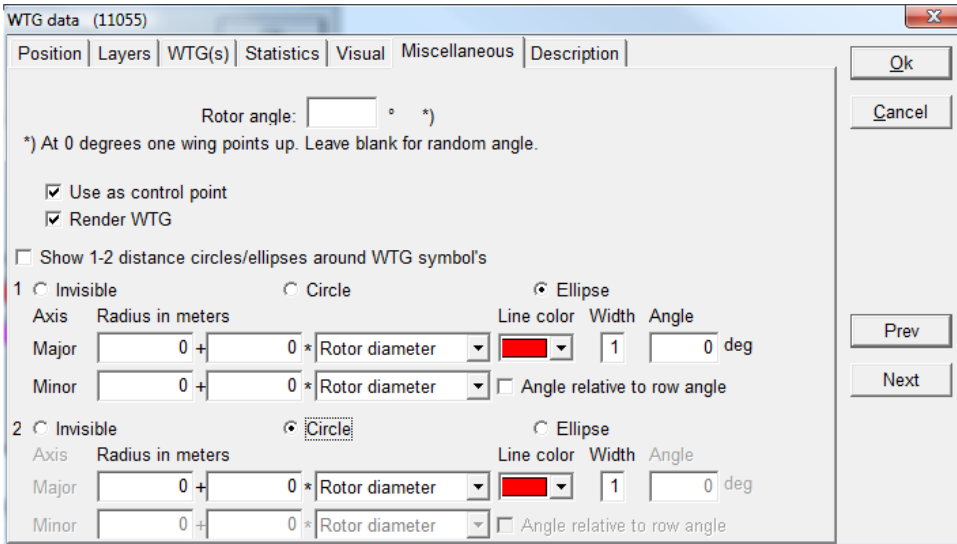
Existing WTGs can be imported (see Chapter 2.7)

2.5.2.4 WTG Object Tab Sheet: Visual

Here, the rotational speed for the WTG rotor can be specified (see Chapter 5, Animation module), and the Aviation light marking can be defined (see Chapter 5, Photomontage).



2.5.2.5 WTG Object Tab Sheet: Miscellaneous



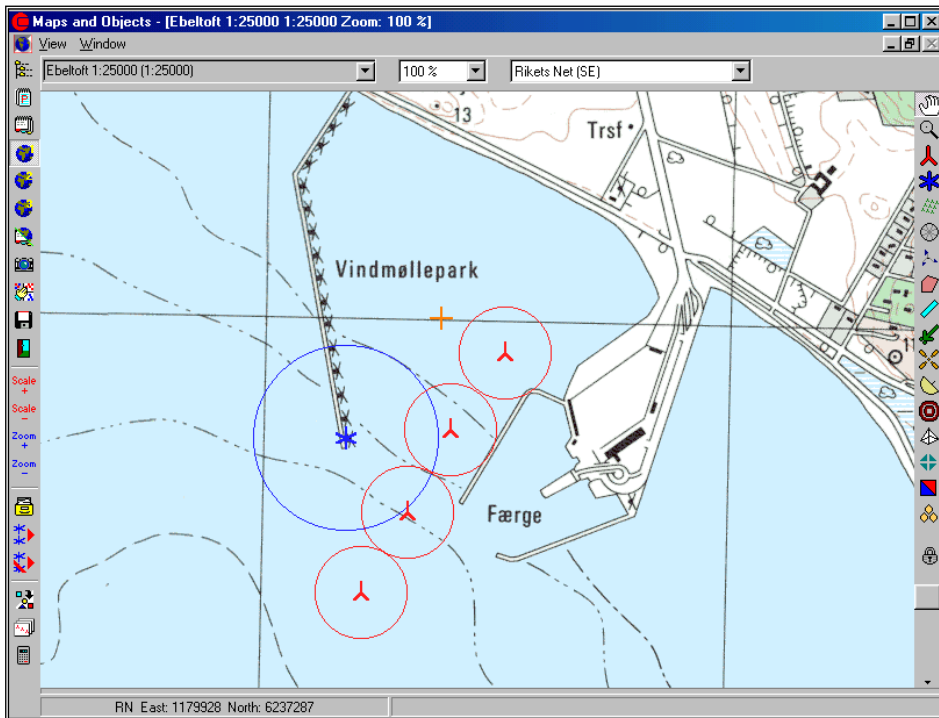
In the Tab Sheet "Miscellaneous" you can enter:

Rotor angle – only for visualization purposes

Use as control point – only for visualization purposes

Render WTG – only for visualization purposes

Distance circle/ellipses – this is often useful for project design. It's activated by right-clicking on WTG symbol and checking "Show distance circle". Two circles/ellipses can be established and the radius can be made dependent on WTG main size specifications. Color and line width can also be specified.



An example of how to use the distance circles to both ensure the distance from the new existing WTG of 200 m and a distance from the pier of 100 m is shown on the map above

2.5.2.6 Object Tab Sheet: Layer

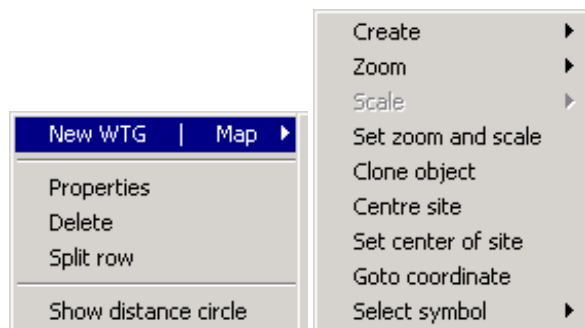
(See layer structure, Section 2.11)

2.5.3 Clone object (copy) and multi-editing

Two useful tools are available for all types of objects.

2.5.3.1 Clone object

Select one or more objects to clone (copy) from the map or the Object List. Select an object simply by clicking on the object with the left mouse button. Select additional objects by holding down the <Ctrl> key when clicking on objects on the map or multi-select in the Object List as you would in Windows Explorer. Once the objects have been selected, click on the right mouse button, then select "Clone Object" (go to the right from the top of the menu "New WTG | Map >" and a local object menu appears) (see below).



The cloned objects are placed 100 m East and 100 m South of the original ones. If the original object positions are locked, the cloned objects will be positioned at the exact same coordinates as the originals. The cloned objects can be moved normally when not locked. Cloning is a useful feature, especially for the terrain data object (see the module Energy Calculation), since you don't have to enter values twice e.g. two roughness classi-

fications nearby each other that are almost identical. It's also a good way to ensure that parallel rows of WTGs have identical properties.

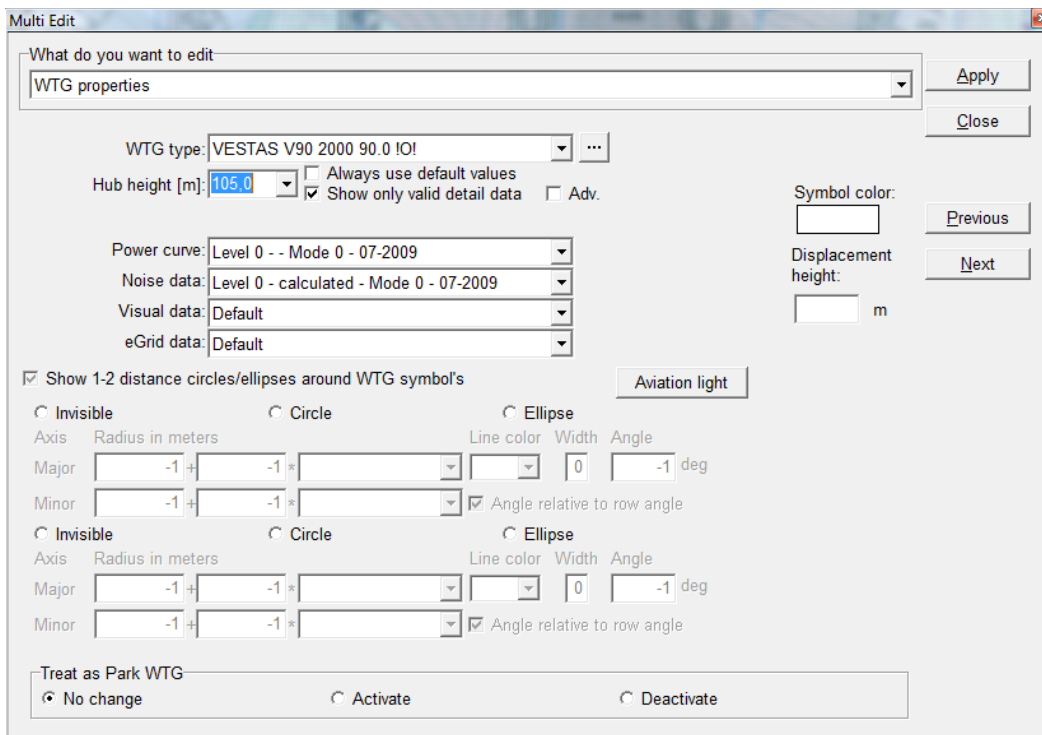
2.5.3.2 Multi-editing

When working with many WTGs or e.g. noise sensitive areas, where you need to change the WTG type in general, the hub height or noise emission data, or attach all objects to a height contour Line Object in order to read the Z-coordinates automatically, multi-editing is an efficient way of changing the characteristics for a large number of objects.

The Multi-editing tool works either by starting to select the objects to edit (possible with different WTG-types if e.g. the Z-coordinates are to be changed) or by firstly starting the "Multi-edit-window" and secondly selecting the objects to edit.



Start the "Multi-edit" tool by clicking on the symbol shown to the left. The "Multi-edit" window will appear as shown below.

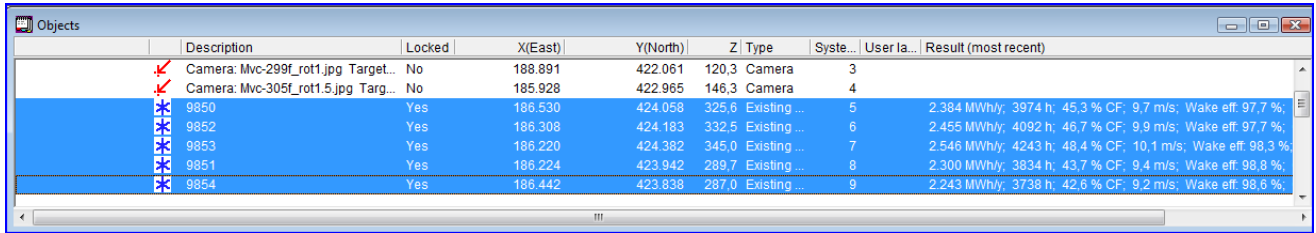


Select which properties to edit as shown above, e.g. the WTG type. Different ways of Multi-editing present different choices to edit different types of objects at the same time. Only the relevant changes for each object are performed. The program will notify you of the different selected types of objects before handling.

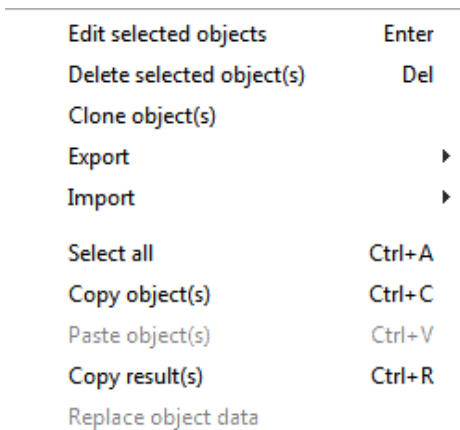
2.5.4 Import/export and copy/paste of object data via Object List

Electronic exchange of data is becoming more and more common. You may receive coordinates for objects (WTGs, neighbors, etc.) via an email that you don't wish to enter manually. Or, you need to make some changes to a wind farm layout with the aid of a spreadsheet calculation. Maybe you want to copy all noise sensitive areas to shadow receptors at the same positions, or copy a roughness rose from one project to another. All of these operations as well as many others can be performed with help from the import/export and copy/paste functions.

The Object List window shown below is where you must be working in order to use these functions. Note that you can sort the objects by the individual columns for faster selection.



To export (copy) one or more objects, simply mark the objects by dragging when holding left mouse button down or, as in Windows Explorer, by holding down the <Ctrl> key or, by marking the first selection and then holding down the <shift> key when marking the last. When objects are selected, right-click and get the menu shown below:



Choose “Copy object(s)” and all the stored information for the objects is placed in the Windows clipboard. The data can be pasted back as new objects or as a replacement of the copied data with the changes made in a spreadsheet, e.g. adding a user label (see next section).

2.5.4.1 Copy/paste for remote editing of object data in spreadsheet

From the clipboard, you simply paste the objects into a spreadsheet (or into the Object List in another project) and if into a spreadsheet, the list appears as shown below.

Descriptio	Object type	System la	Object ID	X	Y	Z	Object de	User label	File name	Hub heigh	Productio	Use defau	Power cur
9850	Existing WTG	5	1	186530	424058	325,6	9850		C:\Users\j...	40,5	2383	yes	
9852	Existing WTG	6	1	186308	424183	332,5	9852		C:\Users\j...	40,5	2501	yes	
9853	Existing WTG	7	1	186220	424382	345	9853		C:\Users\j...	40,5	2632	yes	
9851	Existing WTG	8	1	186224	423942	289,7	9851		C:\Users\j...	40,5	2346	yes	
9854	Existing WTG	9	1	186442	423838	287	9854		C:\Users\j...	40,5	2321	yes	
Paste from here if you want to replace object data													
Paste from here if you want to create new object by type													
Paste from here if you want to get a pop up list for selecting object type													

The following properties are common for all object types:

Description – Same as in Object description

Object type – Name, identifying type of object (see later in list).

(The properties listed above will not be used when copying changed object data back to the Object List).

System label – unique internal number assigned when the new object is created (cannot be edited).

Object ID - Number, identifying the type of object (see list later)

X – East coordinate

Y – North coordinate

Z – Elevation (above ground level)

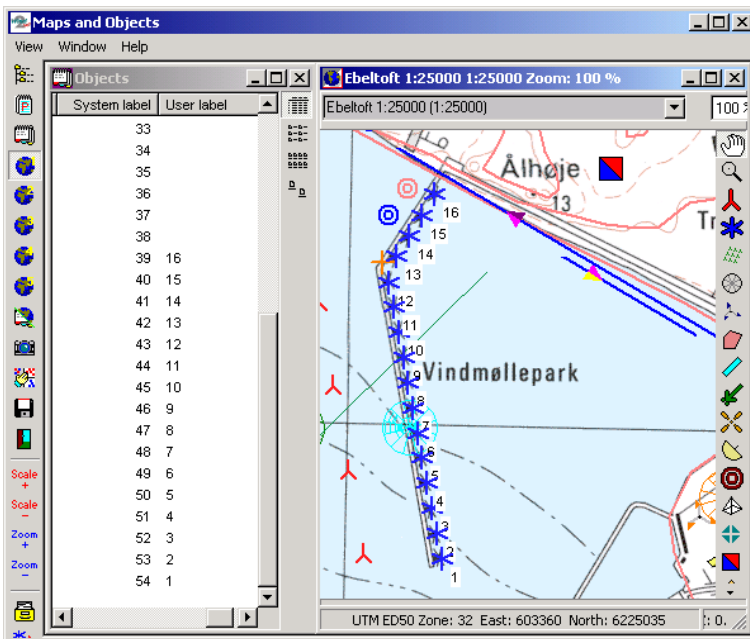
Object description - (User specified description, if no user description it is auto generated)

User label - (User label e.g. internal numbering for sorting in printout)

Lastly, depending of the type of object, additional information such as **Hub height** and **WTG type** for WTGs. See Section 2.5.4.4.

Data can now be modified in the spreadsheet and copied back to object list, see what to include in list shown above.

In the figure below, you can see how the copied 16 existing WTGs in the Ebeltoft DEMO project have been given a user label corresponding to the correct WTG number. This can be used later for deciding the print order in reports.



2.5.4.2 Export data from object list

Export		Export object position(s) to a Shape file
Import		Export to file...
Select all	Ctrl+A	Export object position(s) to a waypoint GPX file
Copy object(s)	Ctrl+C	Export to Google Earth kmz-file

There are at present 4 export options:

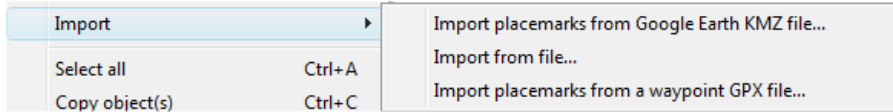
To shape files (for import in GIS software), a .shp file is created.

To file – a WindPRO object file (.wpobjects) is created – this is an efficient way to transport objects from one WindPRO project to another – this includes all data “behind” the objects.

To waypoint GPX file, the “standard” within GPS, meaning this is the format that can be imported into a GPS.

To Google Earth .kmz file, see chapter 2.16

2.5.4.3 Import data to object list



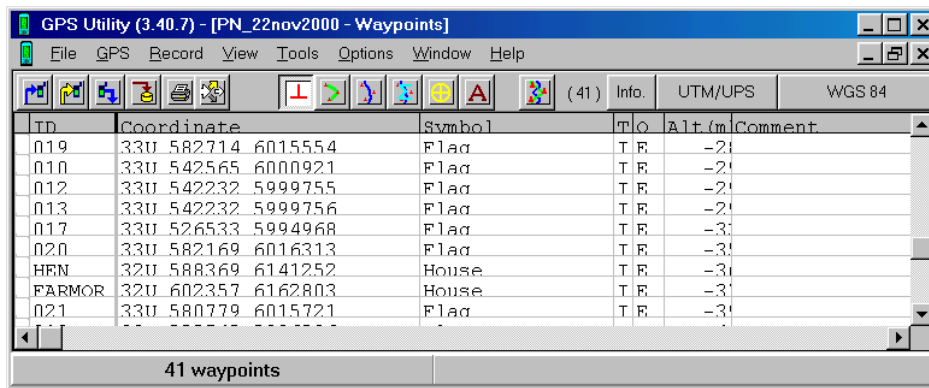
Here are at present 3 different options:

From Google kmz file, the points in the file (e.g. turbine positions specified by client) will be established as control marks in WindPRO. By copy to like Excel and paste back you can change the controlmarks to the wanted object type.

From file – the native WindPRO *.wbjects can be imported including all object information's.

Waypoints from GPX file, the GPS file format, see additional options about GPS coordinates below.

If you have data in a GPS, you need getting the data into a spreadsheet before copying. This can be done simply by typing data from the GPS screen into a spreadsheet. Or, in the case of a larger number of GPS points, by importing GPS data into a PC (a special cable is required to do this). Free software can be found on the Internet – e.g. at www.gpsu.co.uk, or purchased together with GPS. Shown below is an example of the screen in the free GPS software, GPS Utility, after downloading waypoints.



To get the coordinates pasted into a spreadsheet, you need to select one row at a time and then paste. Afterwards, you have to divide the coordinate column into two in the spreadsheet e.g. use the "MID(A1;5;6)" function to extract, starting with the 5th character, the following 6 characters from cell A1 (the X-coordinate). There are other free GPS tools like “Easy GPS” that seem to work better.

2.5.4.4 Identify what can be copy/pasted by object list

While the features that can be copied/pasted between object list and a spreadsheet will be revised from version to version, we recommend you simply copy the objects of interest from object list to spreadsheet, and there you will be able to see which features are included and thereby what can be “pasted back”.

2.5.4.5 List of Object IDs

Object type	Object ID
New WTG	0
Existing WTG	1
Site Data	2
Obstacle	3
Noise Sensitive Area	4
Shadow Receptor	8
Control Point	9
Camera	10
Line Object	11
3D Object	12
Area Object	13
Park Design Object	15
WTG areas	16
User text	17

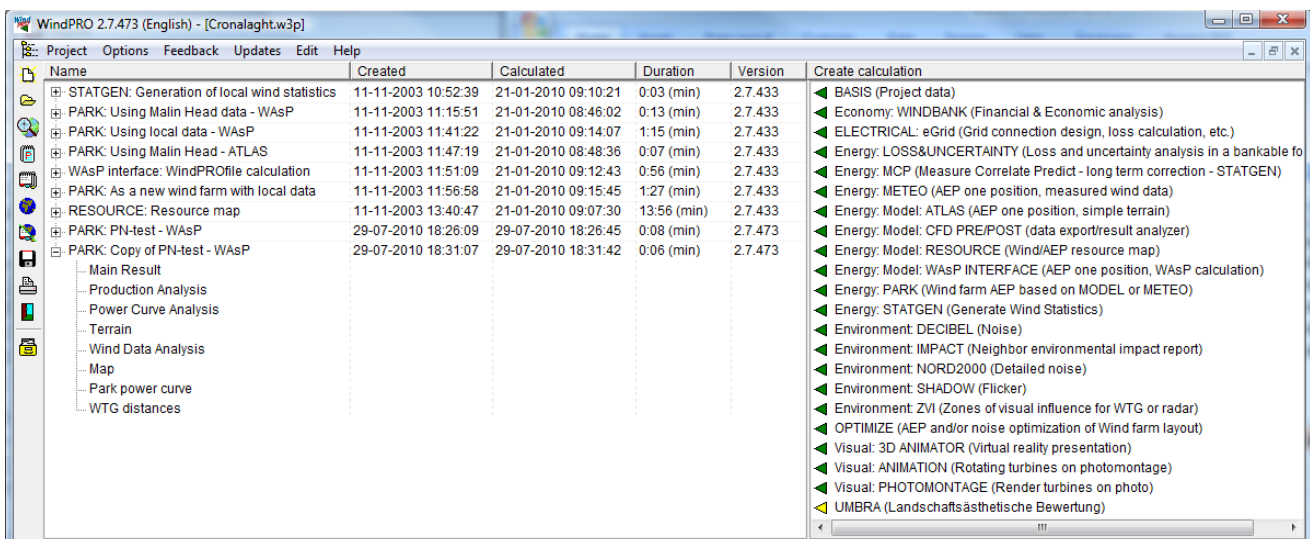
2.5.5 BASIS calculation

With the module WindPRO BASIS alone, it's possible to perform a so-called "BASIS-calculation". The "BASIS-calculation" does not calculate, it merely generates a complete report of the data that has been inputted, and a map with a presentation of the project. This gives e.g. the potential buyer of WTGs the opportunity to work with different project layouts using the WindPRO program at a very favorable price and the ability to forward the information (e.g. a WindPRO export file) to different manufacturers for calculations and quotations.

After a calculation, you can copy the calculation (by right-clicking on the report header). Then a copy of the report and all calculation settings is made. If you later change the WTG layout on the map, you can recalculate the copied calculation, so you now have two calculation reports with same specifications (e.g. air density), but with different WTG layouts so that the two sets of calculations are identical except for the layout.

2.5.6 Printing – general tips and setup

When a calculation has been performed, the following window appears.



Depending on the calculation, two or more reports will be generated. The line with the calculation name (in this case BASIS), is the "header" of the calculations report. The name the user gives the calculation (in this case "My first calculation"), also appears in the header. The reports follow subsequently.

To view ,setup or print the reports, there are a number of options described as follows:

2.5.6.1 Preview print and save file (.bmp, .jpg, .pdf, HTML)

See next sections on how to get into the preview window.

In the top of the preview window there are some functions that are used as follows:



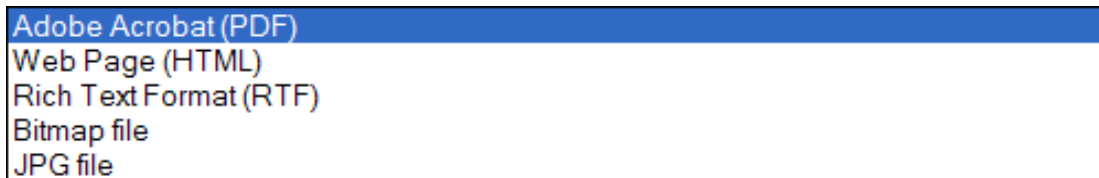
The zoom and "full margin" buttons are self-explanatory.



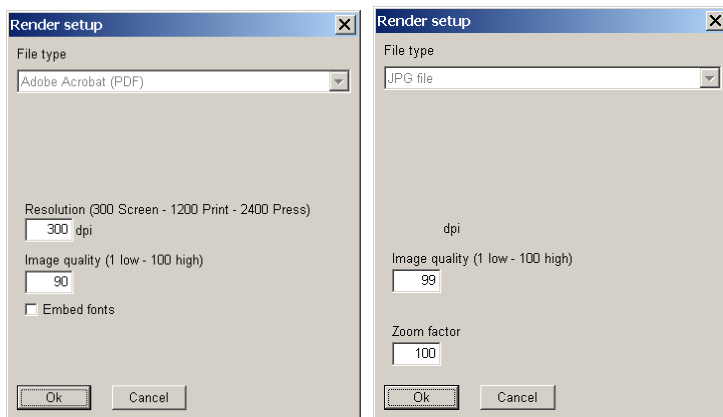
Copy to clipboard – afterwards the entire page can be pasted into another Windows document as a graphic.



Copy to file – or use the menu "file" > "save as" and choose between following options:



Note that the printer driver selected before preview will determine if there will be colors on the print preview and in the print file. This can be overruled by setting "Force color printing" or "Force monochrome printing" in the report setup



If .pdf or .jpg format is selected, then the setup options shown above will appear. This gives the option to decide the quality and size of the file.



The arrows are used to move backward and forward between pages. If only one page exists in the preview, the arrows will be grey.



The printer symbol – print the current page, selected pages or the entire report.

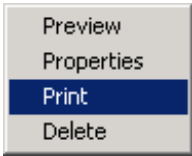


The door – closes the preview.

The Zoom window allows you to user-define the zoom factor. NOTE: Use a large zoom factor to ensure picture/graphics quality if reports are being copied to a file or to the clipboard.

2.5.6.2 Print a single report with default settings/preview

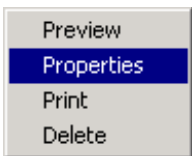
To print a single report, select report (click on report) and click on the printer symbol or right-click and select “print” from following menu:



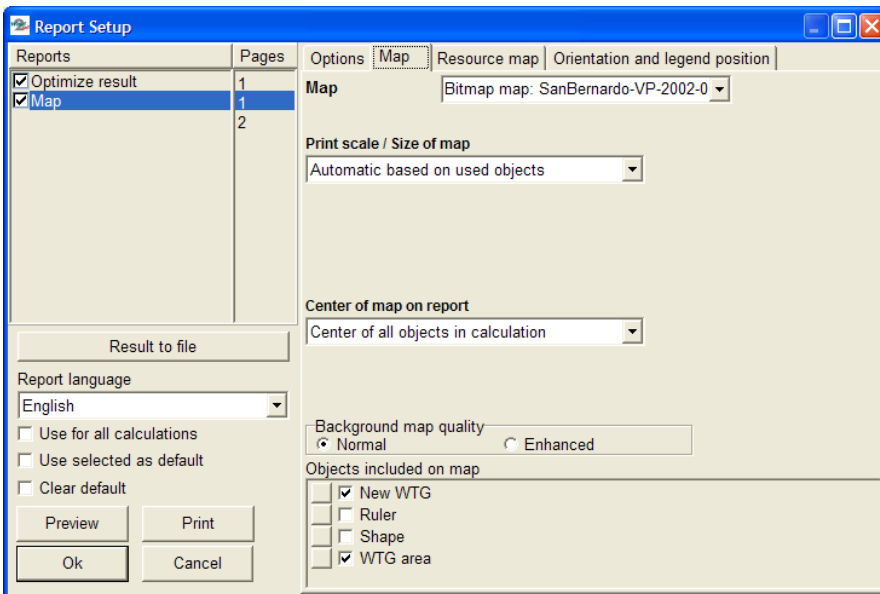
To preview a single report with default settings, simply double-click on the report, e.g. on "Map".

2.5.6.3 Setup a single report

Right-click on report name and select Properties from the following menu:



The following window appears depending on which report you have selected.

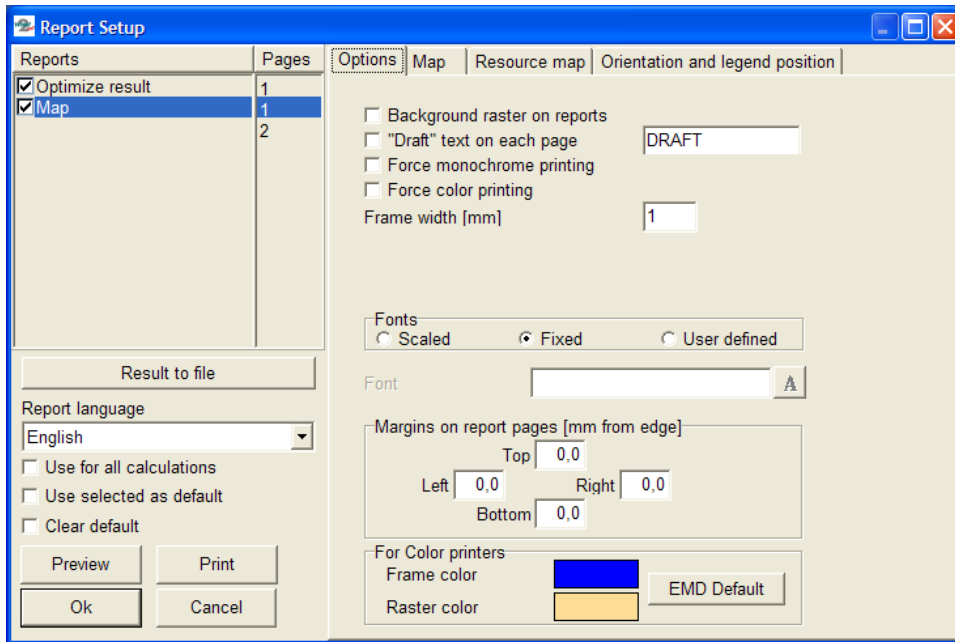


In the right half of the window you get different tab sheets where individual settings can be applied to the report. In the left part are following important features:

Result to file - in more reports; the calculation results can be saved to a file or to the clipboard for further processing in e.g. spreadsheet tools.


Report language – from version 2.4 on, some print languages will be available (if license is purchased).

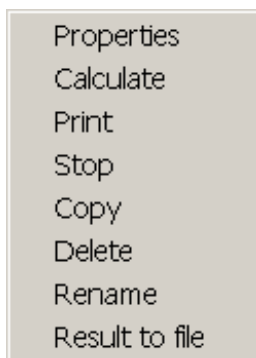
The “Report language” can be checked so it’s used in all calculations until WindPRO is shut down. The next time WindPRO is started, the original language will reappear as a default unless “use as default” is checked.



On the "Options" tab sheet, you can select "Force color printing", which is advantageous if your default printer is a black & white printer, and you want to save e.g. PDF files with colors. The many other layout options should be self-explanatory.

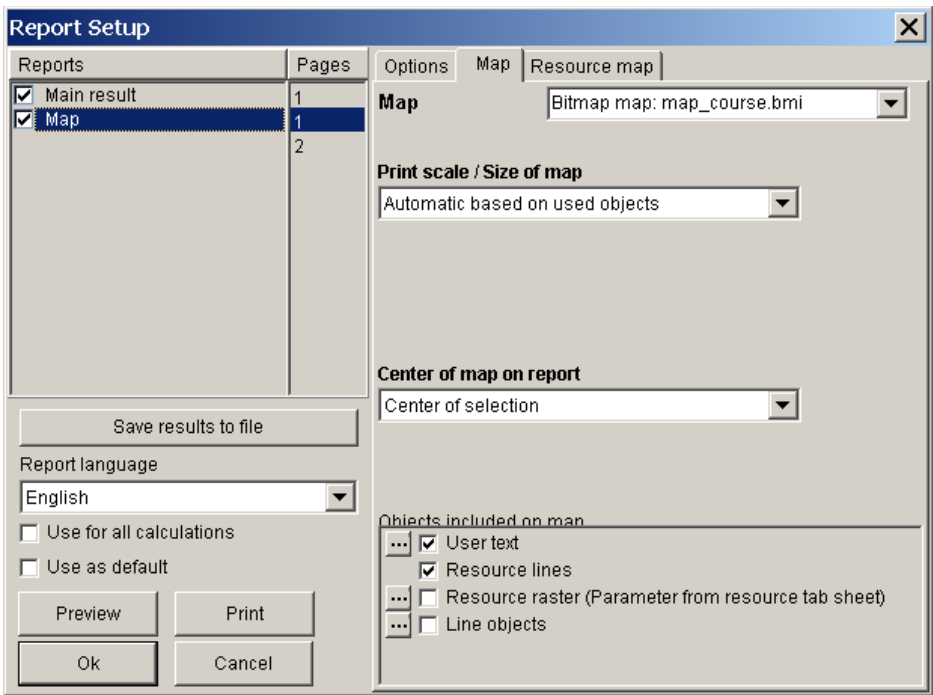
2.5.6.4 Print all reports, define reports and settings, symbol scaling, etc.

To print all reports or to set up a complete calculation report, select the report header by left-clicking on it and then click on the Printer symbol , or you can right-click on the header and select "Print" as shown in the menu below.




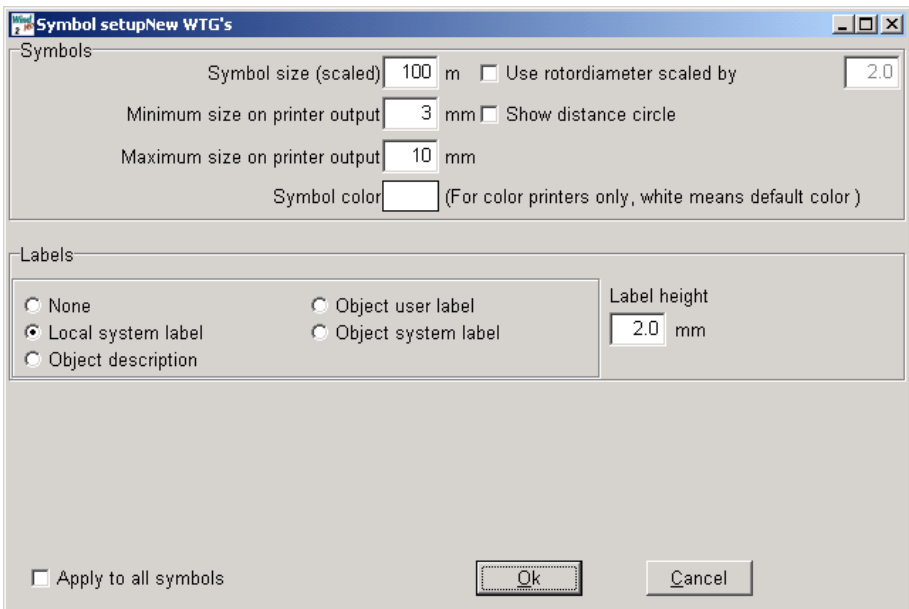
Note: With the "Rename" function you can change the calculation name and the description without recalculating.

When selecting "Print", the Report Setup menu appears.



On the left side you can select the different parts of the report you want to print, and on the right you can set up individual parameters, depending upon which report is selected.

In particular for the "Map" report, you can define which part of the map to print and which objects to be included. By clicking on the dotted button , you can define the appearance of the objects individually in the Map report (it also affects the map on Main report, see below).



Note: Scaling and individual label settings, etc., can only be made when selecting the report "map", see Section 2.5.6.3.

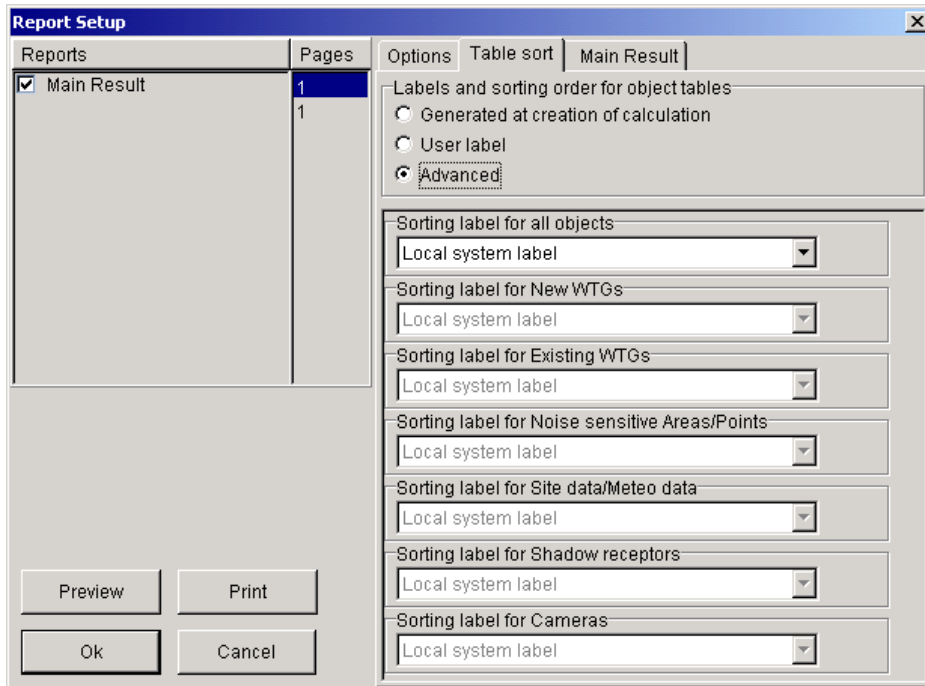
2.5.6.5 Sorting the objects by user label etc.

A unique feature in WindPRO is the ability to sort objects by user or other label. Default objects listed in reports are sorted by object system label, but are numbered after a local system label (where objects are numbered 1, 2, 3...or a, b, c...). This option is called "Auto sort" (Local system label).

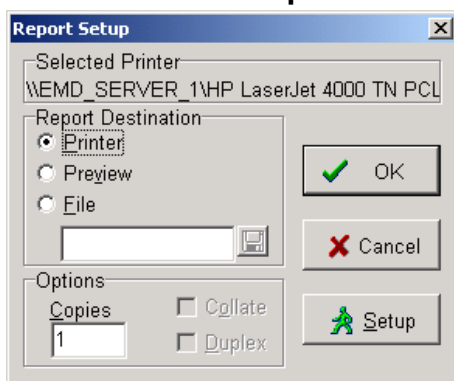
Selecting to sort by “User label”, you specify the label on the print (by supplying the objects user label) and the objects are then sorted by that user label (numerically or alphabetically).

Lastly the "Advanced" option allows you to use the WindPRO-assigned system label in printouts, in which case you always have the same label assigned to the same object, regardless of which objects have been inserted or deleted. In “Advanced”, you can chose different sorting options for different types of objects.

This feature is found under the Tab Sheet "Table sort".



2.5.6.6 Printer setup



Click on “Print” to select a printer or to specify the printer setup. This follows the normal Windows convention (please refer to your local printer manual).

If you want to output a standard file type e.g. for attaching results to an E-mail, choose “Preview”. From the Preview window you can save reports as standard PDF documents (without having to purchase Acrobat writer) or JPEG’s (see section 2.5.6.1).

Note: If you want to print to a file you must have an appropriate printer driver installed. For example, you would need a Postscript printer driver to produce a postscript file, which many copy centers can print for you on high quality printers for inexpensive mass production. An even better solution is to print with Adobe PDF writer (cost: approx. 150 US\$), PDF files are readable from Adobe Acrobat reader, which is probably the most com-

mon file format for mixed text and graphics. The Adobe reader is free on the Internet, so everybody with Internet access can read and print your reports. With a PDF file, the formatting will always remain the same independent of the printer. An advantage is that the PDF format can be highly compressed, although you can select the compression of the bitmaps (graphics), in order to get a reasonable compromise between quality and file size.

2.6 BASIS - The WTG Catalogue

2.6.0 Introduction to wind turbine catalogue

Over the years, more than 700 different WTG types and variations have been collected by EMD from a number of sources, and are included in the WTG Catalogue. The Catalogue is continuously updated.

You can add your own new wind turbines to the Catalogue and you can supply the ones created by EMD with your own data (new power curves, noise data etc.). You cannot edit the data that has been supplied by EMD. You can however, make a copy of an "EMD" turbine, and use it as a template for a new user-defined WTG.

Note, that the WTG Catalogue keeps track of whether the data is created/edited by EMD or the user. In the "Source" field in WTG Explorer, there will be 3 possibilities:

EMD
USER
EMD-U

The EMD-U designation means that it's a WTG created by EMD, but the user has added some information. Depending upon the power curve used in the calculation, it could be either an EMD or a USER power curve. In the printouts of the energy calculation, it will indicate whether an EMD or a USER power curve was used.

The information registered in the Catalogue is primarily the type of information which is most important during the design phase of a project.

The Catalogue is structured such that, if a WTG is considered to be of a certain type (same manufacturer, generator-system, rotor diameter and tower type), it's stored in one file. Inside this file there can be additional power curves, noise data sets, visualization data sets, price data, and different hub heights (tower heights). This is a compromise between reusing data and keeping the structure simple.

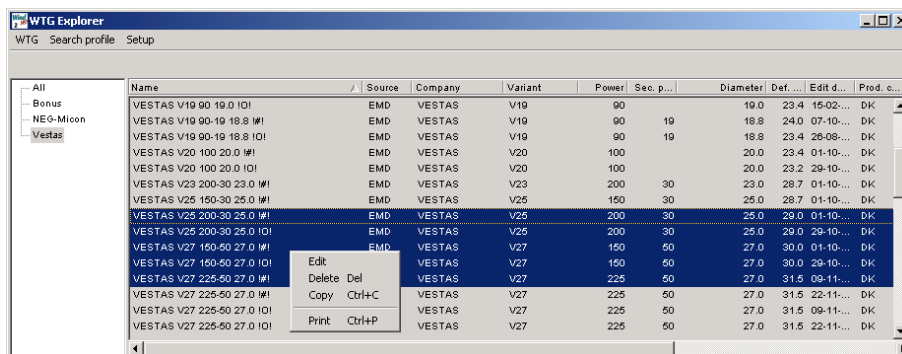
2.6.1 Invoke and Modify the WTG Catalogue



The WTG Catalogue is invoked from the WindPRO main menu by clicking on the "Archive drawer" icon.

2.6.1.1 The WTG Explorer

When the Catalogue is invoked, the WTG Explorer appears. Please see further details in the WindPRO Explorer search path and search profiles in Section 2.3.2 WindPRO Explorer list.

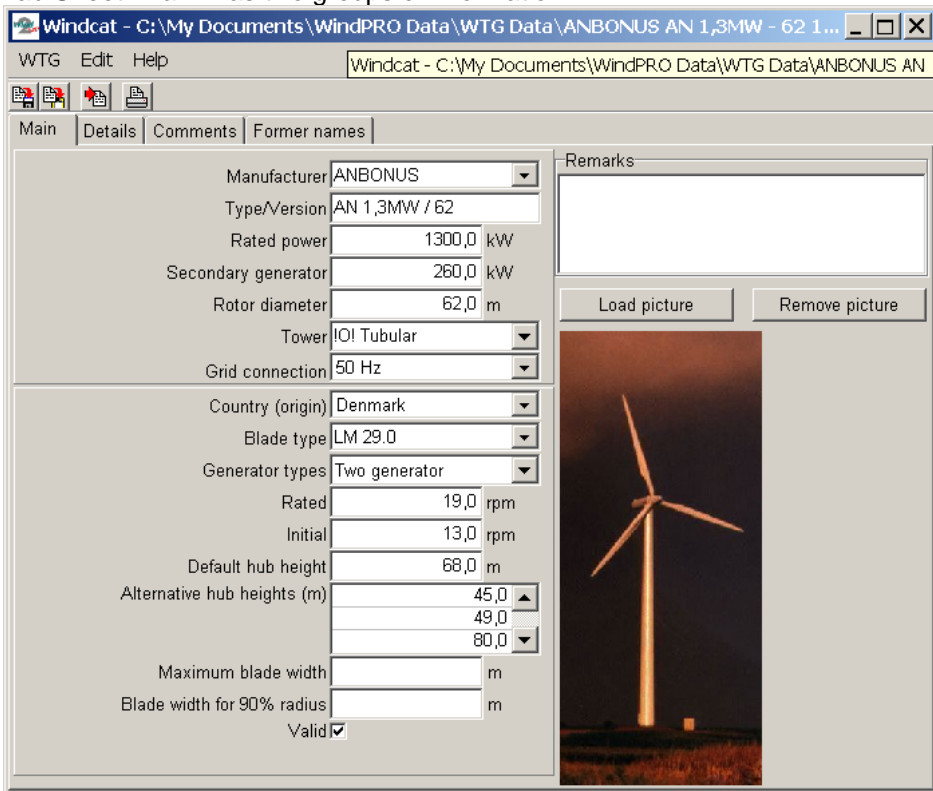


Simply right-click or double-click on a WTG, to enter the edit menu.

If you want to import specific WTG types from a spreadsheet; as in Windows Explorer, you can copy the main information of selected WTGs to the clipboard (see Section 2.5.4). You use the list to get the right file name into the spreadsheet at the point where you want to paste WTGs into the Object List.

2.6.2 WTG Catalogue Tab Sheet: Main

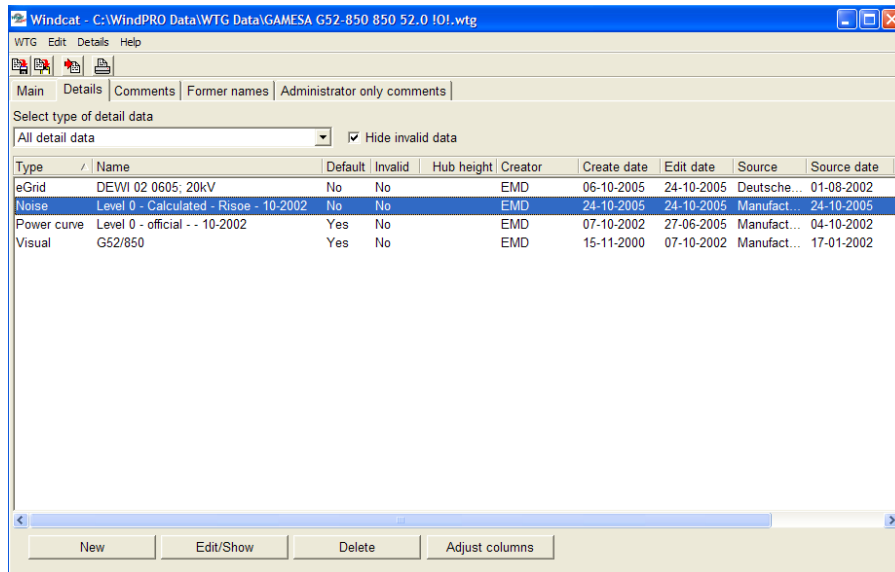
Tab Sheet "Main" has two groups of information:



The upper section contains the unique identification and description for the turbine type, i.e.: Manufacturer, Type, kWh (large/small generator), Rotor Diameter, Hub Height and Tower Type(s).

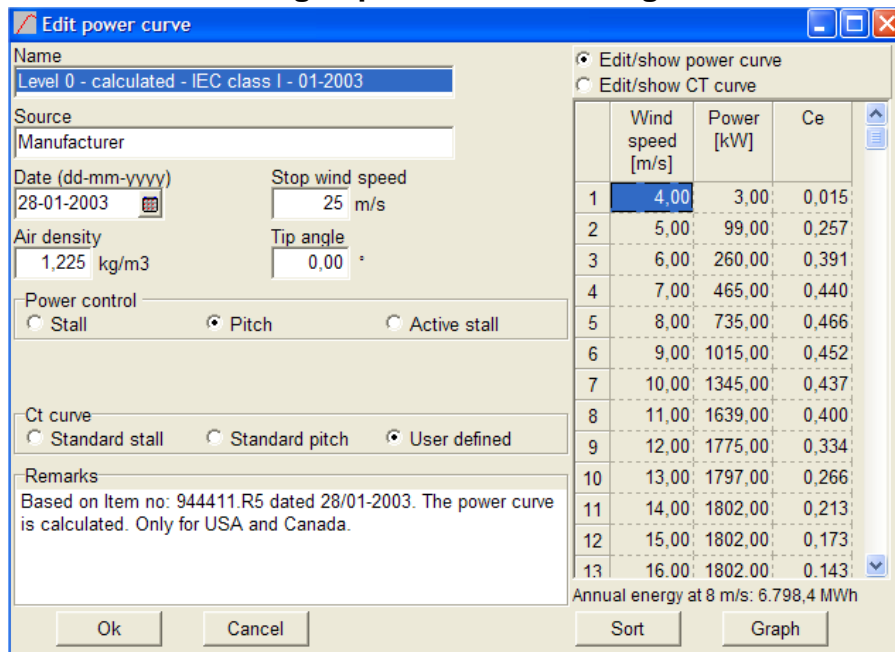
The lower section contains additional information such as: Country of Origin, Blade Type, Generator type (rpm Control), rpm, default hub height and alternative hub heights. For a SHADOW calculation, the blade width can be entered, which allows the shadow calculation to determine the distance from the turbine at which flicker may be a problem (at 20% sun coverage). Lastly, there is a field indicating whether or not the WTG is valid, a remark field and a picture.

2.6.3 WTG Catalogue Tab Sheet: Details



Under Tab Sheet “Details”, it’s possible to add multiple sets of data belonging to different variants of the specific WTG type, different sets of power curves, noise data, visual data, or eGrid data.

2.6.3.1 WTG Catalogue power curve editing



Power Curve tab sheet includes information on Source, Date, Stop wind speed (Cut-out wind), Air density for the specific power curve, Power control system, Ct curve, etc.

The Power curves are named according to different noise levels, where “level 0” is the power curve corresponding to “no noise reduced” operation, and the different noise reduced levels follow as “level 1”, “level 2”, and so forth. The name of a power curve also mentions whether it has been calculated or measured (when the information is available).

NOTE on Air density:

The air density, which has to be entered along with the power curve, is the one that the power curve is valid for. Below a few examples:

1) The power curve is measured at an air density of 1.1 kg/m³ and after that, normalized to a standard air density of 1.225 kg/m³. In this case, the standard air density of 1.225 must be entered.

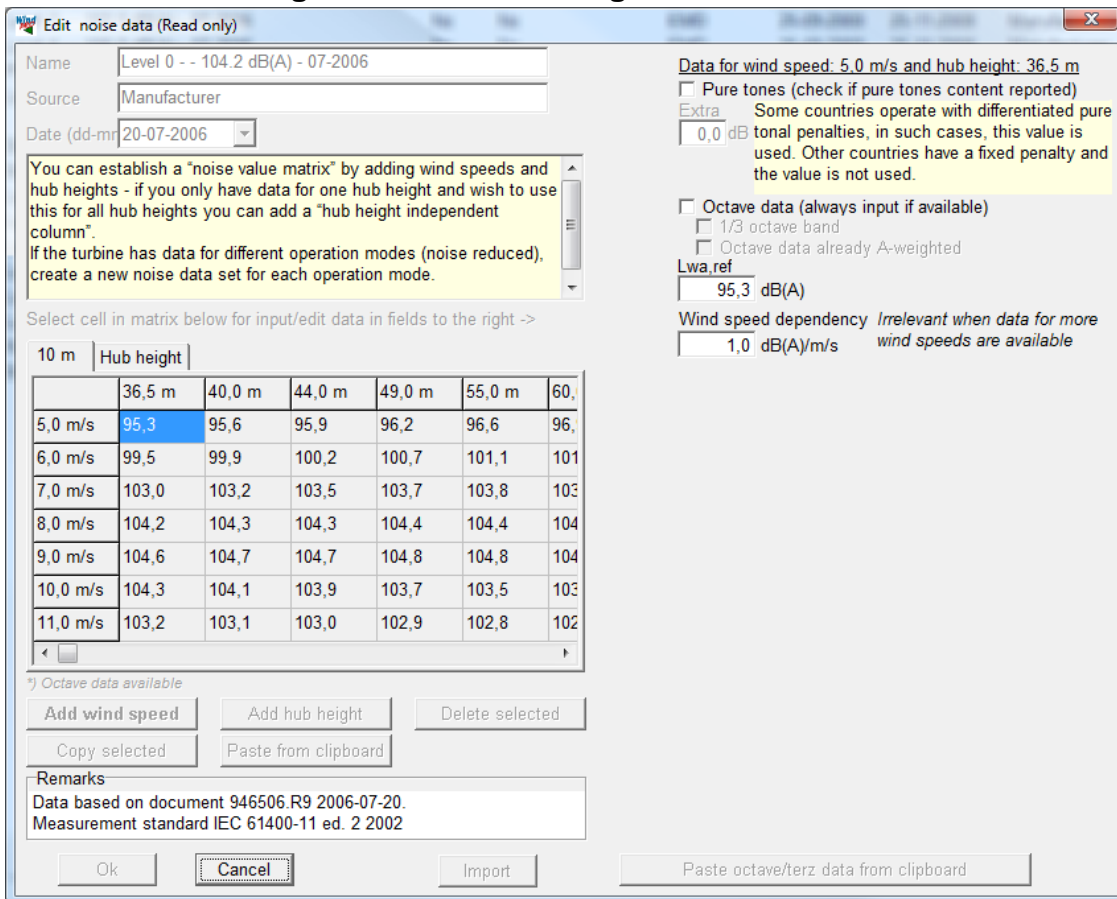
2) A power curve is recalculated and entered with an air density changed from 1.225 kg/m³ to 1.05 kg/m³ (thin air conditions). Then the air density value of 1.05 must be entered (as well as when entering a power curve in the later calculation where used with thin air conditions). The recalculated power curve will then be saved correctly as well as used correctly on the specific site.

Regarding the power curve information, it should be noted that the selection of the Ct curve affects the array loss calculations.

Click on the “Graph” button to get a plot of the power curve and the Ce curve respectively.

It's possible to copy the power curve to a spreadsheet. Mark an arbitrary point inside the power curve (right-click and choose copy). In this fashion, it's possible to copy a power curve or a CT curve to a spreadsheet. Pasting into a power curve can be performed in the same fashion.

2.6.3.2 WTG Catalogue noise data editing



The Tab Sheet “Noise Data” includes information on the noise level at a given wind speed and hub height.

The name of the data set has the following structure:

Level: 0 (no noise - red.), 1,2,3...

Type: e.g. Measured, Calculated

Name: e.g. 105 dB(A)

Date: ..

Level 0 corresponds to the “no noise-reduced” operation, and the different noise-reduced levels follow as level 1, 2,....

Each level can contain data for different reference wind speeds and hub heights organized in a matrix. For each combination (wind speed/hub height), there can be octave data.

The name of the noise data matches with a power curve with the same name. This power curve corresponding to this noise-reduced mode of operation should be used to make the energy calculation.

Pure Tones

If the noise measurement report states that pure tones are observed, then the field "Pure Tones" must be marked. Pure tones will result in more restrictive requirements in the calculation models.

Octave Data

Data available as octave band values (i.e. for 8 standard frequency levels), can be entered. This gives a more precise calculation, but it's not a requirement in most models used today.

Frequency Data

Data available as octave band values (i.e. very detailed, given on XX number of standard frequency levels), can be entered. This gives a more precise calculation, but it's not a requirement in most models used today.

A-weighted

If the data are given as octave band levels, this information may also be given as A-weighted values (if so, it should be stated in the noise measurement report). In this case, you should mark the field "A-weighted".

Wind speed dependency

If data are missing at given wind speeds, WindPRO will use the wind speed dependency factor to calculate the missing noise data. By default, it's set to 1 dB(A)/ m/s but it can be changed by the user.

2.6.3.3 WTG Catalogue visual data editing

Visualization data - describing the geometry of the turbine and its color(s)

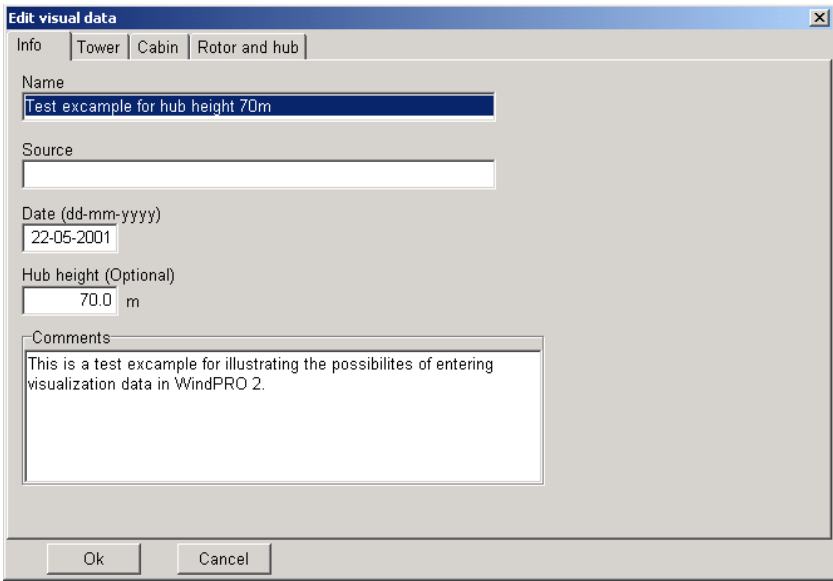
The visualization data are divided into:

Tower
Nacelle
Rotor/Hub

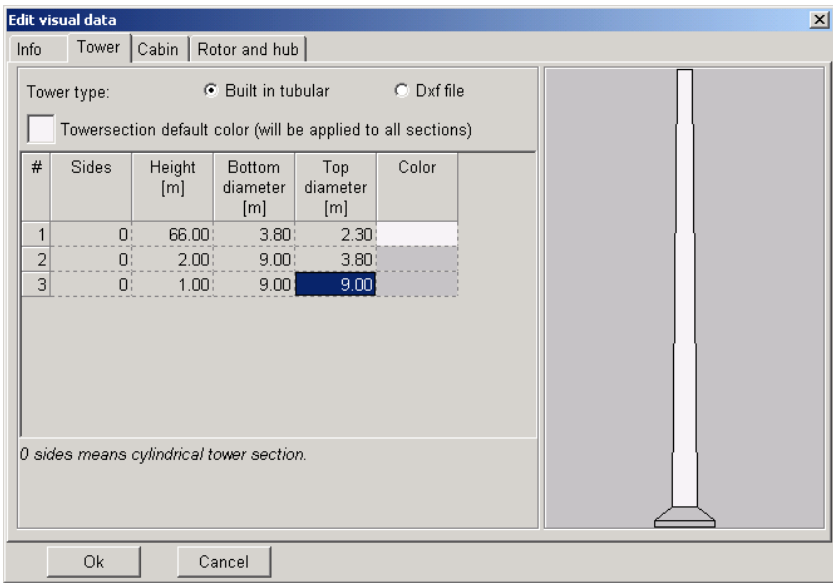
Please notice that a visualization of the input data is shown on a sketch during the input phase. You can build both the tower and the nacelle using up to 10 sections. Note also, that skew edges (different top and bottom lengths) are only allowed for the outer sections of the nacelle.

Lattice towers can be selected from a .dxf (AutoCAD) file. Some standard towers are available from the WindPRO\dxf\ library, but you can also draw your own lattice towers (see also the comments on .dxf files in section 1 of this chapter). Lattice towers are automatically scaled to the correct hub height and can also be scaled to certain widths at the bottom and top of the tower.

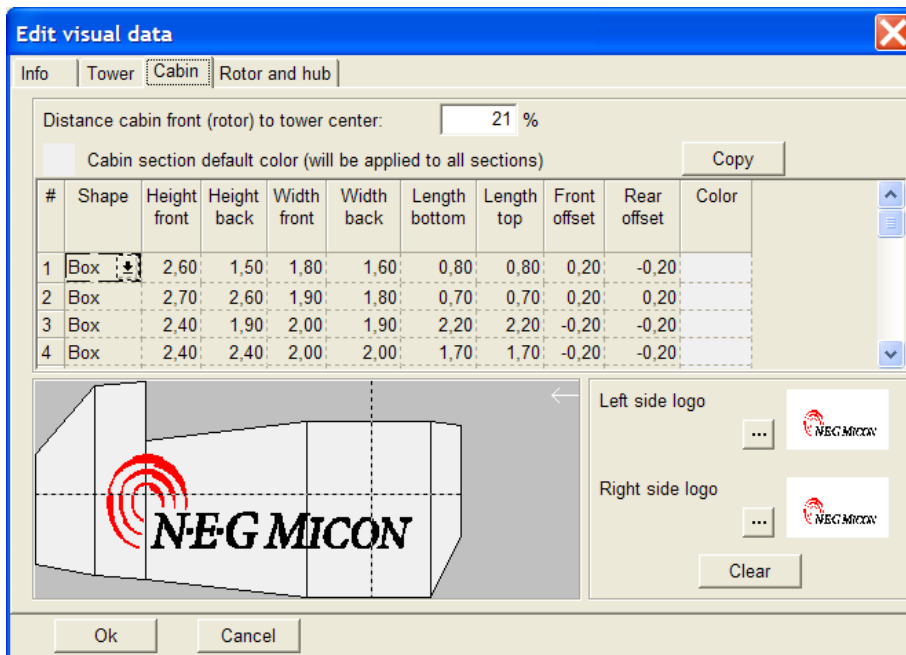
An example is given below:



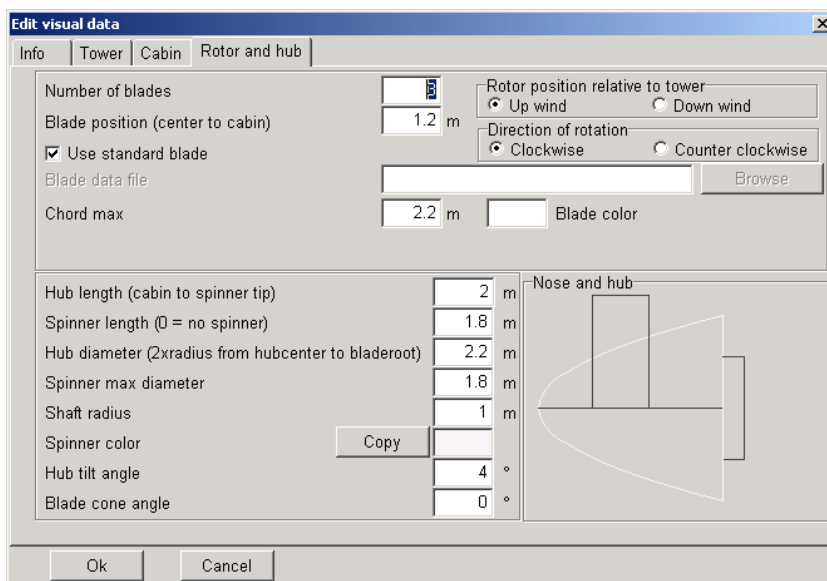
The Tab Sheet “Info” provides the ability to choose a specific hub height. Normally only one data set for all hub heights is provided and the software automatically stretches the tower to the hub height given in the WTG data input field. If data for more hub heights are entered, it will be possible to select the best-suited for the given hub height when selecting the WTG.



The tower can be a built-in tubular tower or a .dxf file, which allows full flexibility to specify the tower with an AUTOCAD drawing. Note that the AUTOCAD drawing has to be drawn following some specific rules (contact EMD to get these). A tubular tower can be fully round or with a user-specified number of sides (edges). More sections can be applied (e.g. 3 sections as shown above). More sections are added by placing the cursor in the lower right data line and pressing the <Enter> key. Data lines can be rearranged by dragging them (right-click with the mouse on the section number column).



The cabin is designed in vertical sections. A bitmap can be attached with a logo. You have to adjust the bitmap yourself so the size and placement on the cabin is correct. The bitmap will use a square around the whole shape for positioning, so it's just a question of having the right bitmap canvas size relative to the logo size.



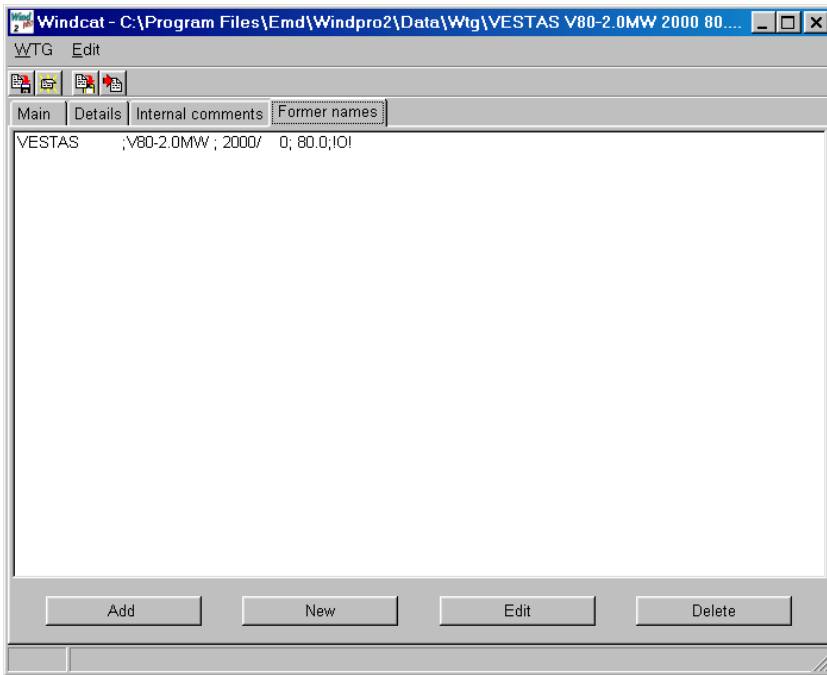
It's possible to choose up-wind or down-wind. This, together with the wind direction set in the Camera Object in Photomontage, determines on which side of the tower the rotor appears. Direction of rotation is only important when creating animations.

By deselecting "Use standard blade", you will have complete flexibility to design the blade yourself. Normally, it's only the addition of different color stripes (e.g. different blade-tip color) that it will be necessarily. Even in short distance visualization it won't be possible to see different blade shapes on a photomontage.

2.6.3.4 WTG Catalogue eGRID data editing

The eGRID data of the WTG catalogue are fully described in the eGRID chapter of the Manuel. Please refer to Section 10.1.4.

2.6.4 Former names



Here, former names from previous software versions can be given so that restructuring names will not affect the link from former projects to the specific WTG type.


2.6.5 Creating a new wind turbine

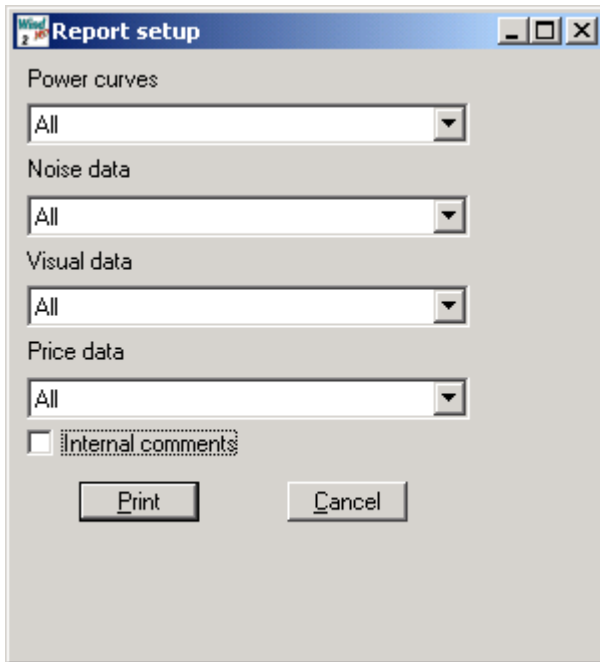
2.6.5.1 Copying and editing an existing wind turbine

It's often advantageous to use an existing turbine as a template for a new one. This can be done by entering "edit mode" of the WTG and then from the menu bar "WTG", choose "Create copy". Now the turbine is ready for editing and can be saved afterwards.

After selecting the "New WTG" icon, you are presented with a blank input form. If a manufacturer is not listed in the "Manufacturer List", you can create a new one under this menu item. The same applies for several other fields where you can select information from a list.

2.6.6 Printing WTGs

 When a WTG is "open" for view/editing use the print option to select which parts of the data to print (see Report setup below).



When one or more WTGs are selected in the WTG Explorer, all data for each selected WTG will be printed. The print function can be selected from the WTG menu drop-down by right-clicking or simply with by pressing the <Ctrl + P> keys.

2.7 BASIS – Import of existing WTGs

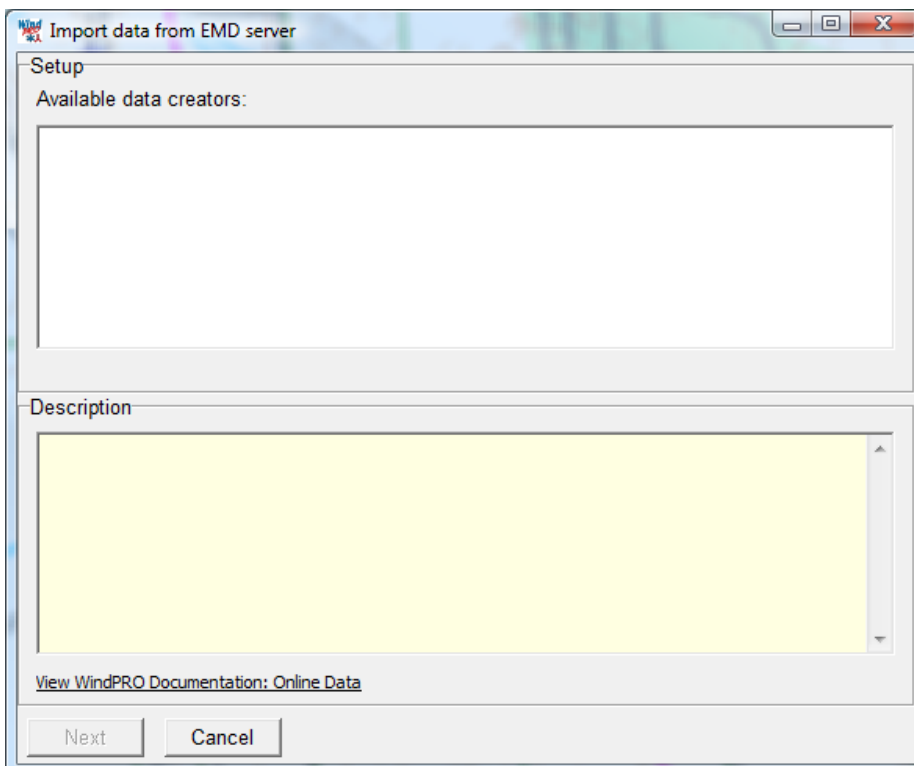
2.7.0 Introduction to Import of existing WTGs

The “Import of existing WTGs” (into a project) is a very powerful function. It can be used for project design in local areas where there are existing WTGs, as well as for planning for a larger region where existing WTGs must be taken into consideration. The use of existing WTGs is especially powerful if information on actual energy production is available. Then, existing WTGs can have a distinct influence on the energy calculation in the new project. Also, it’s often necessary in environmental calculations to include existing WTGs in order to calculate the impact on the environment not only from the new turbines, but also from all existing WTGs in the neighborhood.

2.7.1 Importing from On line data



Via this icon it’s possible to import existing WTGs from the EMD Online data server. Import from a local file is until ver. 2.7 available, but no longer updated.



When there are available existing turbine data for the region, these will appear in the list above. So far only Danish turbines are available, but it is our hope to include data for more countries in the future.

When data are available, the radius for import can be specified and the turbines will be established as “existing WTGs” in the project.

2.8 BASIS - Line Object (height, roughness and 3D-A lines)

2.8.0 Introduction to the Line Object



The WindPRO Line Object gives you a unique visual control over the height contours or roughness lines, which are often the most important inputs for the energy production calculation. The Line Object also contributes to a significant reduction in workload when the user has to find and read Z-coordinates on traditional maps before calculating, e.g., shadow flickering, noise impact and visual impacts. Height contour lines also form the basis for computer generated 3D landscape models used for visualization.

One of the major advantages of the Line Object is that it allows the user to establish on-screen lines just by clicking with the mouse and, in the same way, it's easy to edit existing height contour or roughness line files. The latest development (from version 2.4) also offers valuable help tools in the auto-digitizing features based on color recognition (hold down the <Ctrl> key), or the auto point mode (hold down the <Shift> key) when moving the mouse. Backward deleting of points is performed by holding down the <Alt> key .

Important terms when using Line Objects with height contour lines:

DHM - Digital Height Model: Normally used for a table of (X,Y,Z) values defining discrete points on the surface. An interpolation routine such as the TIN model (see below) is needed to find the Z-values for points in between the table values.

TIN - Triangular Irregular Network: The triangle model established from the digital points (basis of the contour lines), which makes it possible to calculate Z-coordinates at any point. The TIN will usually only be calculated for a selected section of the digitized lines, as they are only needed within the area where the objects are placed. Calculation time depends on the size of the TIN-radius. Due to the large number of calculations required when there is a large amount of data is present, there are very advanced features for the TIN calculation (for more information see Section 2.8.2.2).

2.8.0.1 File formats for height contour lines

WindPRO can load the following file types:

WindPRO format: *.wpo - Internal format optimized for speed. Height contours or roughness lines in one file. Includes the calculated TIN model, which means that the TIN calculations don't need to be done every time you reopen a project.

WAsP MAP file: *.map - From the energy calculation program WAsP (Risoe). Both height and roughness can be included in the same file, but when saved from WindPRO, only the data from selected purpose is saved. For this reason, always make a backup of the original .map file before editing from the Line Object. Note that some binary versions may not be read from the Line Object. If this happens, open the file in WAsP and save it as an ASCII .map file (with the DUM* command in DOS-WAsP) before loading.

(The two formats discussed above are the only two that the WindPRO Line Object can save)

KMS GTX file: *.gtx - from the Danish Ordnance Survey. Only height contour lines can be read from this format.

AutoDesk *.dxf file: *.dxf - standard format from e.g. AutoCAD digitization).**

** Please note, that reading of .dxf files requires that certain regulations be respected when producing the .dxf file.

*.hgt – format of the Shuttle Radar Topography Mission (loads direct from the hgt.zip files)

*.xyz - grid format where you know the Z-value e.g., for each square of a 50 m x 50 m

ArcView *.shp files – standard GIS (Geographical Information System) format from ESRI.

DEM files – standard GIS format in the USA. These files must be converted to *.dxf format using e.g. Micro-DEM before they can be utilized. Please see section 2.8.0.3 below

2.8.0.2 EMD online data

The Online data makes it very simple to establish elevation data. Simply click the online button in line object and everything works automatically. First the service check If there are any data sources available for the site location, then you select the source and specify the height and width or the area you want to cover with data.

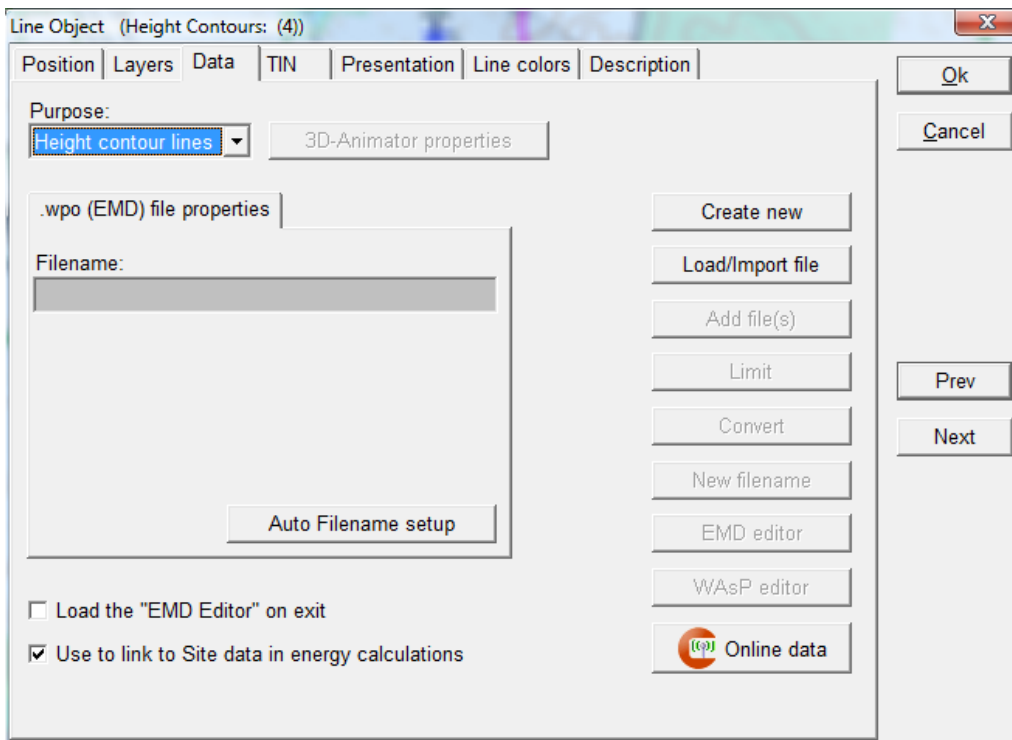


Figure 5 Shuttle Radar Topographic Mission data with 90 m equidistance will be available in the line object. Set purpose to height contours and choose the “Online Data” button.

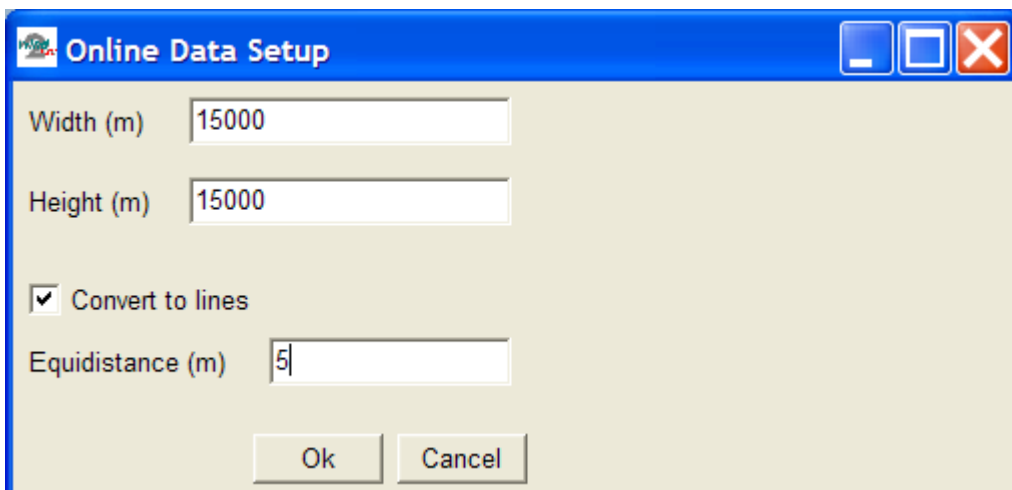
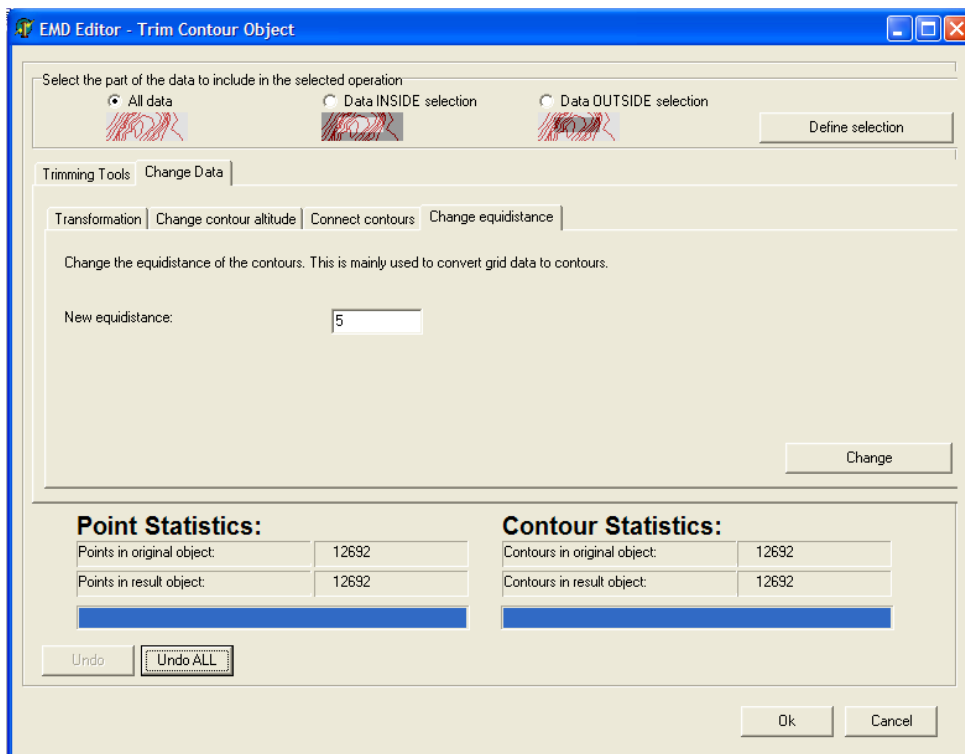


Figure 6 For elevation data, only SRTM data are available at present, but later more sources will be added. You will be able to choose “convert to lines” and the equidistance (contour separation). Then the downloaded SRTM data are automatically converted from the 90 m grid points to connected height contour lines.

2.8.0.3 Conversion of X,Y,Z and hgt data formats to lines

Height data from .xyz and .hgt files are inserted through the Line Object as point data. Point data are usable in all WindPRO modules except for energy calculations based on the WASP interface (PARK, RESOURCE and WASP interface).

If you want to use the height data in WASP, or show the data as a line, you need to convert the point data to lines using the EMD Editor. The conversion is done in the EMD Editor by changing the equidistance of the file.



In the EMD Editor, click “Change” and then “OK”.

2.8.0.4 Conversion of DEM data formats to .dxf files

DEM files can be downloaded from the Internet. Try the Internet locations:

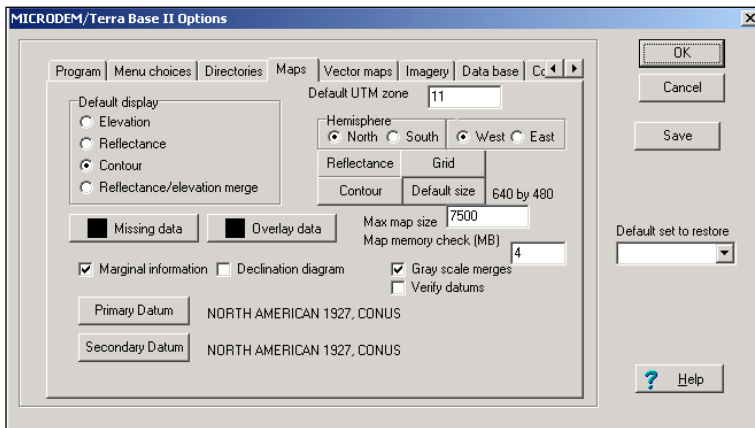
www.mapmart.com

<http://data.geocomm.com/dem/demdownload.htm>

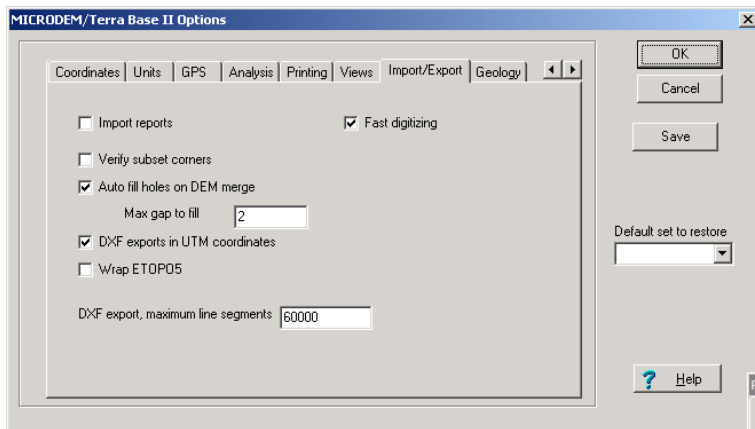
In order to convert the downloaded DEM file to DXF format, which can be read by WindPRO follow the procedure below:

Install MICRODEM on your computer if you don't already have it installed. There is a copy of MICRODEM Version 6.0 on the WindPRO installation CD.

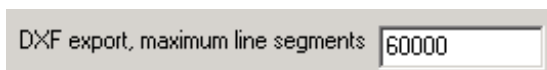
Run MicroDEM, then click on “Options” and enter the Tab Sheet “Maps”. Set the Primary and Secondary Datum to North American 1927 Conus.



Next, find the Tab Sheet “Import/Export”.



Set DXF export, maximum line segments to 60,000.



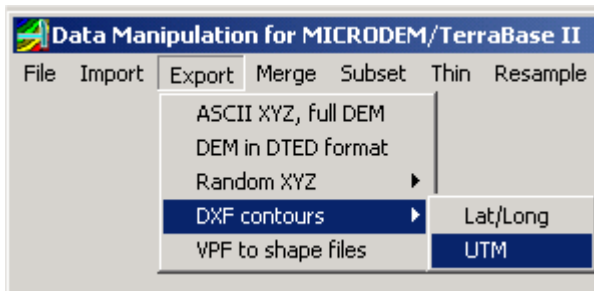
This makes the MicroDEM export larger .dxf files so there will be fewer files to load later on.

Click on “File”, then “Open DEM” and choose the files one-by-one in order to open them.

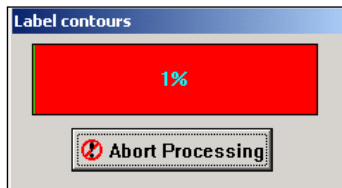
Next, open the file. The “Label contours” operation can be aborted. Now close the contour file. The only reason to open the file is that the “Export to DXF” function automatically takes the last opened file.



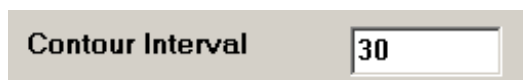
Next, click on the “Data Manipulation” icon and select “Export”, then “DXF contours >” then “UTM”.



The contours are now loaded in again. The “Label contours” operation can be aborted



Depending upon the settings in MicroDEM (and/or the region), the unit for contour interval may vary. The default unit seems to be feet, so set the contour interval to 30 feet (approx. 10 m) so that the height contour files don't get too detailed. Later on you can digitize important regions manually.



The DXF height contour vectors will be saved in: C:\mapdata\DXF (this directory was created when installing MicroDEM, and it must exist in order for MicroDEM to work properly).

The .dxf files can be loaded directly into the Line Object in WindPRO. The .dxf files should be converted to .map or .wpo format immediately after loading as this will greatly reduce the file size.

2.8.1 How to use the Line Object

In the current version, the Line Object can work with three types of data:

Height Contour Lines - The Line Object can use a number of different formats (see section 2.8.0.1), but lines can only be added or edited if the format is converted to the WASP .map format or to the *.wpo format.

Roughness Lines - The Line Object can use .map or .wpo file formats. Please note that the Area Object (next section) can also be used for digitizing roughness areas, which can then be exported as roughness lines. This is a very useful method, because it protects against crossing and inconsistent roughness lines. We recommend using this method for new projects, since the new project won't be based upon previously established .map roughness line files.

3D Animator Lines - Used for roads or tracks to follow when creating a virtual drive or flight in 3D

Height contours as well as roughness lines can be used together with WASP or WindSIM for energy calculations.

The modules DECIBEL, SHADOW and VISUAL can only use the Line Object if it contains height contour lines. With the Line Object, you can calculate triangles (TIN) between all the digitized points to allow interpolation of elevations (Z-values) to any specific location on the map within the specified TIN radius. Zones of Visual Influence (ZVI) are calculated based upon height contour lines, so for a ZVI calculation, no TIN radius is needed.

The principle is that, WTGs, noise sensitive areas, shadow recipients, etc. that are included in the calculation will automatically take their Z-coordinate (their height above sea level) from the TIN.

The calculation of shadow isolines (SHADOW module) and noise isolines using the TIN provides a more realistic calculation of the isolines by taking the variation of the terrain's elevation into account.

For visualization, you can use the TIN for the calculation of either an artificial landscape, or the visualization of a wire grid landscape. The latter is well-suited to control the camera model or to view the WTG project in proportion to the landscape without "disrupting" elements in the landscape.




For 3D Animation, a Line Object can be assigned the special purpose "road". This presents two possibilities:

- It can show a road bitmap in the 3D animation
- It can be used as a track that the camera "locks on to".

Both can be used individually, or in combination so that you can see the road you are following (see Section 5.3.4 for further details).

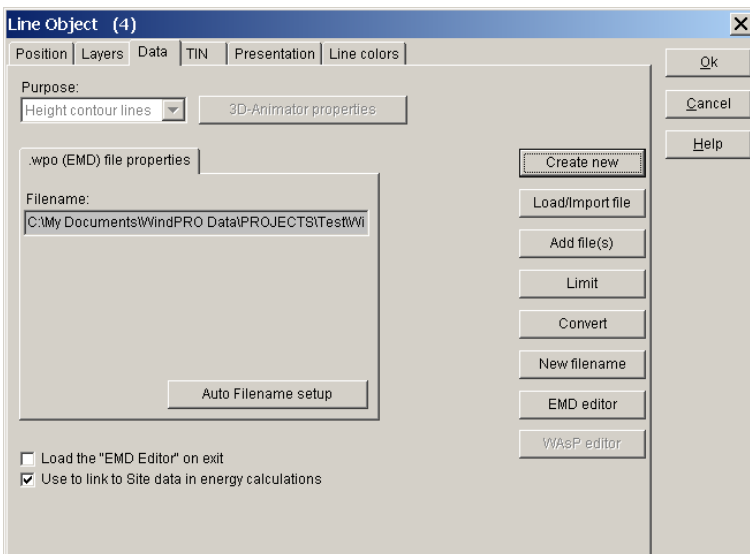
2.8.2 Establishment and presentation of the Line Object

Line Objects can be edited on-screen when they are in edit mode. The symbols shown below indicate whether the Line Object is in edit mode or not. You can activate or deactivate the edit mode by right-clicking the object symbol on the map or by pressing the <Ctrl + c> keys when an object is selected.

-  A Line Object which is not in edit mode
-  A Line Object which is in edit mode on the current map.
-  A Line Object which is in edit mode on another map (from version 2.5 this should not occur because you now can change maps while staying in edit mode).

The same principle applies for the Area Object and WTG Area Object.

2.8.2.1 Tab Sheet: Data



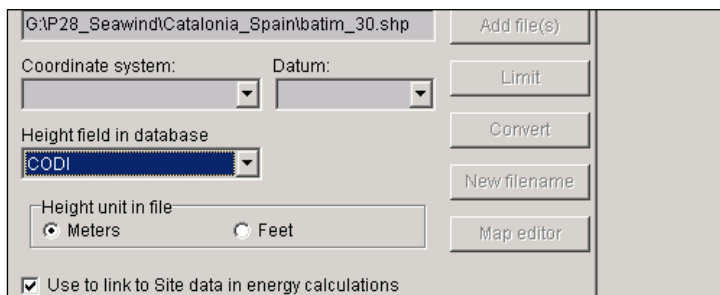
Create new - Used when starting digitizing data from scratch. First, select the input type, i.e. height contour lines, roughness or 3D animator lines in the "purpose" field.

You can choose to save data in the WAsP .map file format or in the WindPRO .wpo file format. When choosing a file format, the following points should be taken into consideration:

If files are large, the .wpo format is faster and for large TIN calculations (height contour lines only), the .wpo format has the advantage that the TIN is saved in the .wpo file, avoiding the need for recalculating when reopening the project. On the other hand, the .map file format has the advantage that the file can be used for stand-alone WAsP calculations (if this is relevant), and that the file can be loaded directly from the WAsP map editor (if installed and the path is set under "options", see Section 2.2.2.2). However, you can convert between these two formats at any time using the "Convert" button.

Load file - Loads an existing file with line data. Additional file formats can be loaded (imported). The coordinate system in which data is given must be known. If the coordinate system is a local system (or a system unknown to WindPRO) the system can be defined in "Project properties" before loading.

When GIS shape files with height contours are loaded, the dialog box changes as shown below:



In addition to the normal input, the projection datum (e.g. ED 50) must be entered along with the selection of which field in the shape file contains data on the elevation and the height unit used.

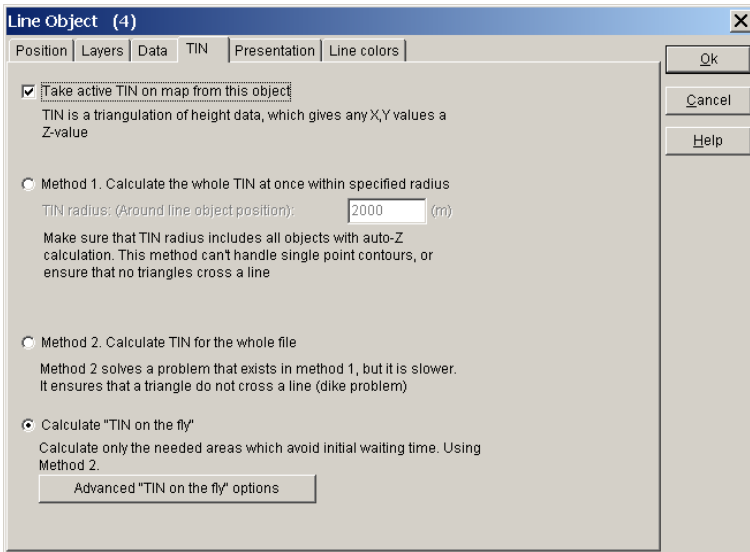
Add file - Used for merging additional files together in the same object. (see Sections 2.8.0.1 and 2.8.0.2 for file formats and conversions).

By clicking on "New filename", the file name of the file in which data is saved is changed and a copy of the file is made. The following corrections will only appear under the new file name.

After loading large files, you may not wish to use the entire amount of data for the specific project. In order to make the file-handling process faster and to save space on disk, you can limit the file so that only lines with points inside a given radius will be stored. For more advanced data-limiting operations on a .map file (e.g. cut out a square, spline, etc.), the WAsP Map editor can be used. You can also use the new EMD editor since most functionality from the WAsP map editor now exists directly in WindPRO. The EMD Map editor also works with the Area Object (see Section 2.13 for a detailed description).

By checking the box "Use to link to Site data in energy calculations" the data contained in the Line Object will be used by default in energy calculations when creating a Site Data Object.

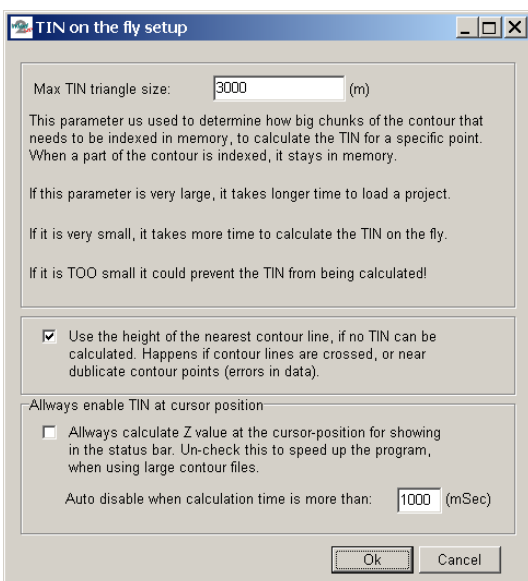
2.8.2.2 Tab Sheet: TIN



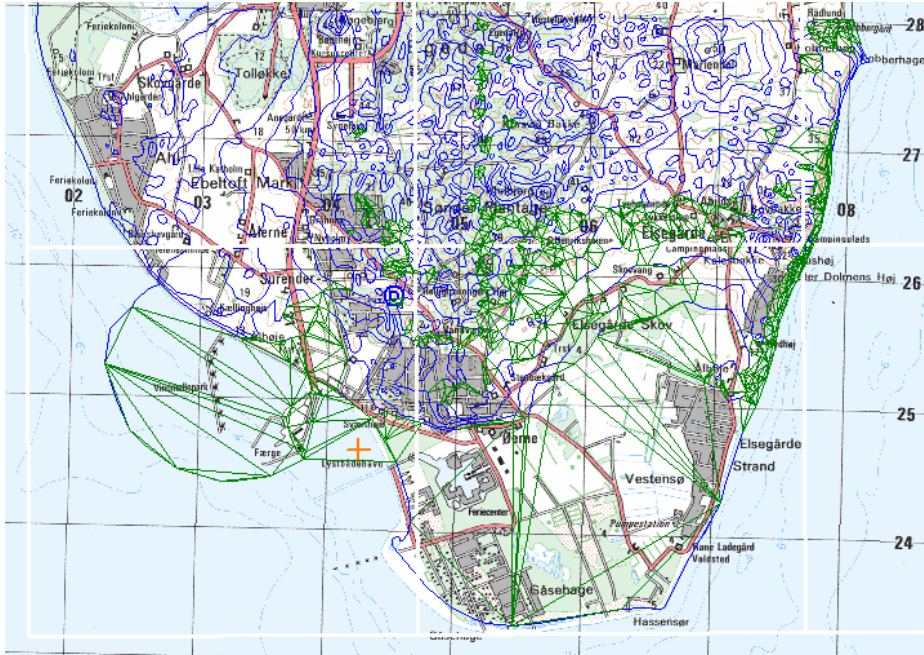
The TIN calculation can be very time consuming. For this reason, advanced settings for the TIN calculation are available. For smaller, less complex projects with a limited amount of data, method 1 or 2 will be the best choice (typically used when a .map file is preferred). Method 1 is the fastest, but doesn't guard against crossing triangles, a problem that can cause problems, particularly at dikes, where long lines based on a few points can result in triangles across the dike.

For larger amounts of data, the "TIN on the fly" method (used as default) is recommended. With this method, the TIN is calculated only as-needed while you work. The TIN database is built up as a background calculation without disturbing the current operation and will always have the necessary TIN values (e.g. where the objects is placed). It's important to know that the "TIN on the fly" calculation will be auto-disabled if it uses too much of the computer's resources. The default setting is to auto-disable the calculation if it takes more than 1000 ms (1 second) to complete.

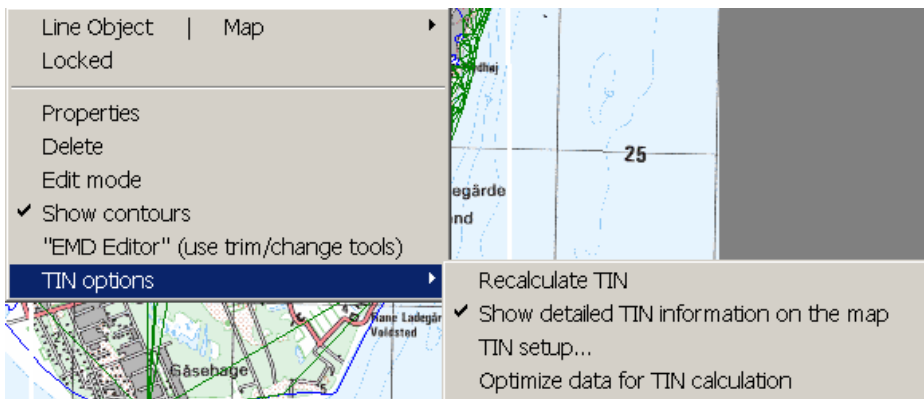
In the "Advanced "TIN on the fly" options", the unchecked box "Always enable TIN at cursor position" in the form below indicates that "TIN on the fly" at the cursor position has been disabled. This is simply because when working with large files, the "TIN on the fly" calculation will interrupt the user too much. When the TIN is needed in some calculation, the TIN is automatically calculated for the needed region. If you need the TIN for inspecting Z-levels in specific regions while working on the map, you can enable "Always enable TIN at cursor position" and eventually increase the auto-disable time limit.



When Calculating the TIN on the fly, the model is divided into a number of squares as shown below. If there are TIN triangles larger than this grid size (white lines shown on the map), there may be problems calculating the whole region. For this reason, the “Max TIN triangle size” should be set to avoid this problem.

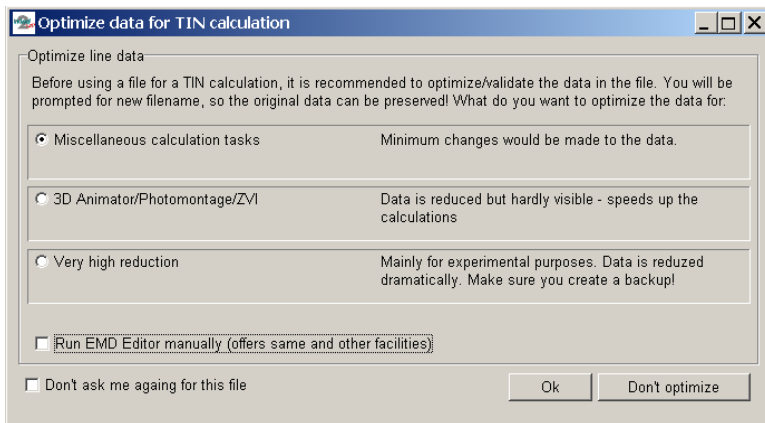


In the map shown above, the green lines show the TIN triangles that have been calculated so far. These can be shown by right-clicking on the Line Object or by right-clicking in the square in the bottom line where the Z-level is shown. After right-clicking, the menus as shown below will appear. Note that the option “Show detailed TIN information on the map” has been selected, which allows the green TIN triangles to be visible on the map.

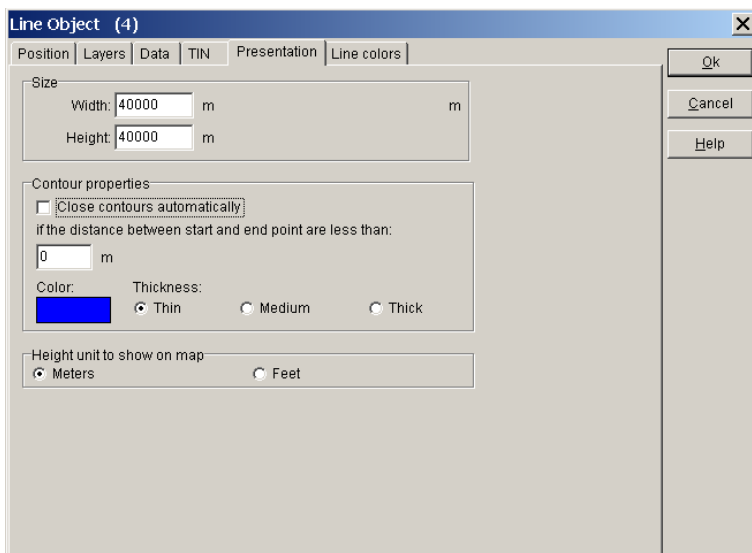


Optimize file when loading

When a file is loaded, by default, an optimizer will pop up that removes unneeded points. The first of the three options can be chosen without the loss of any relevant information. Data will be lost when choosing option 2 or 3, but calculation speed will be increased. The selection should be made based upon your modeling requirements.



2.8.2.3 Tab Sheet: Presentation



On this tab sheet, you choose how much of the line data you want to see on the screen. Usually it's only necessary to limit the amount of data if you work with very large data sets. The TIN radius is the radius within which the Triangular Irregular Network is created. It's only within this radius that the Z-coordinate is automatically calculated and an artificial landscape can be generated.

Due to calculation time, it may be necessary to limit the calculation of the TIN to the specific area for which you need full 3D information.

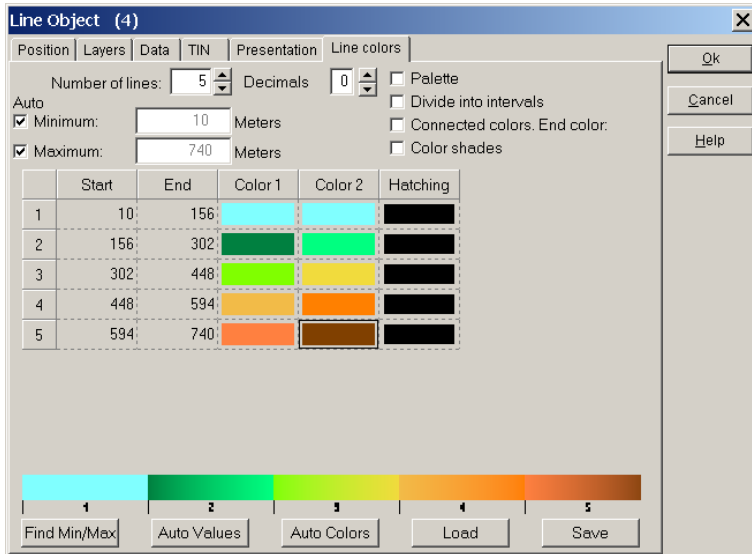
You may set the object to "Close contours automatically" for lines where two end points are positioned within the specified distance (this may improve the accuracy of the calculation and create nicer looking documentation).

You can also change the color and thickness of the isolines.

Lastly, you can choose whether the Line Object will show data in meters or feet.

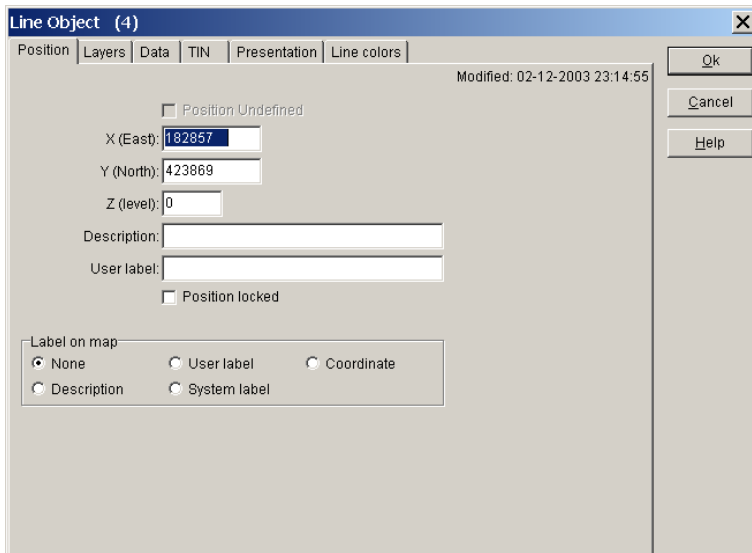
Note: In WindPRO, height contour data is always stored in meters, since e.g. WAsP always assumes meters when calculating. So if you accidentally end up with a .map file that is in feet, please use the WAsP map editor to convert it to meters. WindPRO does not convert the height data. It only offers the ability to show and digitize in feet.

2.8.2.4 Tab Sheet: Line colors



Line color definitions can be freely set. Line color definition schemes can be saved and reloaded later.

2.8.2.5 Tab Sheet: Position



In the "Position" tab sheet, you will find the coordinates for the object that represents the Line Object. These coordinates are important when you wish to relocate the object. It's recommended that the object be placed close to the site center.

2.8.3 Digitizing and editing lines

2.8.3.1 Digitizing new lines in simple mode

When a new Line Object is placed on the background map, it will be in edit mode by default. Place the cursor where you want to start digitizing the first line, then right-click and select "Create new contour". You will now be asked to enter the elevation (for height contour lines) or the roughness on the left and on the right side of the line you are going to digitize (for roughness lines). Then simply click along the line you want to digitize.



Note: In the contour elevation form, the step size when using the up/down arrows can be set in the "step" field. This is helpful when digitizing lines of equidistant elevations.

When you finish a line, you can choose between "Stop" and "Close". If you choose "Close", the last point will then be connected to the first one you digitized.

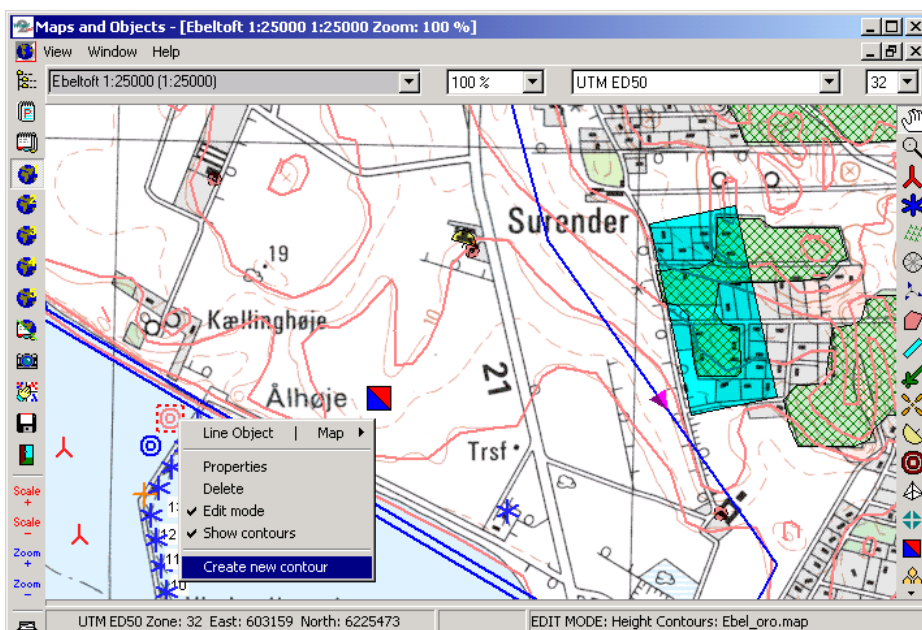
Important: When you reach the edge of the map shown on the screen, you may want to move the map while digitizing (without stopping). This can be done by setting one of your mouse buttons (if more you have than 2) to the function "middle mouse button" in Windows mouse setup. When this button is held down, you can move the map while digitizing.

Note on digitizing roughness lines:

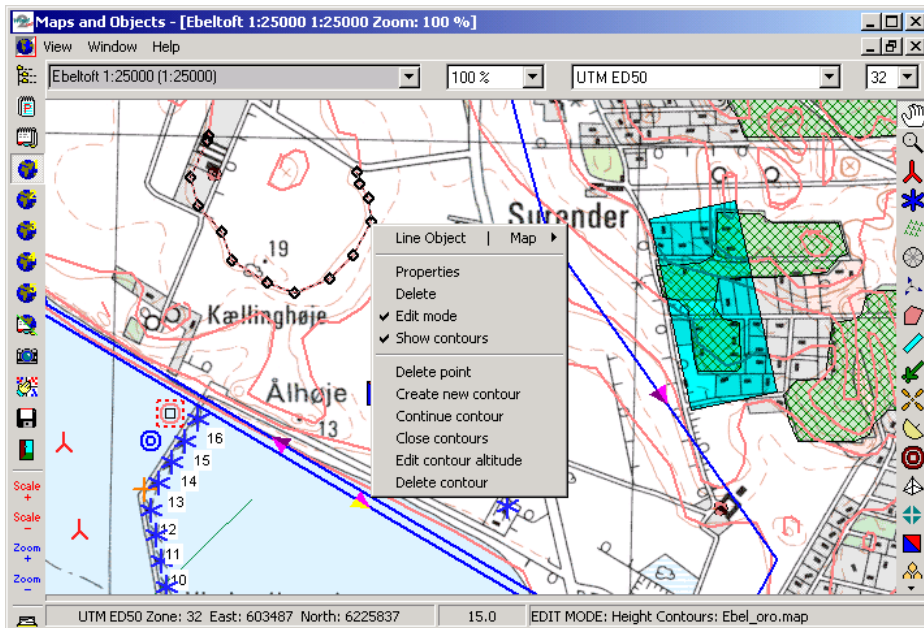
It's necessary to enter the roughness values on both the left and right side of the line in the direction of digitization. It's the user's responsibility to ensure consistency between different roughness lines. Considerable differences, e.g. unintentionally crossing lines, can result in large calculation errors with no warning message given, when using WASP. Another way to digitize roughness lines is to use the Area Object. With this method, area polygons are digitized, and lines are then exported. The export procedure makes sure that there are no consistency problems with the lines.

2.8.3.2 Viewing and editing existing lines

The Line Object makes it possible to import a file containing height contours on top of a background map. If the object is marked "Edit mode", you can edit in the imported contours by clicking once on the curve to activate it. You can then drag the individual lines or points to their correct positions by holding down the left mouse button when the cursor is inside a point and then dragging. You can also add new points, delete points, connect lines, or add new lines. In addition, it's also possible to edit the values of the individual lines.



As shown on the map above, when right-clicking on the object, a pop-up menu appears containing several options including the "Edit mode". Lines cannot be edited unless the Line Object has been set to "Edit mode".



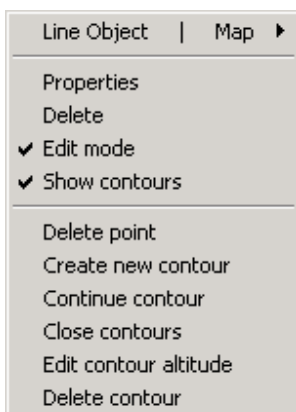
As shown above, with the Line Object in “Edit mode”, clicking on a line will activate all the points in that line. When you hover on the height contour line, its value will be shown in the line at the bottom of the window.

After selecting a line, you can drag any one of the activated height contour lines in any direction. You can also right-click on the isoline to get a menu, which gives you several options for further manipulation.

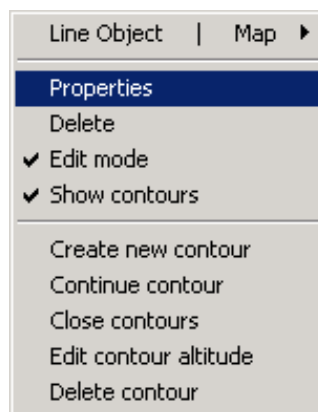
Note: Right-clicking will present different menus depending upon whether the cursor is placed on a point or on a line between two points (see below).

Another line edit function is to connect two lines. If you click on one line, and then hold down the <Ctrl> key while clicking on another line, you can select "connect contours" and the two lines will be merged. If the two lines have different values, you will be asked to enter a value.

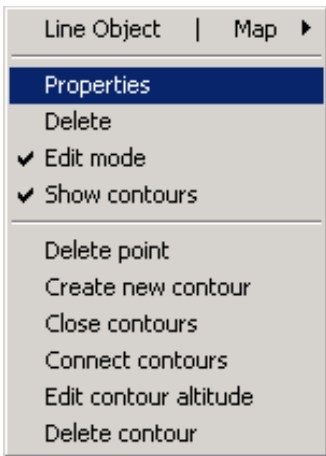
Shown below are the four "right-click menus" that can appear when line is activated.



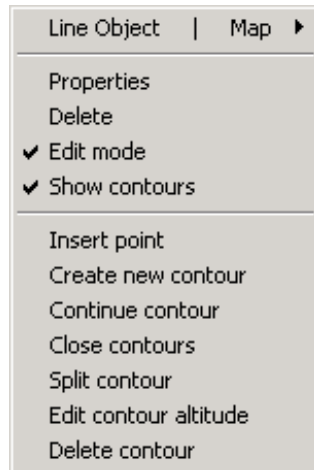
1) Cursor outside the line



2) Cursor on a point on active line



3) Cursor on a line



4) Two lines selected (between points) on an active line

Lastly, when you exit the "Edit Mode", the TIN is recalculated.

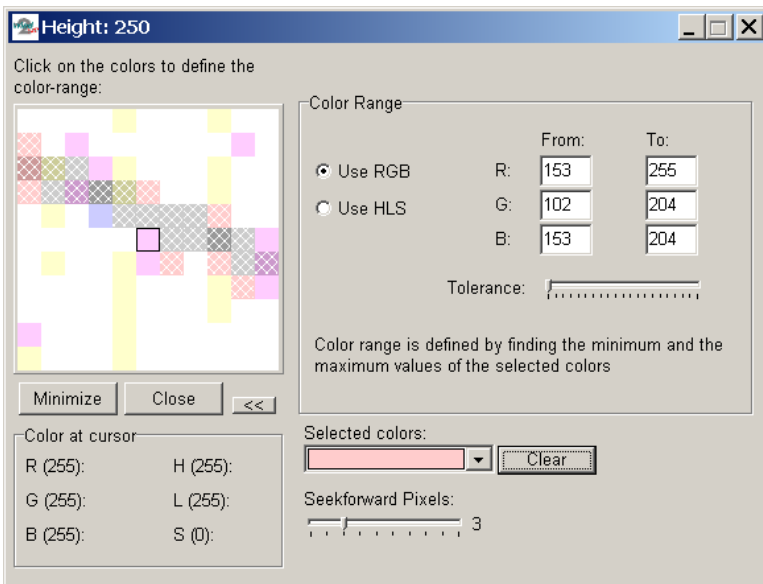
2.8.3.3 Digitizing new lines without clicking

Instead of mouse clicking for each point, simply by holding down the <Shift> key, the software will do the clicking for you. When the mouse is moved while the <Shift> key is held down, the points are set automatically.

2.8.3.4 Digitizing new lines by auto-detect

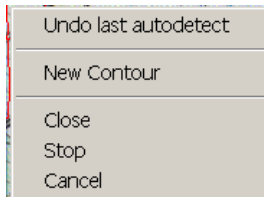
The most advanced way to digitize lines is by letting the software recognize the lines on the map by color recognition. This works as follows:

When you hold down the <Ctrl> key, a window appears in the upper left corner. Place the cursor on a line you wish to digitize then release the <Ctrl> key and move the cursor up into the window. Click on the colors (pixels) that can be identified as having the color information of the contour lines. Diagonal cross-hatching indicates the selected pixel colors (see below).



When the relevant pixel colors have been marked, move cursor back to the line you want to digitize, again hold down the <Ctrl> key and click on the line. WindPRO will auto-detect the line until it comes to a section where it does not know how to proceed further. Click on the line to help WindPRO continue in the right direction. If it finds the wrong way, simply right-click and select "Undo last autodetect" as shown below. In addition, the <Alt>

key or the <Backspace> key can be used to delete the last point and thereby “move backwards”, until the digitized line is back on the track.



Then manually click a few points (release the <Ctrl> key) to help it past the critical point and press down the <Ctrl> key again to continue the auto-detect operation.

It's important to select the right pixel colors in order to achieve successful auto-detection. It's also important that the background map has relatively clean colors for the lines. If it does, then this method can be very efficient and large maps can be digitized quickly.

2.8.4 Save and use data from Line Object

The data file containing the lines is saved when you exit the edit mode. Note that if you are working on an existing file, it will be overwritten. To prevent this (if you've made changes that you don't want to save), open the file from Windows Explorer and make a copy before leaving edit mode.

The Energy Calculation module can use the Line Object's height contour data file (only with WAsP). There are two ways to use the data; by linking the Line Object to a Site Data Object (default) or by attaching the saved file to a Site Data Object. The latter option allows you to use the data without having a Line Object in your current project.

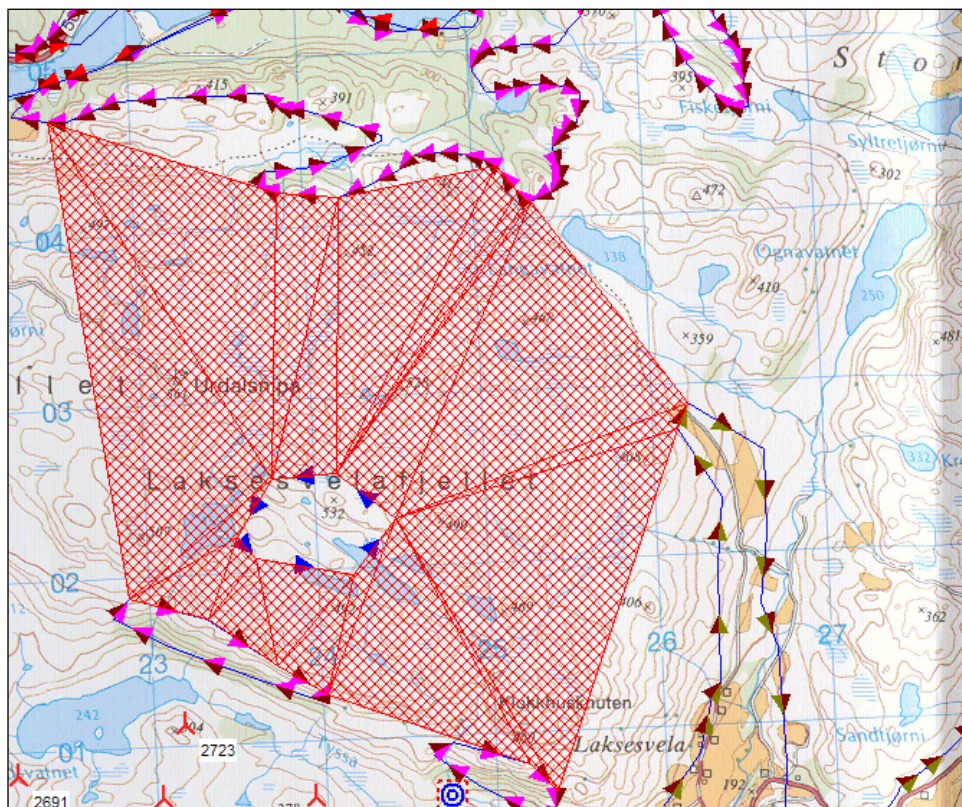
The other calculation modules (SHADOW, VISUAL, and DECIBEL) can only use DHM (the TIN) created within a certain radius around the position of the Height Contour Object. In order to be able to use the DHM you have to mark this option on the Tab Sheet "Position" under the Line Object, and indicate that the Z-coordinates of the relevant objects (WTGs, Shadow Recipients, etc.) are taken automatically from the DHM. This must also be marked on the "Position" tab sheet for the relevant objects.

2.8.5 Trimming data in Line Object

There are a number of tools available for trimming (see Section 2.13)

2.8.6 Roughness consistency check

The Line Object can be used to check the consistency of roughness lines. Inconsistency is indicated as red dots or red shaded areas (see example below).



In the figure shown above, the inconsistency due to an incorrect roughness value assigned to the roughness line digitized in the middle of the area is clearly indicated (red shaded area) by the roughness consistency check.

2.9 BASIS - Area and WTG Area Object

2.9.0 Introduction to Area Objects



The Area Object in WindPRO provides the user with a tool for importing or digitizing areas as closed polygons, each having similar characteristics. Elements such as forests, cities, water, or other landscape feature can be described using the Area Object. They typically have uniform characteristics and so can be treated similarly in e.g. a roughness classification or other landscape evaluation.

The Area Object has the advantage of allowing the user to quickly establish areas directly on-screen simply by using the mouse or importing data from e.g. GIS systems or maps in vector formats.

Note: Digitized areas can be used for other purposes also, and it is important to consider the intended purpose prior to digitizing.

Advanced digitizing options with auto-point settings are available from version 2.4. The auto-point setting is invoked by pressing the <Shift> key. Pressing the <Alt> key launches an eraser tool for deleting points.

If the areas will be used for exporting a roughness line map or for a ZVI calculation, it may require the definition of landscape types. When carrying out ZVI calculations, farm land can normally be considered as one type.

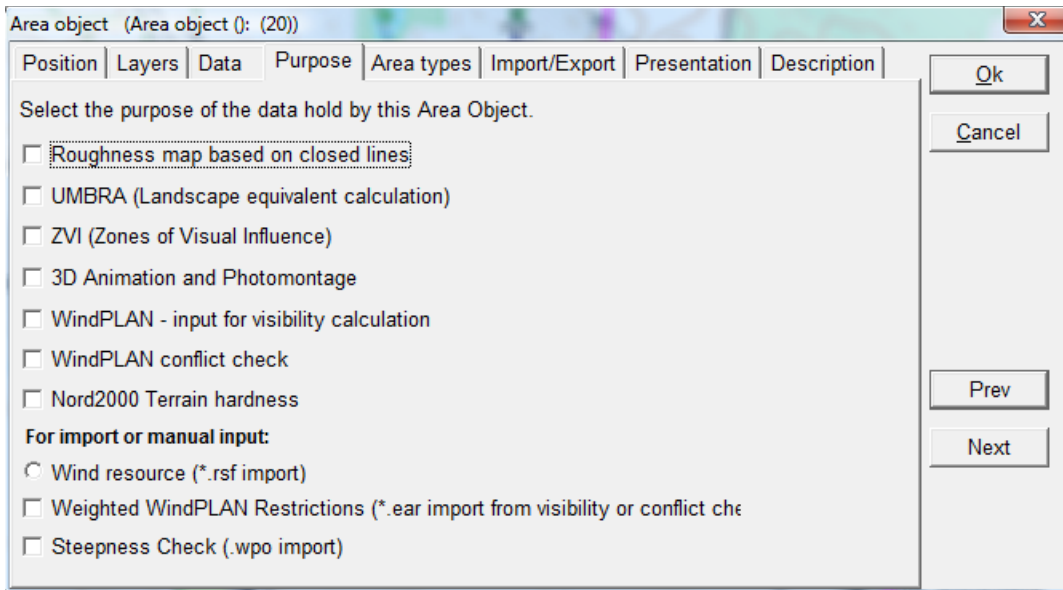
In order to use the Area Object for the export of roughness lines, it's necessary to divide the farmland into different areas controlled by a roughness subset representing the farmland. For example, a division into "farm land with low roughness" and "farm land with high roughness" (many windbreaks) may be necessary.



The WTG Area Object is a special variant of the Area Object, specialized for OPTIMIZE and WindPLAN purposes and for use together with the Park Design Object. See these chapters for further details on this object.

2.9.1 Where to use the Area Object

In the present version, the Area Object can be used for a number of different purposes including the shown below:



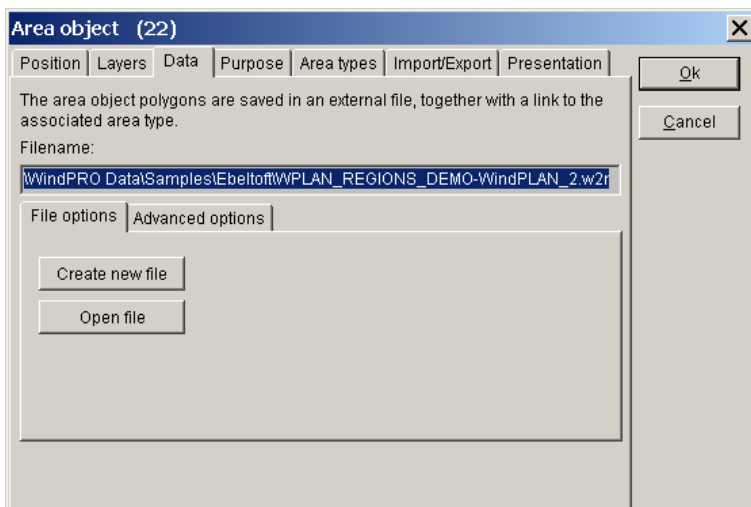
Note that the Area Object can also be used to produce roughness lines, a very useful method because it protects against crossing and inconsistent roughness lines. However, you must perform an “Export to roughness lines”, before they can be used. The exported file must be attached to a Site Data Object (via a Line Object). With regard to crossing lines, the rule when exporting is; if areas overlap, the area with highest roughness value takes precedence over the area with the lower roughness value.

Although roughness areas can also be used direct in calculations, Where EMD has established a converter from roughness areas to roughness roses. It has to be noted this feature go beyond the WAsP model, and for a full WAsP compatible calculation, the export to roughness lines should be used. Direct use of roughness areas in energy calculations shall be seen as an experimental feature so far.

The ZVI, UMBRA and WindPLAN modules depend directly upon the existence of the Area Object, which is the primary data source for the calculations along with a Line Object containing height contours.

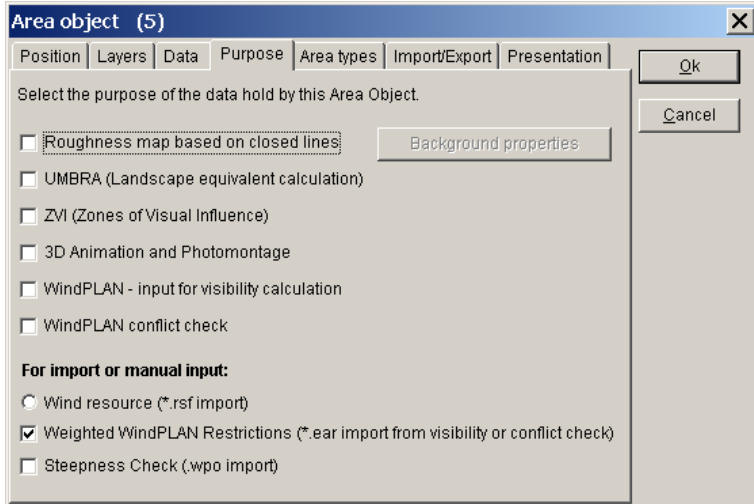
2.9.2 Establishment and presentation of the Area Object

2.9.2.1 Tab Sheet: Data



The data associated with an Area Object is saved in a file. You can create a new area file or load an existing file saved from another Area Object (a WindPRO regions .wpr file). To import data from other sources, see Tab Sheet “Import/export”.

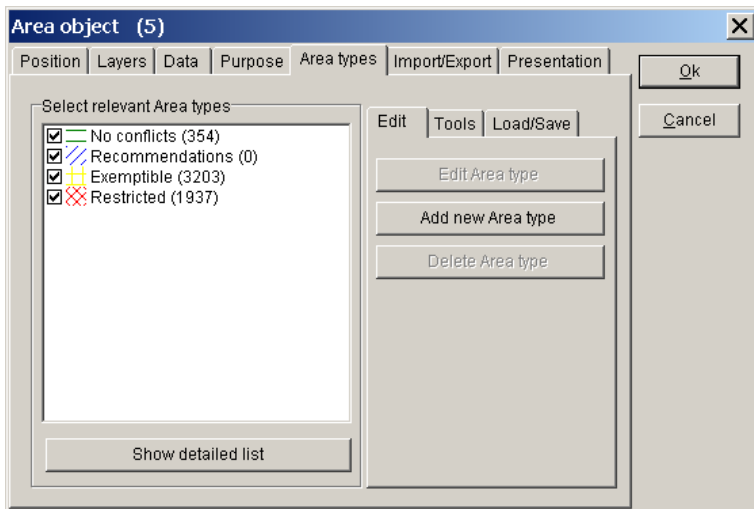
2.9.2.2 Tab Sheet: Purpose

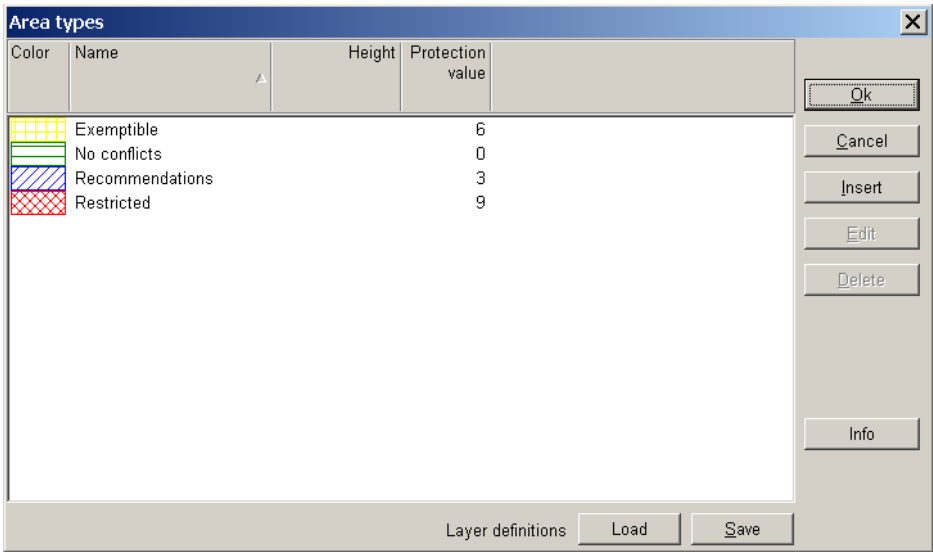


The Area Object can have multiple purposes. More than one purpose can be checked at the same time. The top group (the first six) are normally physical landscape elements such as a village, a forest, or water, while the bottom three are used for more specialized data. Note that the purpose “Steepness Check” is described in more detailed in Section 2.9.6 (last section in this chapter), while the “WindPLAN” features are described in Chapter 7.

2.9.2.3 Tab Sheet: Area types - definition of areas

To define area types, click at an Area Object and then select either "Edit Area type" or “Add new area type”.

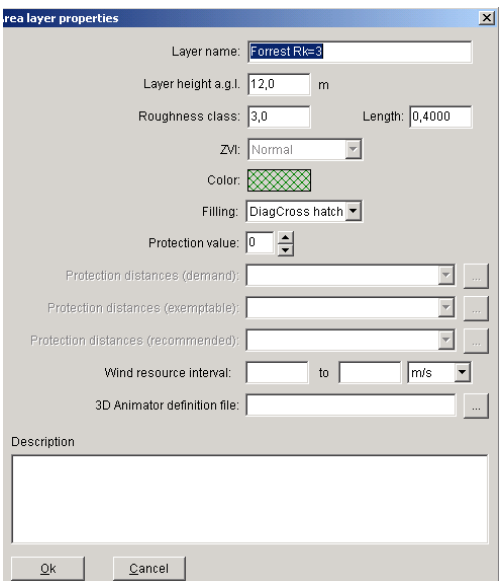




Definitions can be imported from a previously-defined Area Object, or from an .lty file which can be saved from the “Area type” dialog box. Some area definitions are available in the folder WindPRO Data\Standards\.

Some area types shown above are mainly for roughness classification purposes, but they are also useable for ZVI purposes.

New area types can be added by clicking on the "Insert" option. Previously defined area types can be edited by double-clicking on an area layer name and the dialog box shown window below will appear.

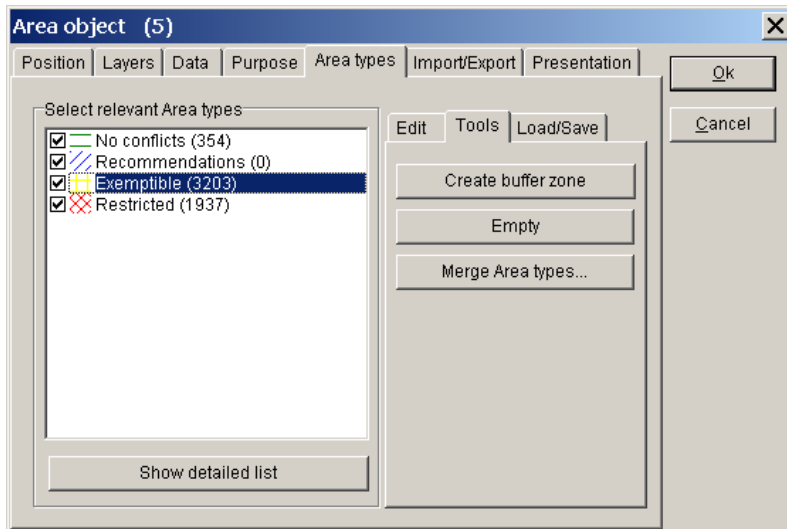


When finished defining or editing area layers, click “OK” and you are returned to the “Area types” window.

In this dialog box, you can check the area types you want to use for your current task. These are the ones that will appear in the drop-down selection menu when digitizing new areas, and will be visible on the map.

Tools

There are various tools available for utilizing the area types.



The tool "Create buffer zone" allows you to create new area types based upon already defined areas, where a new area is created in a zone defined by the user. This is used primarily for WindPLAN purposes.

Clicking on "Empty" simply deletes the areas of a specific type.

Lastly, the "Merge Area types..." moves area data from one type to another. This is very useful when importing data in multiple steps.

2.9.2.4 Tab Sheet: Import/Export – with online data

The Online data run fully automatized, while import from other sources require more settings.

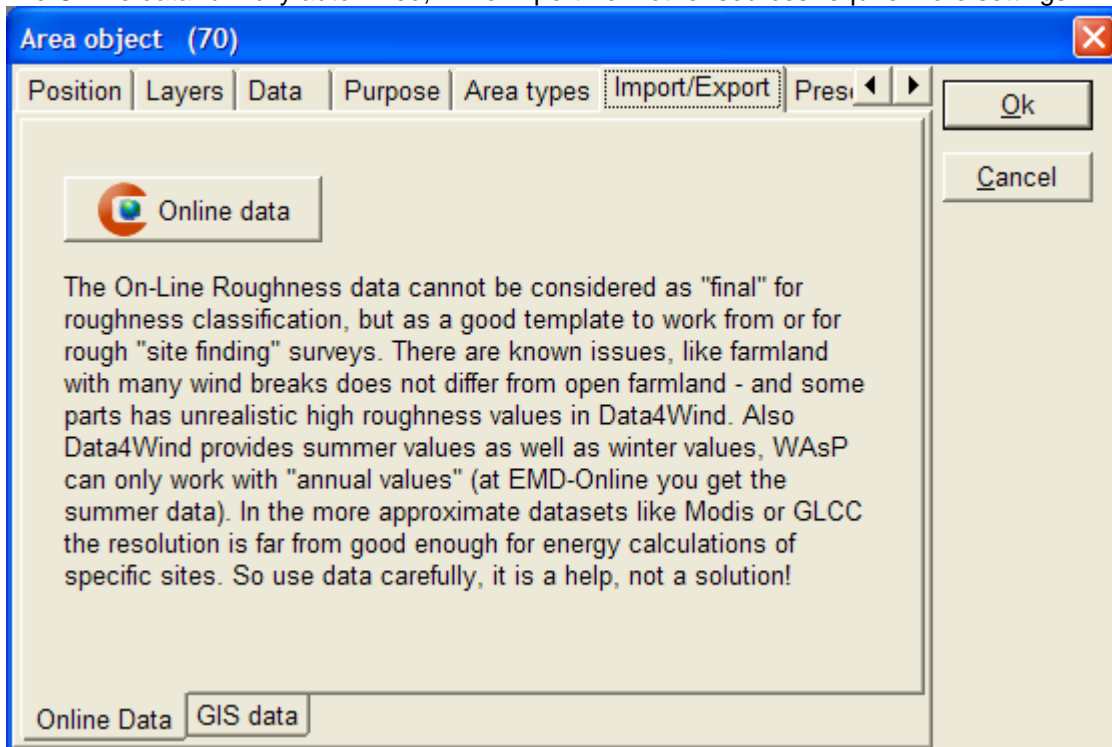


Figure 7 With the area object set to "roughness data" as purpose; you can get access to on-line data from the "Import/Export" tab.

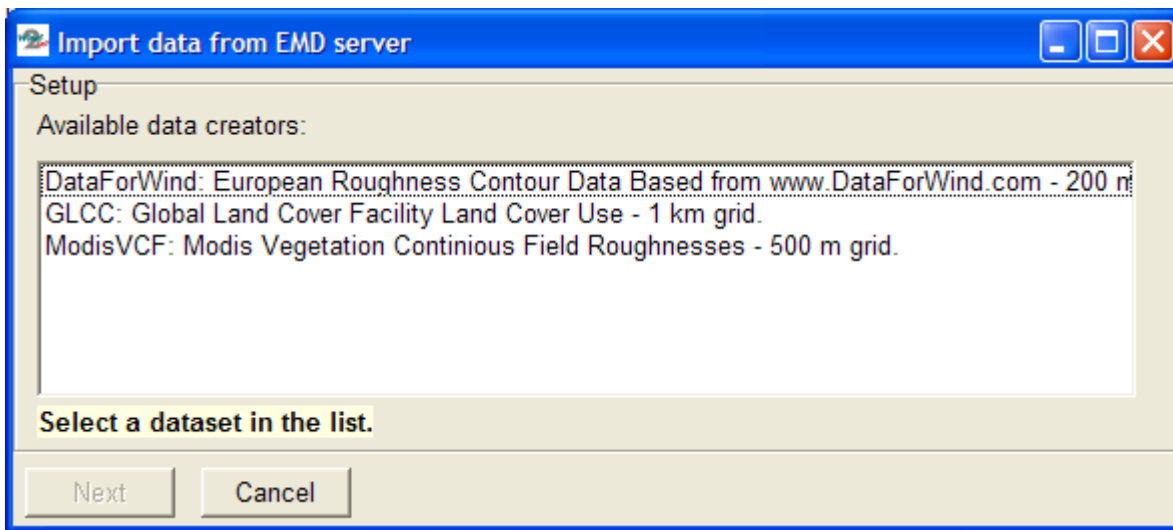


Figure 8 Example of roughness data sources at a European site.

There will be more or less types of roughness data files available describing the roughness in more or less detail, depending on where in the world the site is located. NOTE: these data will not be sufficient for a detailed energy calculation for a specific project, but are to be considered as an initial classification of roughness around a site. E.g. the Modis data only holds information on vegetation, not urban regions, so there will be some manual work required to edit and improve the accuracy of these data before they can be used for an energy calculation.

Import from other sources

Previously digitized data (polygons) from other sources (.dxf and .shp files), or for a Wind Resource map, output files from WAsP calculations, can be imported.

The process of importing data is as follows:

Press the "Import" button.

Select the file to be imported

Select the coordinate system and the datum in which the data is geo-referenced (e.g. ED 50). NOTE: This must be known. If it is a local coordinate system (or a system unknown to WindPRO), it can be defined in "Project properties" prior to importing.

The procedure for importing .dxf and .shp files is slightly different as follows:

DXF-files

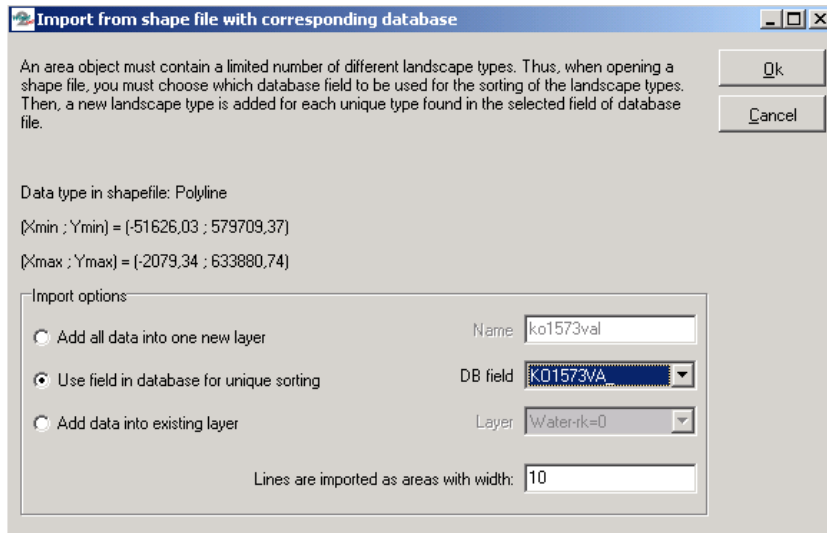
After reading the file (which may take a long time, start with a small file to test), the layers from the imported file appear in the list of landscape types with the layer number as the name.

Identify the imported layers and then select "Merge area layer" to place it into the defined layer that matches the type of data in the file (or redefine the layer).

Repeat the above steps until all imported layers are defined.

Shp-files

After defining the coordinate system, the dialog box shown below appears:



Here you can see the corner coordinates of the shape file limits (which will indicate whether or not you've chosen the correct coordinate system – if not, cancel and chose "Import" again).

There are several options for importing .shp file data:

Adding all data from all database fields into one layer

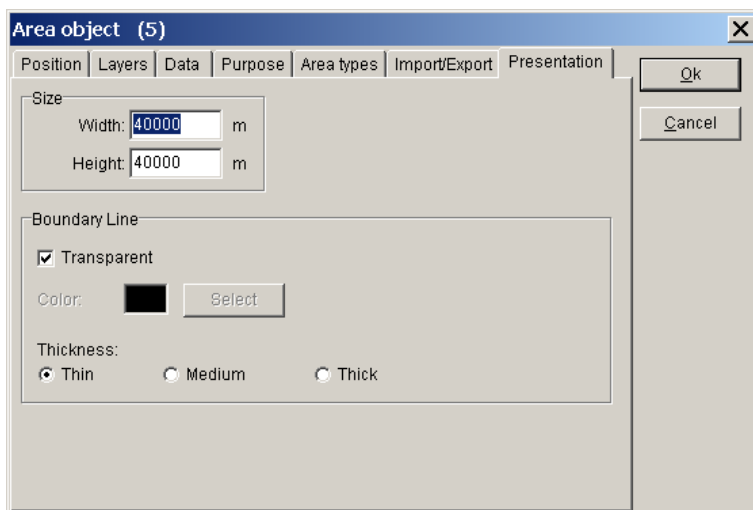
Creating one separate area layer for each unique entry into one of the database fields or adding all data into previously-defined area layers (more typical option).

After reading the file (which can take a long time – start with a small file to test), the layers from the imported file appear in the list of landscape types.

Caution:

When classifying roughness using areas, everything outside the digitized areas will be interpreted as background values. The background roughness must be given a value. For example, on islands far from the mainland, it's appropriate to use the roughness value for water as the background roughness. However, if the mainland is closer than approximately 40 km in any direction, it must be digitized. On mainland, it's usually appropriate to choose the value for "open farmland" as background (roughness class 1-1.5) and then digitize the cities, forest, water areas, and farmland with higher roughness values. In general, everything within a 20-km radius must be digitized. At a distance of 40 km, the influence of the surface roughness normally has no effect.

2.9.2.5 Tab Sheet: Presentation



In this dialog box, the visible parts of the areas are defined. The only reason to limit the visible parts would be to increase computer response when regenerating on-screen graphics.

Note that the boundary line separating each area can be made transparent. This is useful for a Steepness Check or for a Wind Resource map, where the areas cover the entire map.

2.9.3 Digitizing on-screen, editing, and viewing

Using a background map brought into WindPRO as a background bitmap image (containing all relevant information, e.g. forests, cities, etc.), it's possible to digitize the sites manually, or to view the imported data on top of the map for editing as required. The same principles as described for the Line Object in Section 2.8.3 apply to the Area Object.

2.9.4 Save and use Area Objects in calculation modules

The data file containing the area information will be saved in the file specified in the Tab Sheet "Data" when you exit the edit mode. Note that if working on an existing file, the file will be overwritten. To prevent this (if you have made changes you wish to undo), open the file from the Windows Explorer and make a copy before exiting the edit mode.

2.9.4.1 Export of roughness .map files from the Area Object

From the Tab Sheet "Data", you can export the digitized polygons (if the purpose "Roughness" is checked) to a WAsP .map file format. In the so-called polygon-cutting routine, the areas with the highest roughness have the highest priority when the areas are overlapping. Remember to define all none-digitized areas in "Background properties" on the Tab Sheet "Areas". Complex polygons may cause the polygon-cutting routine to fail, particularly if two or more polygons are overlapping or if polygons have corners with very sharp angles. Data should be checked carefully. You should check the results by loading the exported line file into a Line Object.

2.9.4.2 Use of the Area Object data in a ZVI calculation

In a ZVI calculation, every area defined with a height will be built "on top" of the digital height model. This means that, for every point with an assigned height inside a polygon, the assigned height from the area region will be added to the height model and, if the height of the area polygon is higher than the observer point in the ZVI calculation, the WTGs are treated as invisible from any point within this area, e.g. a forest.

Naturally, this will not always be the case. For example, WTGs can be visible from some points inside a forest or city. If this needs to be taken into account, these regions must be digitized in greater detail, e.g. each house modeled as a separate area.

2.9.4.3 Use of the Area Object data in an UMBRA calculation

This module is "on hold", not supported in current version.

2.9.4.4 Use of the Area Object data in a WindPLAN calculation

This module is "on hold", not supported in current version.

2.9.5 Trimming data in Area Object


There are a number of tools available for trimming, see section 2.13

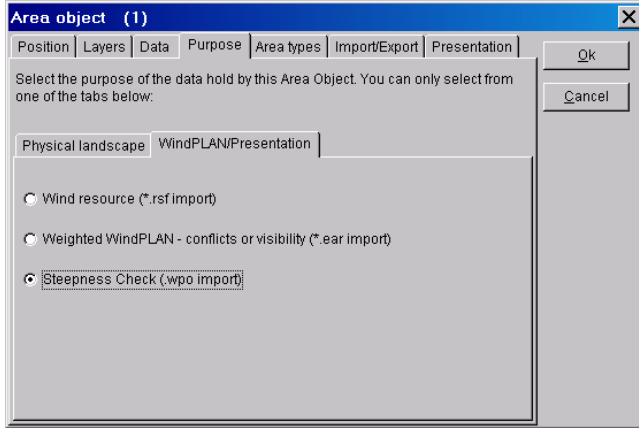
2.9.6 Steepness calculation and presentation

2.9.6.1 Purpose of the Steepness calculation

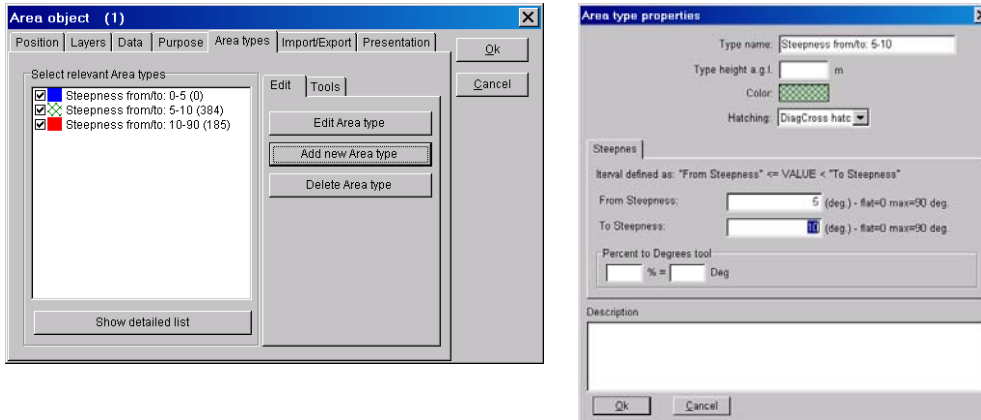
The Steepness Check (.wpo import) is used to generate areas (polygons) containing the "steepness" within certain intervals. These intervals may be used to exclude areas where it's impossible construct turbines or to build roads due to the steepness of the slopes of the terrain. The input data is a *.wpo file from a WindPRO Line Object, and the result is placed in an Area Object.

2.9.6.2 Calculation setup in the Steepness calculation

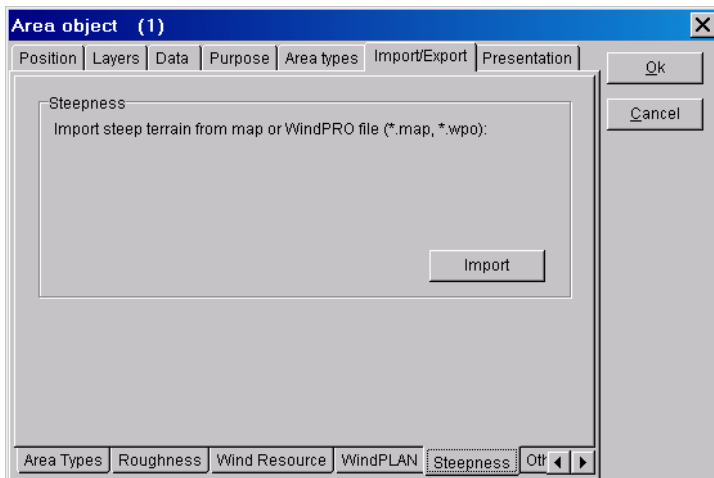
1. Insert an Area Object onto the map using the  icon.
2. Select “Steepness Check” as the purpose for the Area Object.



3. Create an area type for each steepness interval that should be created. Click on the “Add new area type” button on the “Area types” tab sheet.

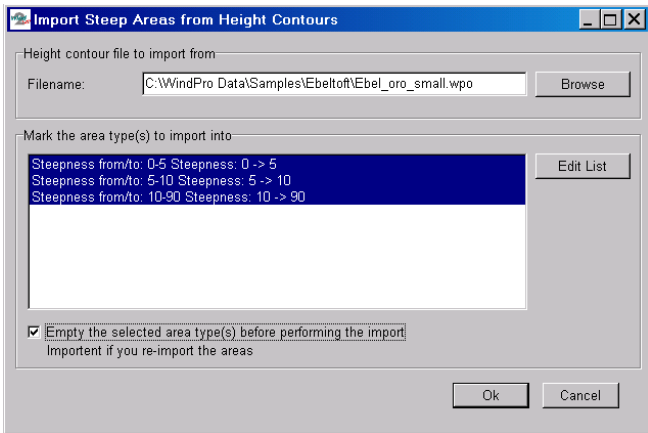


4. Select Import from the Import/Export | Steepness tab sheet.

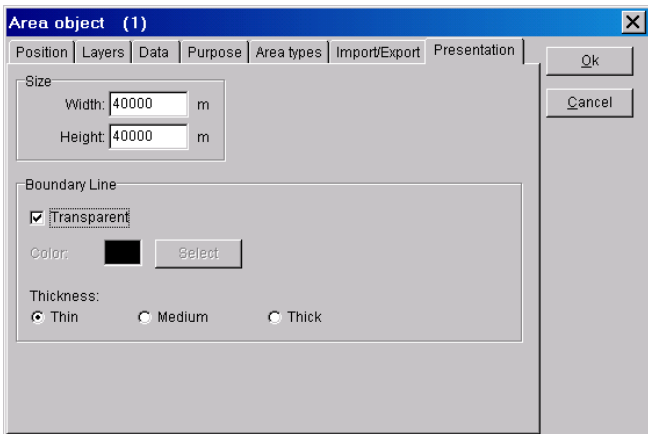


5. Now, select the *.wpo file (Line Object data file) to calculate or import the steepness data from. Mark the area types to import into (the areas that you just created). On import, WindPRO reads the steepness intervals

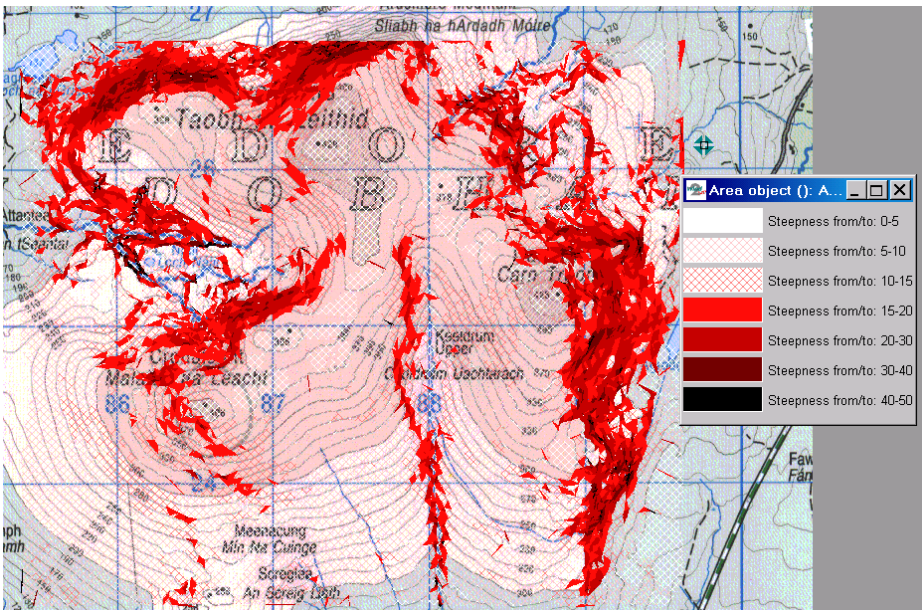
from the area types. Make sure to mark the “Empty the selected area type(s) before performing the import”, if you re-import the areas. Otherwise, duplicate areas are created.



6. Lastly, in order to make the slopes look good on the map, select the Boundary Line to be “Transparent” on the Presentation tab sheet.

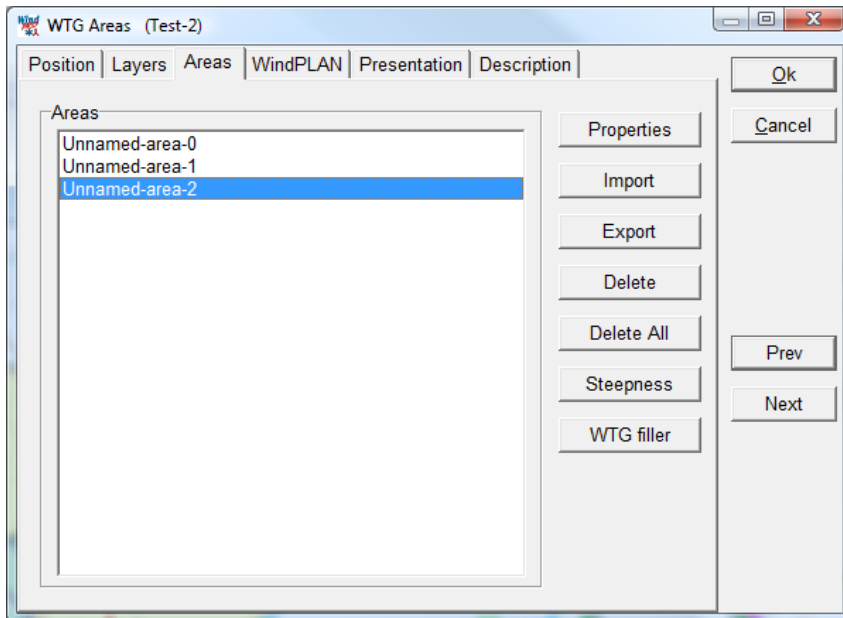


An example of results from a steepness calculation is shown in the figure below. Note that the turbines are erected in areas where the steepness (slope of the terrain) does not exceed five degrees.



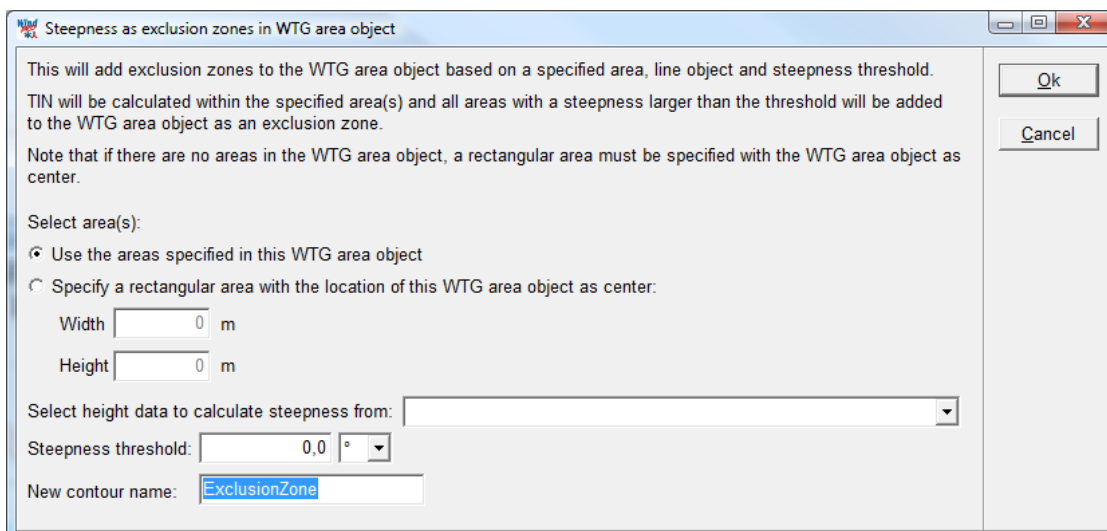
2.9.7 Specific WTG-area features

The WTG-area are as mentioned a variant of the Area object, with limited features, but specific designed for having the most needed features for designing a wind farm. The object is central for the OPTIMIZE module and shall typically always be used as the object that defines the borders of the site, e.g. based on land owner agreements.



The WTG area has some specialized features.

2.9.7.1 Steepness in WTG-area



Steepness can be established as exclusive zones based on a given steepness threshold. This is very efficient for avoiding placing turbines from e.g. the Optimize module in areas that are too steep.

2.9.7.1 WTG filler in WTG-area

The WTG filler can establish as many turbines as there are space for based on required distances, a fast way to evaluate the MW potential at a given site.

2.10 BASIS – Result Layer Object

2.10.0 How to use the Result Layer Object

With the Result Layer Object, it's possible to present the calculation results in a raster format on the working map(s), and to use the information when optimizing a project layout. It's probably most useful in an energy calculation, where a wind resource calculation (WAsP .rsf file) shows the best energy production possibilities within a given area. In addition, the Result Layer Object provides for the interactive minimization of the noise impacts from a wind park. It's also possible to represent ZVI and Shadow calculation results in the same way. The typical use would be analyzing environmental impacts from one or more projects. This can be used in evaluations to determine what can be changed in order to obtain a more acceptable environmental impact.

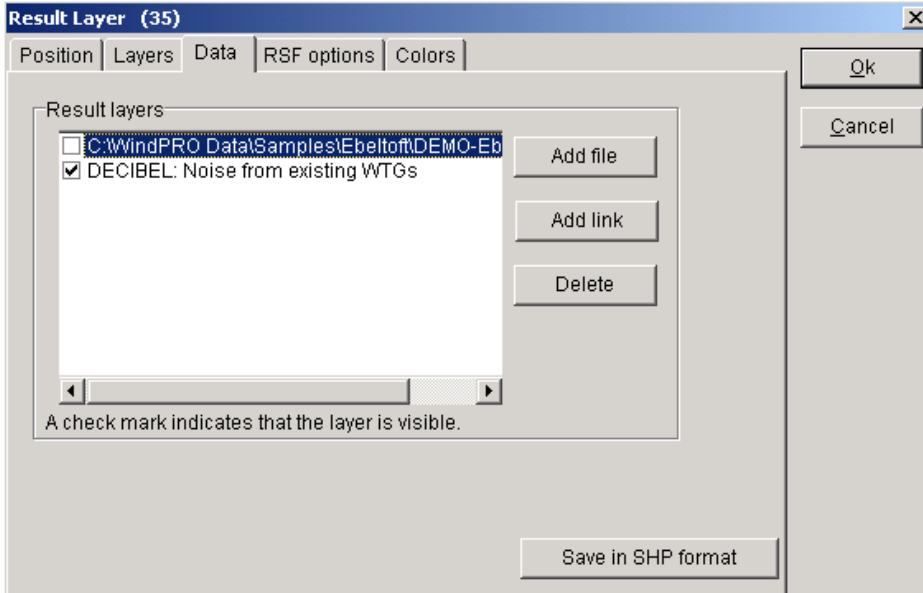
2.10.1 Creating a Result Layer



Clicking on the object button creates the object.

Please note, that by default it's only shown on one map. It is recommended that you place it on your "preferred map". Later, it can be shown on other maps.

2.10.1.1 Tab Sheet: Data



On the Tab Sheet "Data", you specified which data to use. Click on the button "Add file" to specify one of the following file types:

- .rsf - wind resource file from a WAsP calculation.
- .ear - EMD array result - a grid data file that is e.g. output from ZVI or a shadow map calculation.
- .evr - EMD vector result - a vector data file, an option which is not yet used.

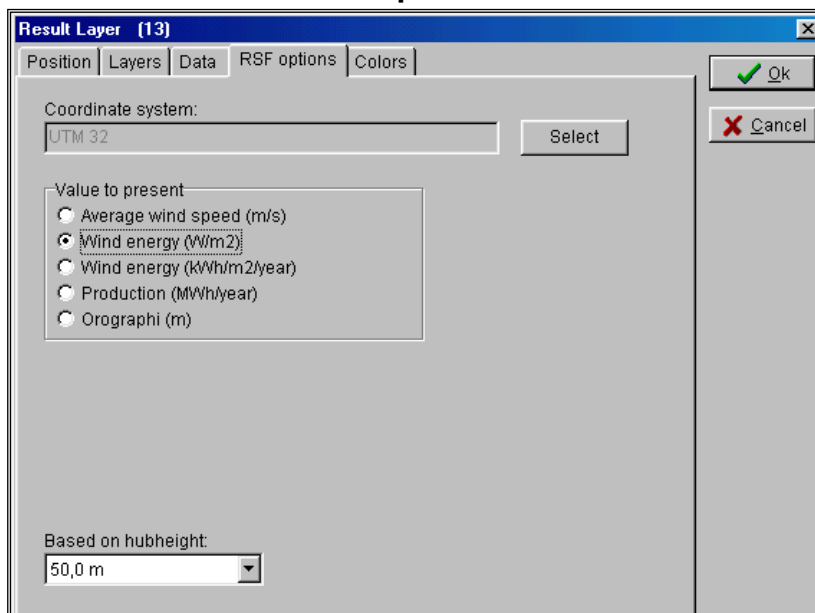
You can attach several results files to the same object. For example, if you calculated a large wind resource file, and later added additional potential WTG sites, you simply calculate a wind resource file for the additional sites and then attach it as an extra file to obtain a presentation of the entire site with identical properties.

You can select or deselect files for the presentations by means of the check boxes in front of each file.

On-screen noise optimization

Click on the "Add link" button and specify results from a previous noise calculation. The noise isolines from the calculation will appear directly on-screen when you click on "OK". Now you can change the layout of the wind farm in order to fulfil the noise demands at the neighbors. Simply move the wind turbine and the isolines are updated automatically. The isolines will also be updated (recalculated on-screen) when the type or version of the wind turbines are changed.

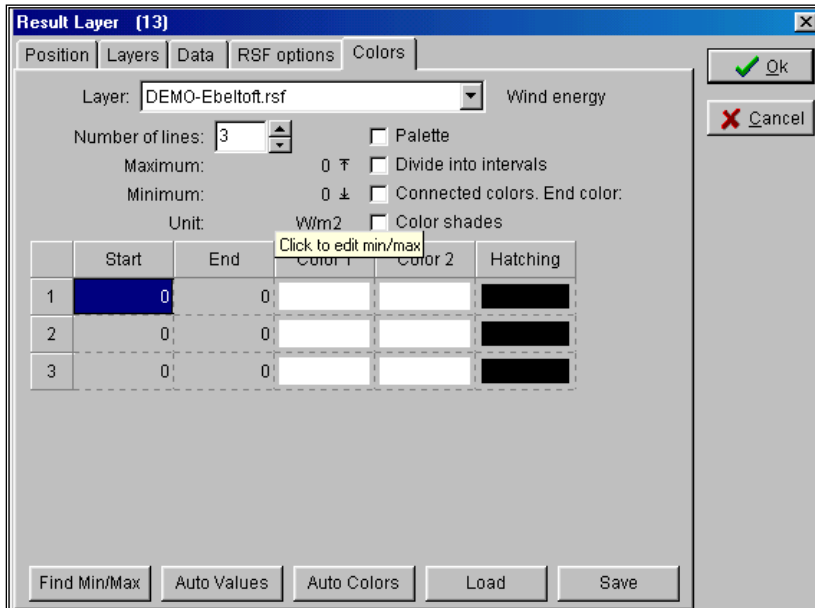
2.10.1.2 Tab Sheet: RSF options



When the wind resource is chosen for presentation, you can select which parameter to show.

Please note that if the WTG production is selected, you gain access to select a "generic WTG", that is, to specify power, rotor diameter, regulation (stall/pitch) and fixed or variable speed (rpm). The program will then, by means of standard tables from Helge Petersen (HP-tables), find the expected production values of a WTG of this size. Since these tables are valid only within a certain range, white areas will occur if the production is very high, or very low, and thereby outside the range of definition.

2.10.1.3 Tab Sheet: Colors



To define a range of colors for presentation, start by using the "Find Min/Max" function to determine the interval for which you wish to define the colors. Note that you can specify your own min/max values as well as the number of decimal places. This can be used to select more reasonable start/end values for the range.

The number of color graduations or "value intervals" is selected under "Number of lines". Start and end values can be entered manually or automatically. In particular, please note that start/end values for auto-generation can be found automatically as the min/max values in the data set or they can be entered manually in the appropriate boxes.

Also note the "Load" and "Save" options, where you can save your favorite color definitions for later use in other projects.

Lastly, colors for the presentation are chosen. There are a number of possibilities.

In short they are:

No choice: (Default) Intervals are pre-set with smooth color changes.

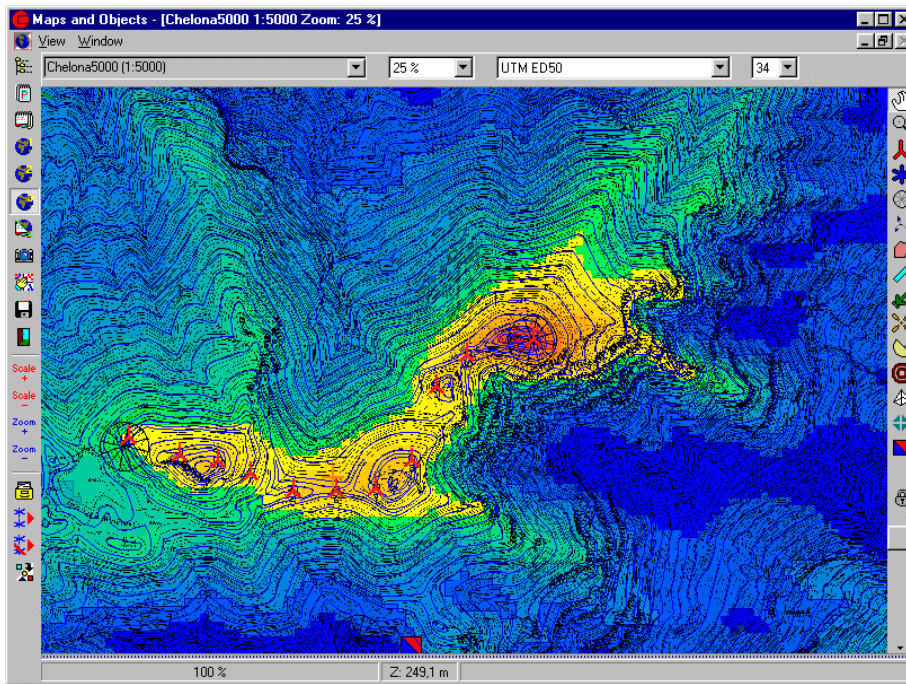
Palette: Single colors - one color for each value interval.

Divided into intervals: A start and an end color for each value interval, sub divided into nuances of colors.

Connected colors: Select a color for each interval and an end color. This will create sliding nuances of colors.

Shadow colors: Each color is "Phased out" in order to create a shadow effect.

When the color settings are ready, the program renders the results layer onto the map on which the Result Layer Object was placed. The rendering may take some time, but once rendered, the image remains in memory so that it does not need to be rendered again.



The above figure is an example of an .rsf file rendered on a map with the result layer. The map illustrates how four colors are used to show "non-usable", "usable", "good" and "excellent" WTG placements. With this information, available, it becomes much easier to place the WTGs at the best locations, although the park efficiency must also be considered.

2.10.2 Result layer handles xyz and GRD files

Golden Software's Surfer has a proprietary data format (*.DAT). Many programs use this as an export format (e.g. the advanced CFD modeling program, Meteodyn). Exported Surfer files can be converted in Surfer to *.GRD files showing, for example, inflow angle or turbulence as the modeled parameter. These can now be imported into a Result Layer object in WindPRO and shown on top of the map or draped across a 3D view.

The .wrg file reader in the Result Layer object is now more flexible, so Meteodyn export files can also be read. From Microsoft Excel you can save any x,y,z data as a text file and rename to .xyz; the files can be also be shown in a Result Layer object. On that basis you can display any chosen parameter placed in the third column with x and y co-ordinates in the first two columns.

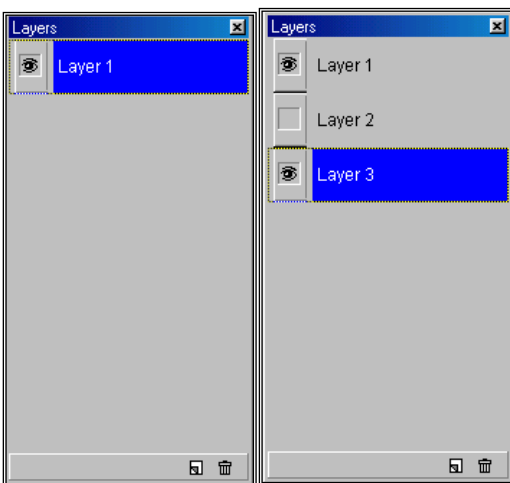
2.11 BASIS - Layer structure - organizing objects

2.11.0 Introduction to layer structure

Using a layer structure similar to that used in many programs such as AutoCAD or PhotoShop, you can organize the objects in WindPRO.



Start the "Layer Manager" with the "Layer" button in the lower left menu bar.



2.11.1 Create new layer

In this window you can create a new layer by clicking on the small icon at the bottom of the page next to the "trash bin" icon (which deletes layers). In the right window shown above is an example of two newly-created layers (3 layers total). The eye indicates whether the layer is visible or not, meaning in this case that Layer 2 is deactivated and is therefore not visible either on the map or in the Object List. Just click on the "eye" button to activate or deactivate the layer. The blue background (Layer 3) indicates the current active layer. Any new objects created will be assigned to this layer.

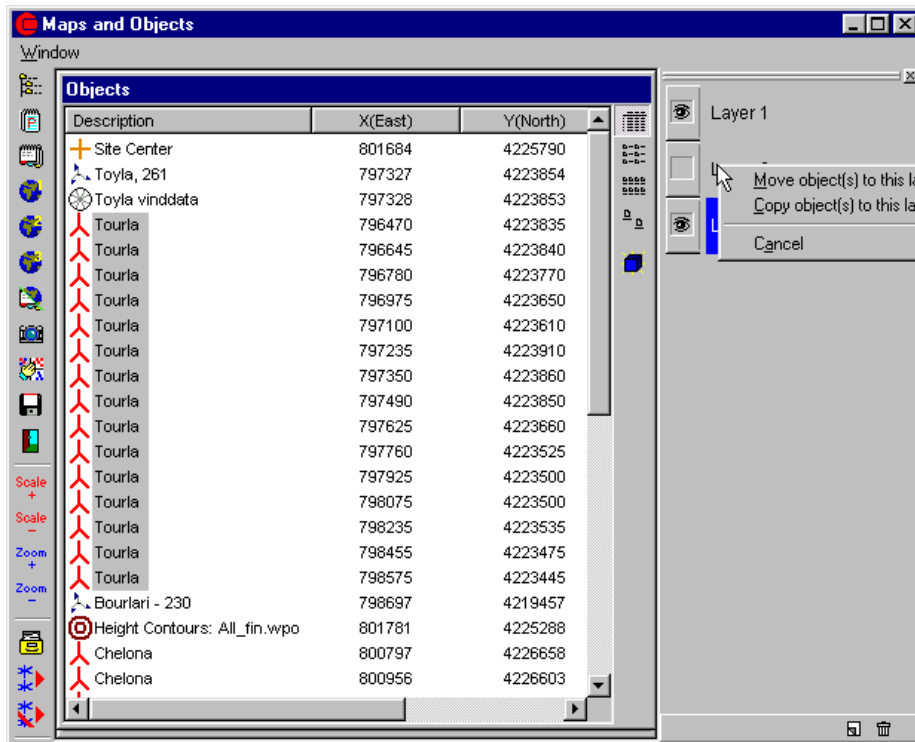
2.11.2 Layer Manager as a "docked" or a "free" window

Sometimes it's preferable to let the layer manager be a docked window (a part of the "linked" windows instead of a "free" window within (on top of) the map). Simply dragging the window to one of the edges and releasing docks the window. Then it will automatically convert into a bar. To change it back into a free window, right-click on the Layer Manager and check "docked" from the pop-up menu.

2.11.3 Move or add objects to another layer

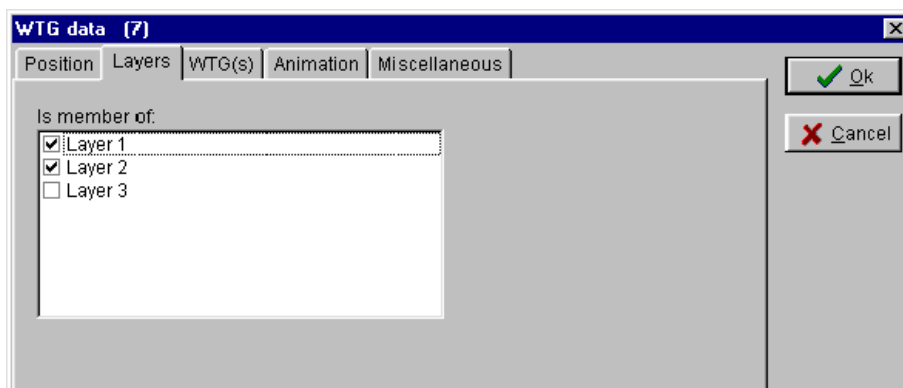
This can be done in two different ways:

1) Drag the selected objects you want to move or copy from the Object List to a layer in the Layer Manager. WindPRO will then ask whether you want to move or add them to the layer. Please note that when adding objects to a layer, a duplicate set of objects are not created on the second layer. The objects are merely assigned to both layers. If you want to duplicate objects, use the clone or copy function.



In the above figure, all WTGs called "Tourla" are selected (click on the first one with the left mouse button, hold down the <Shift> key and click on the last one). Hold down the right mouse button and drag the selected objects to the Layer 2 icon. The program will ask whether you want to "move" or "add" them to the layer. If added, they will exist in Layer 1 as well as in Layer 2.

2) In the Object Properties, you can assign the object to one or more layers.



2.11.4 How to organize objects in the layer structure

WindPRO supports many ways of organizing objects in the layer structure. Here are a few examples:

a) Several different layout alternatives for one WTG project

Here it would be natural to organize each layout in its own layer. All the basic objects such as Terrain Evaluation, Height Contour, Neighbor, Camera etc. could then be placed in Layer 1. Each layout alternative has its own layer which makes it easy to quickly see and compare the different alternatives for an evaluation. When adjusting a given layout, only one layer is visible at a time so you don't risk modifying other alternatives when moving the WTGs on the map.

b) Different object types for each layer

It's often difficult to "select" on object e.g. a noise sensitive area beneath a shadow recipient. This can be avoided by organizing all the noise sensitive areas in one layer and the shadow recipients in another. You can

now make the final adjustments to the placements with one active layer without interference from the other objects.

c) Photos for visualization with different focal lengths

If, for a visualization, you have photos with different focal lengths, but taken at the same location, the Camera Objects will be placed on top of each other on the map and will be difficult to work with. Assigning each Camera Object to a separate layer is an easy way to work around the problem.

d) Line- and Area Objects disturb the overview

The map overview becomes cluttered if you have digitized many objects such as roughness, contour lines, areas, etc. If the various information is organized in layers, it's faster to activate or deactivate the layer than to find the individual objects in the Object List and then deselect "show lines" etc.

e) Several projects in the same area

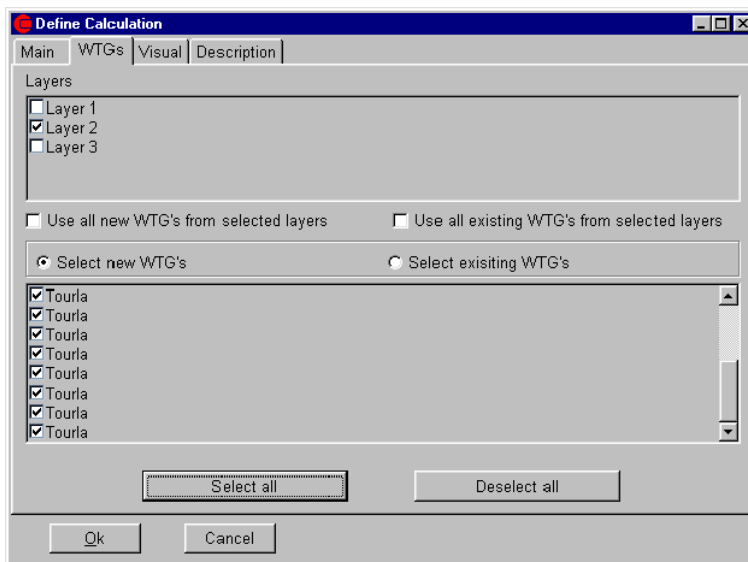
If you work with several projects within a limited geographical area it's possible to reuse much of the data and take advantage of working with many WTG projects in one WindPRO project. Information relating to each project is placed in its own layer, while all joint objects are placed in a "joint-layer", e.g. Layer 1.

f) For planning purposes

When a municipality for instance, is planning its WTG policy, they may want to organize the existing WTGs according to expected dismantle time or prioritized removal, for example. It's also possible to place new WTGs in different layers according to different development alternatives. Subsequently, it's very easy with the layer structure, to combine different dismantling and development alternatives and to perform different environmental calculations such as a ZVI calculation.

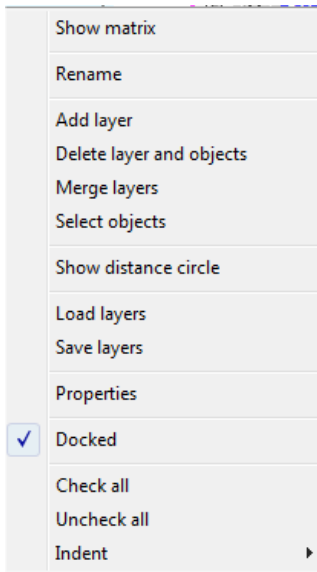
2.11.5 Usage of the layer structure in a calculation

When starting a calculation, it's possible to include WTGs from selected layers only for the calculation. You can deactivate single WTGs within each layer. Essentially, it will be much faster and more efficient to work with different alternatives in the same project.



2.11.6 Save/load layer structure

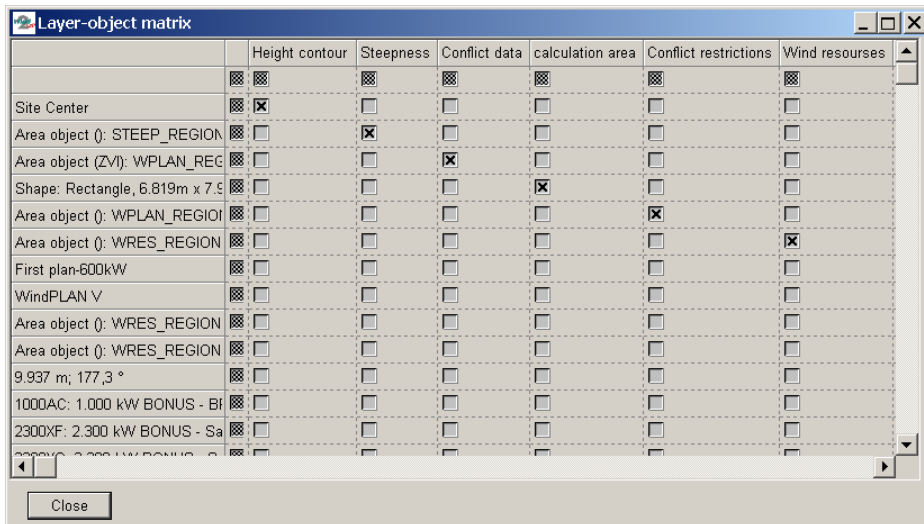
Right-click in the layer window and get the menu:



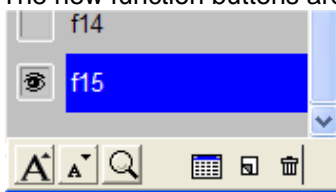
From this menu, a layer structure can be saved or loaded, which means that a good layer structure can be reused in another project.

2.11.7 Matrix view, font size, magnifier, and move layers

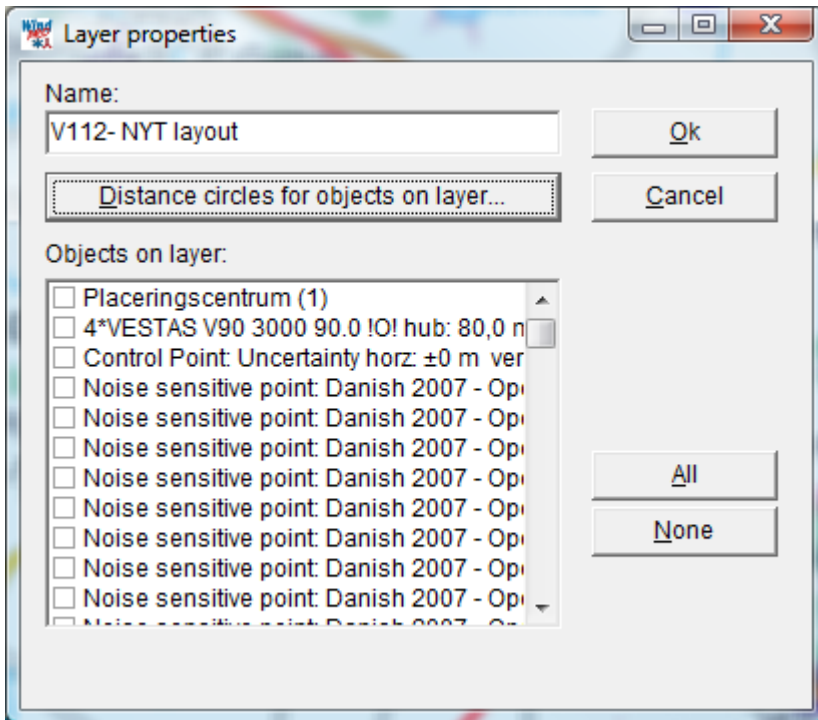
Note the “Show matrix” which allows you to see a complete overview of all layers and objects that are assigned to them (see example below).



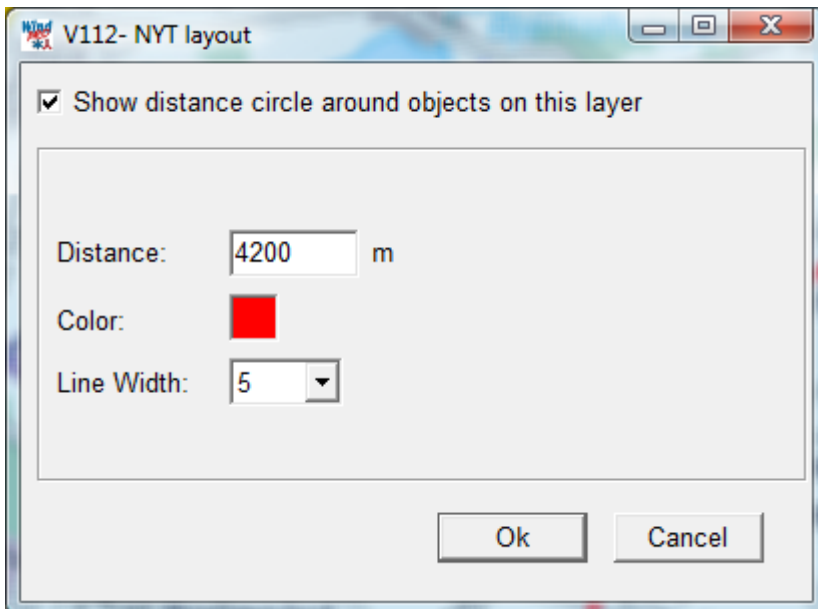
One of the recent improvements (from version 2.5) is the “Change font size” function. The magnifying glass is also new. When the magnifying glass is activated (toggle by clicking on it), only the objects in the layer that you hold the cursor on will be shown in Object List. This can help you get a quick overview on which objects belong to which layers. Lastly, you now can move layers simply by dragging them with the left mouse button down. The new function buttons are shown in the screenshot below.



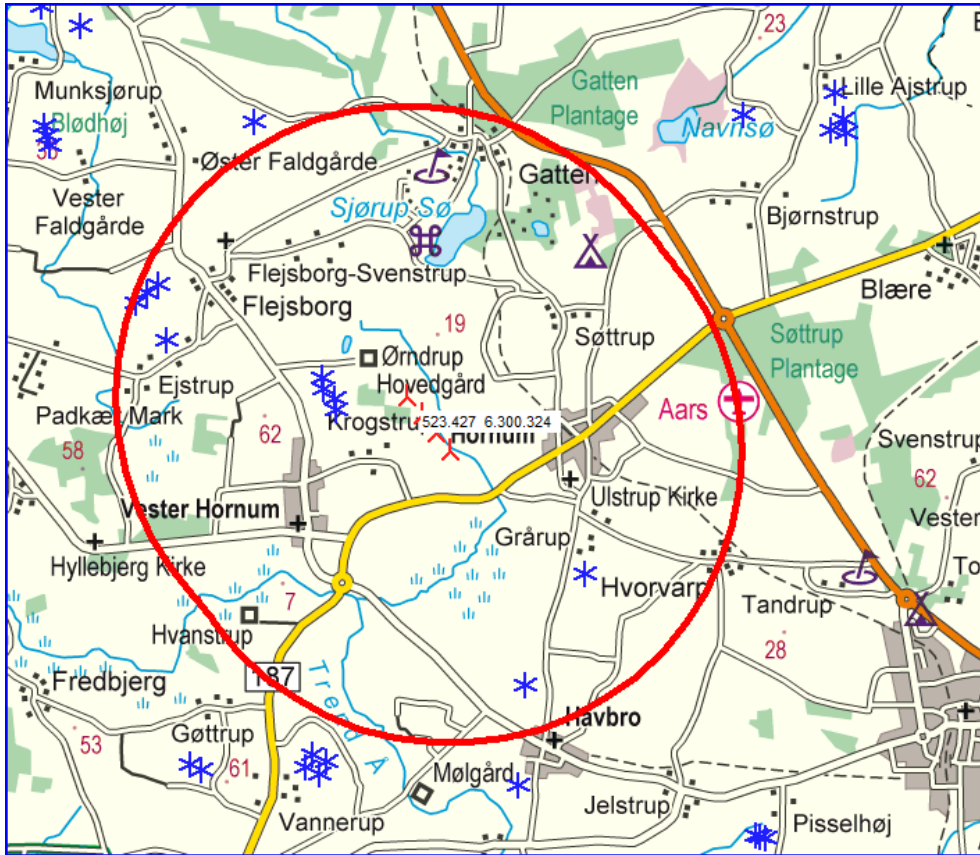
2.11.8 Distance circle around layer objects



The button "Distance circles for objects on layer" gives access to following:



Here the distance, color and line width be set. In Denmark e.g. there must be a special investigation if wind farms are established closer than 28 Rotor diameters to existing turbines. With this feature it is fast investigated if this is required:



28 x rotor diameter around the new proposed project show which existing turbines that are closer.

2.12 BASIS – Text, ruler and Shape Object

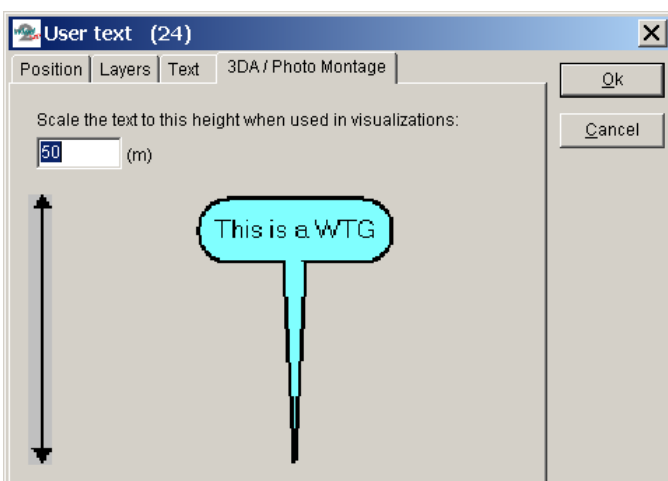
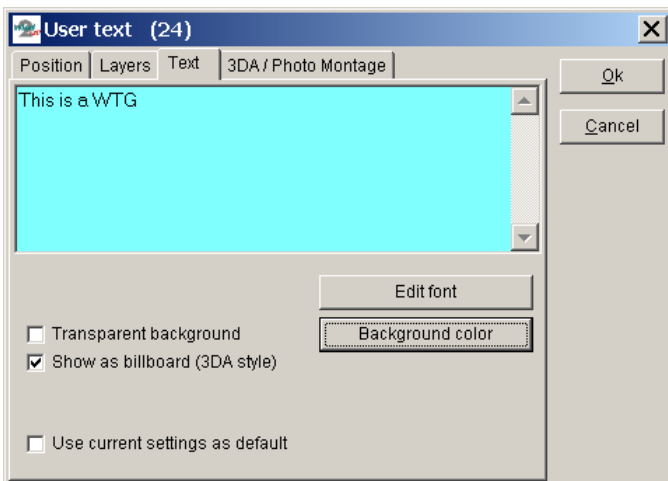
2.12.0 Auxiliary objects

WindPRO also has a group of objects that are not directly involved in calculations, but are very helpful for designing, measuring and presentation.

2.12.1 BASIS - Text Object

T

With the Text Object, you can attach text to the project map and later include it on the map printed in one of the calculation reports. You simply select the Object from the Object Bar and place it on the map and then enter the text. You can move or edit the position of the text exactly the same way as with all other objects.

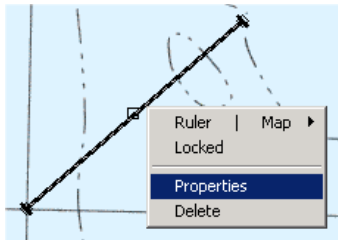


A unique feature in WindPRO is the ability to use the Text Object for showing “balloon text” on maps, as well as in Photomontages and 3D Animations, so that a specific location can be identified on map, on photo, or in the terrain model.

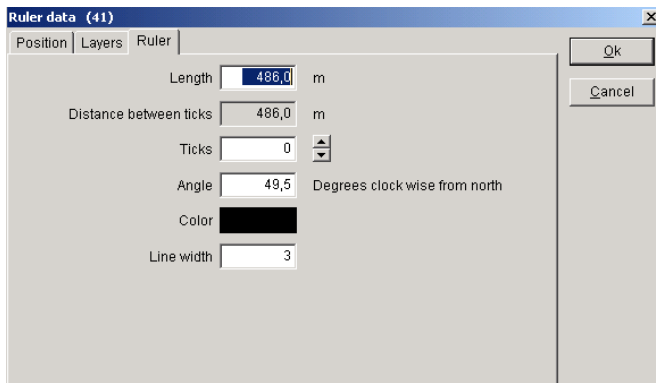
2.12.2 BASIS - Ruler Object



With the Ruler Object you can measure distances on the map. You select the button shown above from the Object Bar and place it on the map at the location where you want to start the measurement. Then you click on the location where you want to end measurement. Hovering with the cross hair over the measurement will cause the distance and the compass angle to be displayed in the status bar at the bottom of the screen. It's also possible to change the properties of the ruler. To do this, left-click on the line in order to activate it, then right-click and select "Properties" in the pop-up menu as shown below.



The following dialog box will now appear.




Here a fixed length or angle can be specified. The number of tick marks can be specified (e.g. to mark every 100 m distance) and the color and line width can be changed.

You can also move or edit the ruler line. Left-click on the line in order to activate it. Place the cross hair inside the center mark, then left-click and drag to move the ruler parallel to its original position. Place the cross hair inside an outer mark to rotate the ruler around the opposite outer mark. Hold down the <shift> key while dragging an outer mark to change the ruler length.

Lastly, you can measure a distance without creating a new Ruler Object. Simply create the ruler with left mouse button, but instead of finishing with a second left-click, use a right-click and the ruler will not be created.

2.12.2.1 Quick profile, based on object "ruler"



This button (at the bottom of the left-hand toolbar on "Maps and Objects" window) activates the profile after inserting a ruler;  found in the right-hand toolbar.

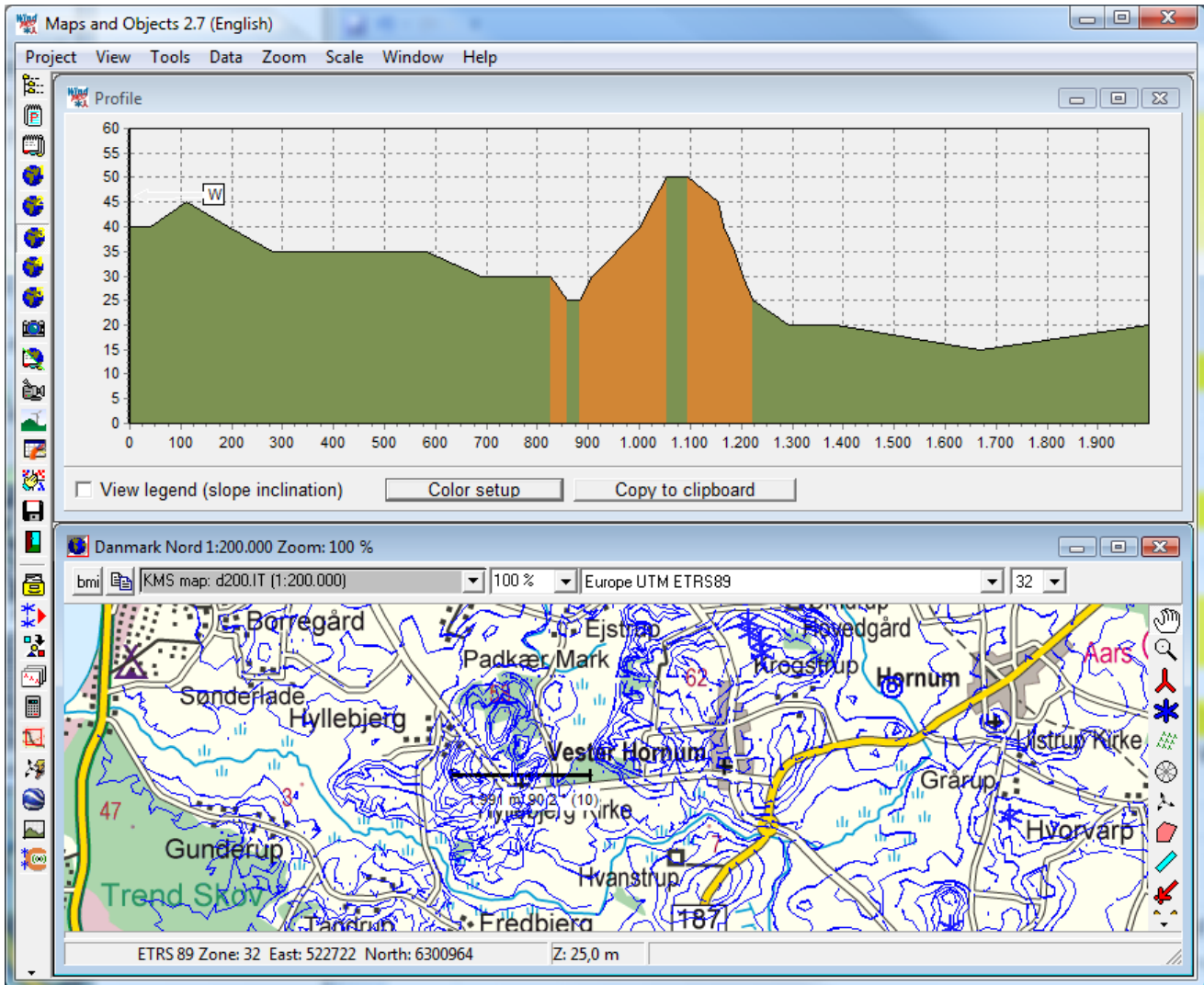


Figure 9 Create a ruler at map and right click, choose "Show Quick Profile" and a cross-sectional view is shown along the ruler line. Note: this tool uses the actual contour lines, the alternative "rendered" terrain profile based on the shape object, using the TIN.

The colors shown are pre-defined:

Green < 8°

Orange 8° - 17° (installing or transporting turbines may not be possible)

Brown > 17° (flow separation or WAsP model problems will start)

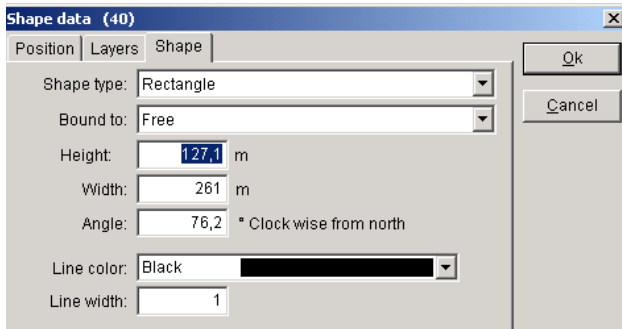
With the "color setup" button the colors and values can be user defined.

2.12.3 BASIS - Shape Object (also Grid lines)



With the Shape Object, rectangles, squares, circles, or a grid can be placed on the map as a helpful tool for measuring. Select the button shown above from the Object Bar and place it on the map where you want one of the corners of the rectangle or square to be located. Then mark the location of the opposite corner. For a circle, the two corners define the square of the inscribed circle. When the Shape Object is used as a grid, the object can be placed anywhere.

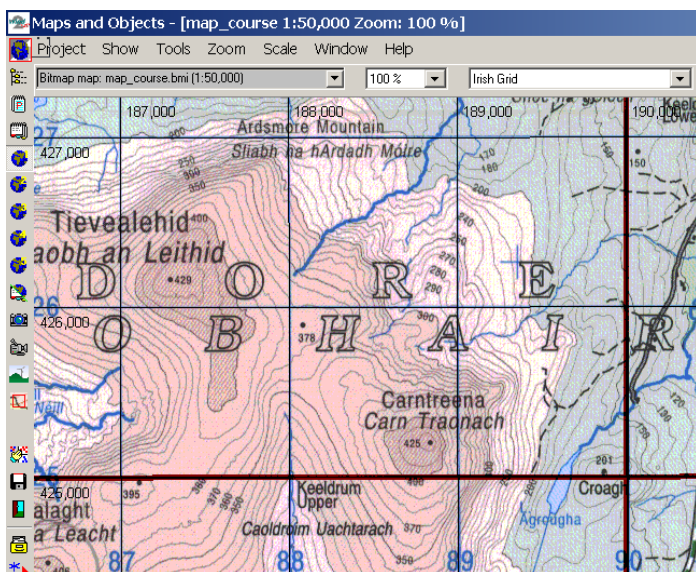
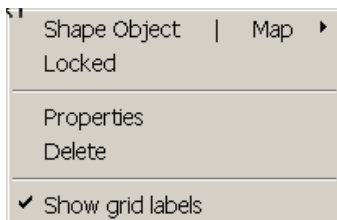
The shape object as rectangle is basis for terrain profile rendering, see 2.15.



After selecting the second corner, the dialog box shown above appears. Here the shape type, size, angle, color, and line width are defined.

The size, angle, and location of the shape can also be edited on-screen. Left-click on the Shape Object in order to activate it.

When used as a grid, right-click on the map to access the option “Show grid labels”.

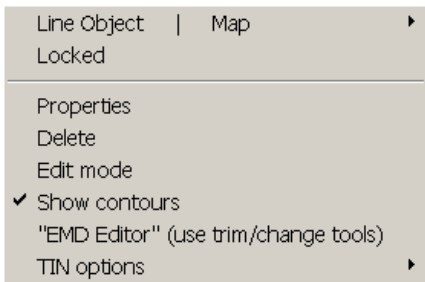


Shown above is an example of establishing two grid objects, one with thin black lines for every 1 km, and one with thick red lines for every 5 km. Notice the grid labels on the top and left edges of the map window. The labels will scroll in order to remain on the edges as the map is dragged.

2.13 BASIS – EMD Editor (Line and Area Objects)

2.13.1 EMD Editor - trim and change data

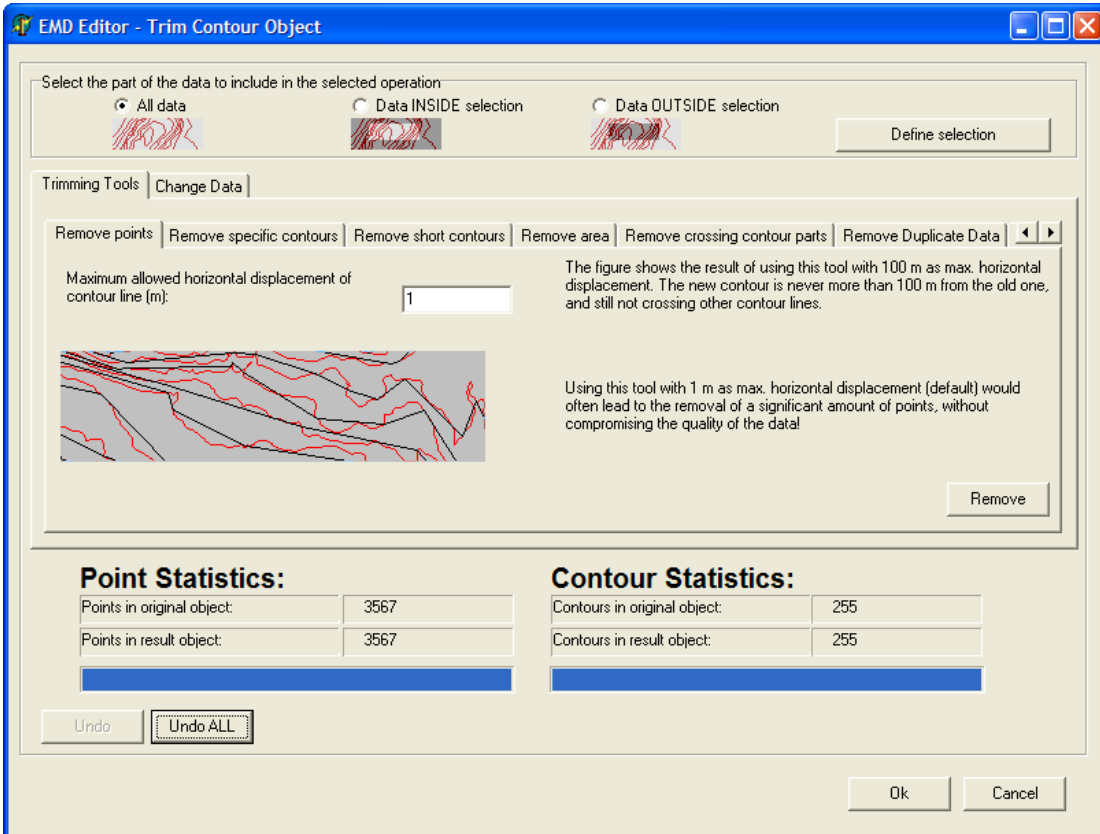
The EMD Editor works with data files associated with both Line Objects and Area Objects. Often the data files hold far more points than needed, or they may be misplaced on the map due to digitizing in the wrong coordinate system, or they may simply contain errors, possibly from converting from one file format to another.



The EMD Editor is started from the pop-up menu that appears when you right-click on the Line, Area, or WTG Area Object. If the object is in Edit mode, the Trim menu cannot be selected. The editor can also be started from the Line or Area Object form.

There are two main groups of tools: Trimming and changing data.

2.13.1.1 Trimming tools

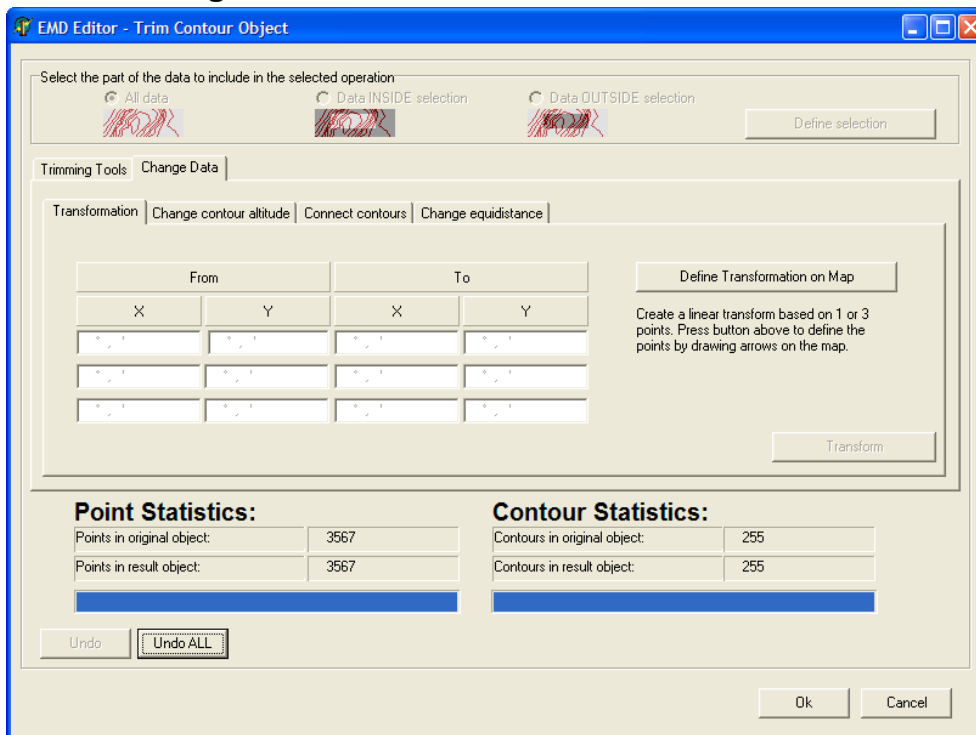


Trimming tools are typically used for removing points or lines or parts of a region to reduce the amount of data.

There are five main Trimming Tools and each is explained in detail on the respective tab sheet:

- Remove points
- Remove specific contours
- Remove short contours
- Remove area
- Remove crossing contour parts
- Remove duplicated data
- Remove “No TIN” data

2.13.1.2 Change data



Change data tools are used for moving, scaling, or converting data, or simply manually changing of a group of data.

There are four main Change Data tools and each is explained in detail on the respective tab sheet:

Transformation (move, rotate, or twist data to correct for digitization errors, e.g. digitizing based on local or wrong coordinate system or datum). The transformation can be made graphically, where either 1 or 3 arrows on the map are dragged so the “from” and “to” points are shown, indicating the coordinates for the transformation.

Change contour altitude (user-specified conversion formula to change from e.g. feet to meters).

Connect contours (spline).

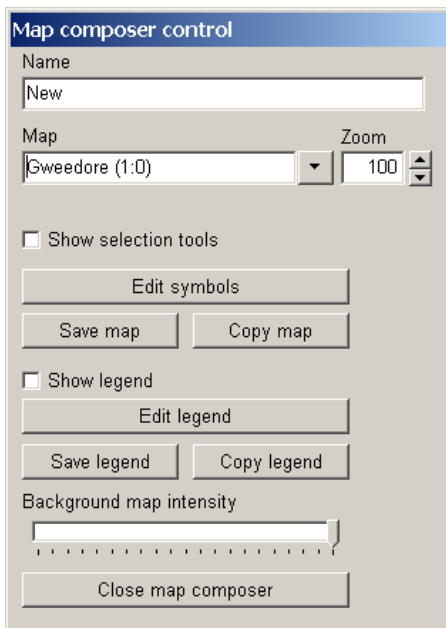
Change equidistance.

2.14 BASIS - Map Composer

2.14.1 Start the Map Composer



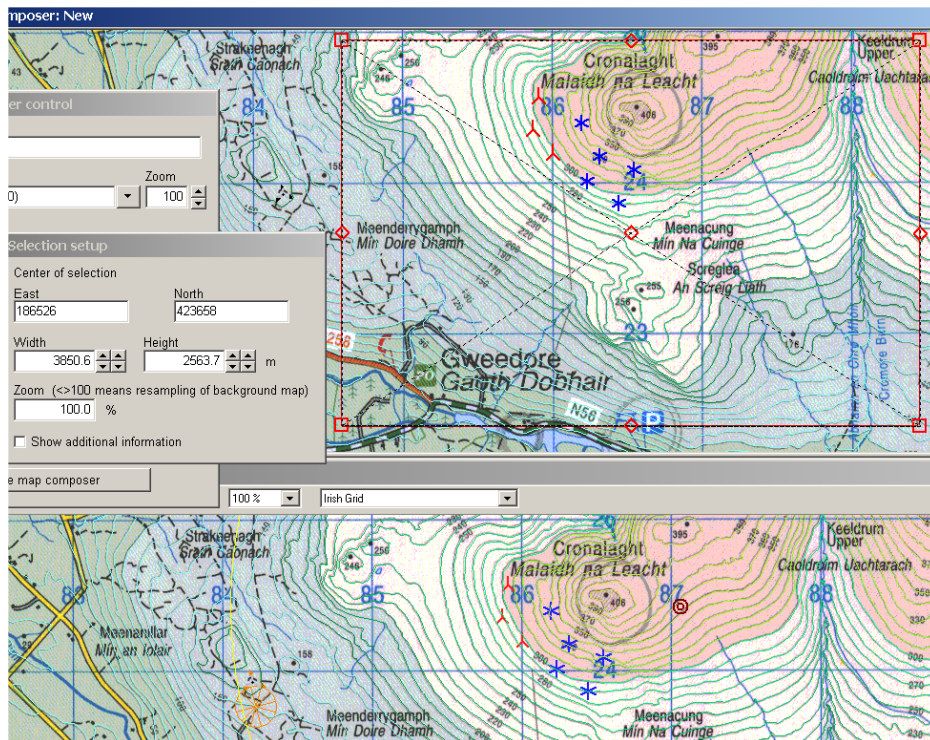
The Map Composer is used to prepare maps for use in reports. The Map Composer is started from the left tool bar by clicking on the button shown above.



Starting the Map Composer opens a split window containing the map (where the design of the composed map can be viewed), and the Map Composer Control window.

The Map Composer Control window has following options:

A name can be entered in order to find the map setup later. Different maps with different elements, scales, or symbol configurations can each be stored with a different name.

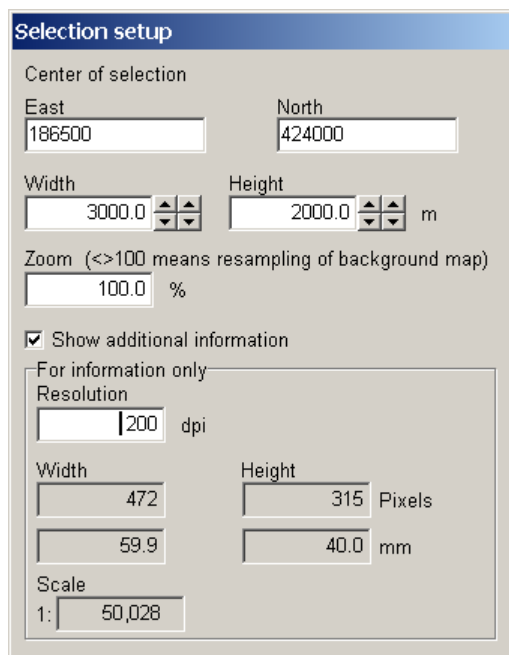


When the Map Composer option “Show selection tool” is checked, you can drag the square defining the part of the map that is to be copied to a report. This can also be specified exactly by specifying the coordinates, size, and zoom level.

With the option “Show additional information” you can specify a graphic resolution in dots per inch (dpi), which is important for reports that must be printed with high graphic quality.

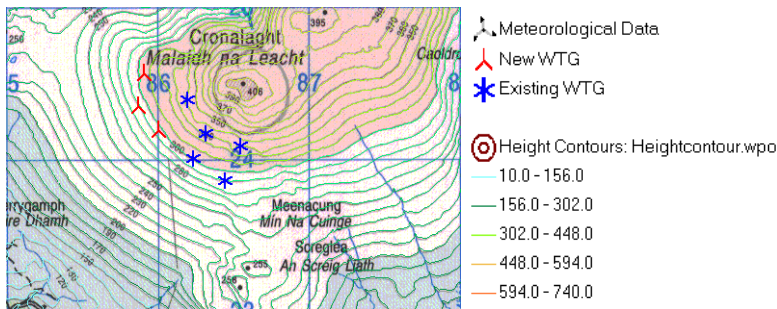
2.14.2 Select map portion and resolution with the Map Composer

Changing the resolution will change the size of the graphic in millimeters. If you specify a resolution (dpi value), the resulting width and height of the image as it will appear in the report are displayed.



If you want to show a larger map area while maintaining the size and resolution (dpi value), the zoom must be adjusted. The map will be resampled in order to fulfil your requirements.

In the example above, a 3 km x 2 km portion of the map is selected. For a 200 dpi map, an area that is 59.9 mm x 40 mm will be required on the report page. The scale will then be 1: 50.028 (it should actually be 1:50.000, but a slightly inaccurate coordinate setting makes the difference).

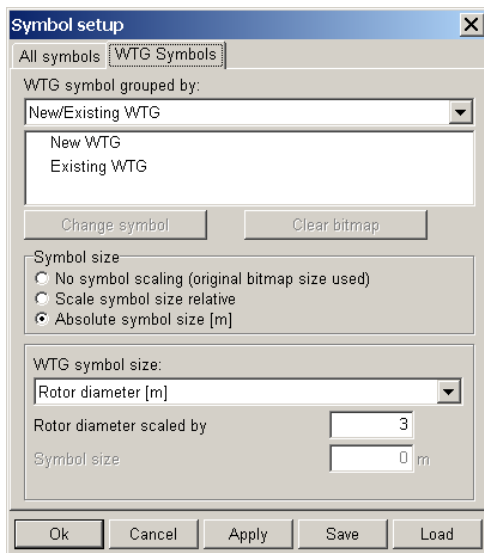


Above, the map is copied to the clipboard, and then in Word, the height is set exactly to 40 mm so that the map will print at a resolution of 200 dpi and a scale of 1:50000.

Shown above is an example of an ordinary screen dump (print screen), without the Legend, which can be added by clicking "Copy legend" in the Map Composer Control, and then pasting it into the Word document.

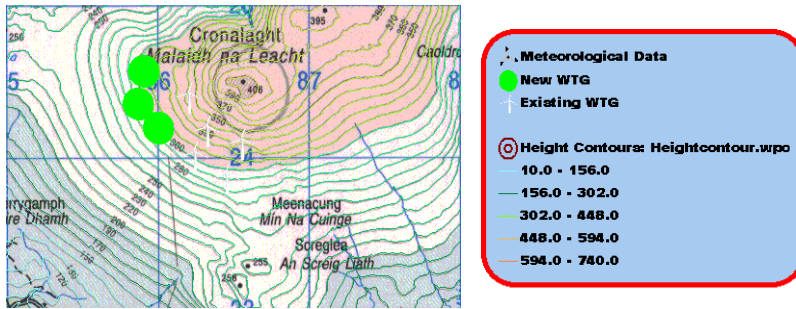
Note how the height contour lines have different colors for different heights (this is configured by a setting in the Line Object).

2.14.3 Symbol setup in Map Composer



One of the more useful features of the Map Composer is the one that allows you define custom symbols (mainly for WTGs), and to scale them according to the size of the WTG.

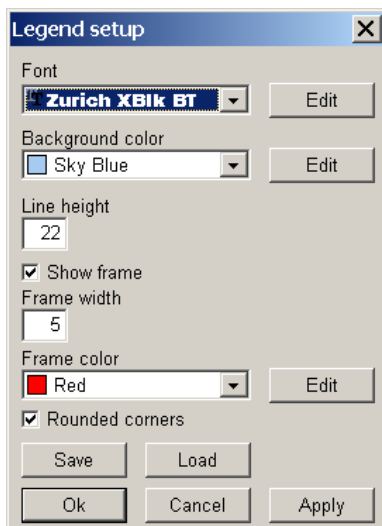
Any bitmap file can be used as a WTG symbol. Some examples can be found in the folder ""WindPRO Data\Standards", but any bitmap can be used. A map example with different types of symbols for new and existing WTGs is shown below.



If custom symbols are defined, the legend will be updated with the new symbols. In the example shown above, the legend has been modified slightly in order to illustrate the possibilities.

2.14.4 Legends and more options with Map Composer

The legend can be modified by the user in a number of different ways. The various options available can be seen in the Legend setup window shown below.

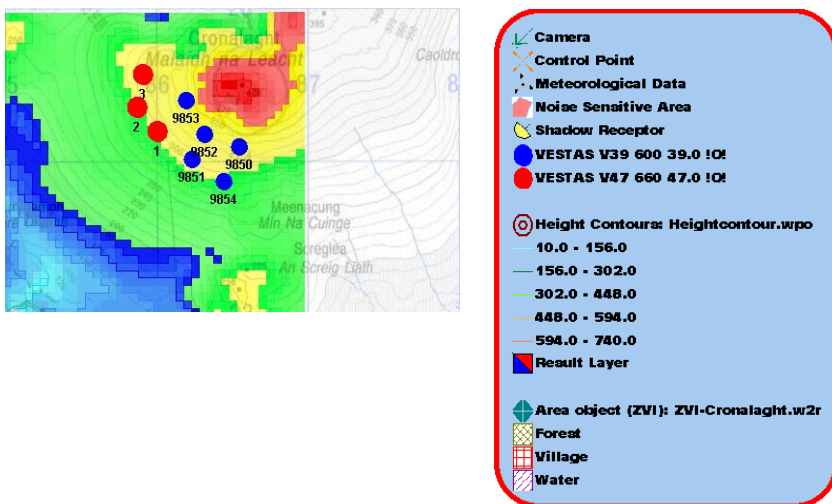


Font, background color, line height (the distance between lines in the legend), show frame, frame width, frame color, as well as rounded corners are the available options.

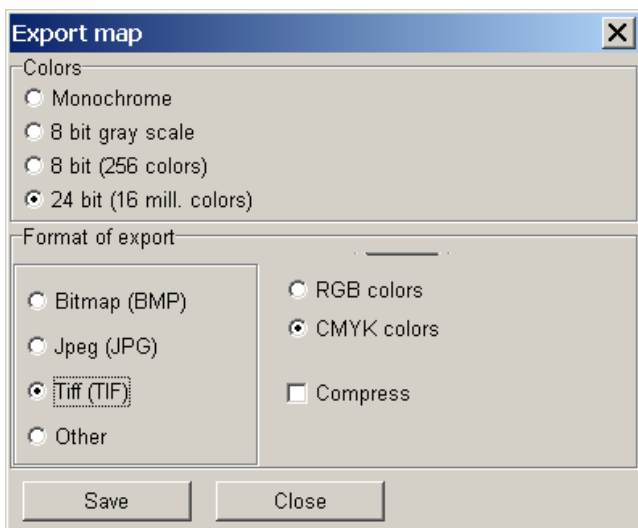
Lastly, shown below is an example which includes reduced background map intensity, symbols scaled by rotor diameter, labels, and the wind resource map from result layer.

The WTG symbols can also be divided by WTG type or manufacturer, which is illustrated by the legend for this example, with two different WTG types.

Note: The type of objects that appear in the visible layers will determine the appearance of the Legend, even though the objects may not be within the selected portion of the map.



After designing your individual map layout, you can copy it and make another map based on the same parameters, while including additional elements, e.g. one map for noise, one map for flicker, etc. This allows you to make a template, no longer limited by the default symbols in WindPRO, and then with the features you require, to copy the relevant elements to a professional report with uniform and high quality map presentations.



One final note on the Map Composer: When saving maps as .tiff files, you also have the option to save the file in the CMYK color format, which is the basic requirement for offset printing equipment.

2.15 BASIS - Terrain profile

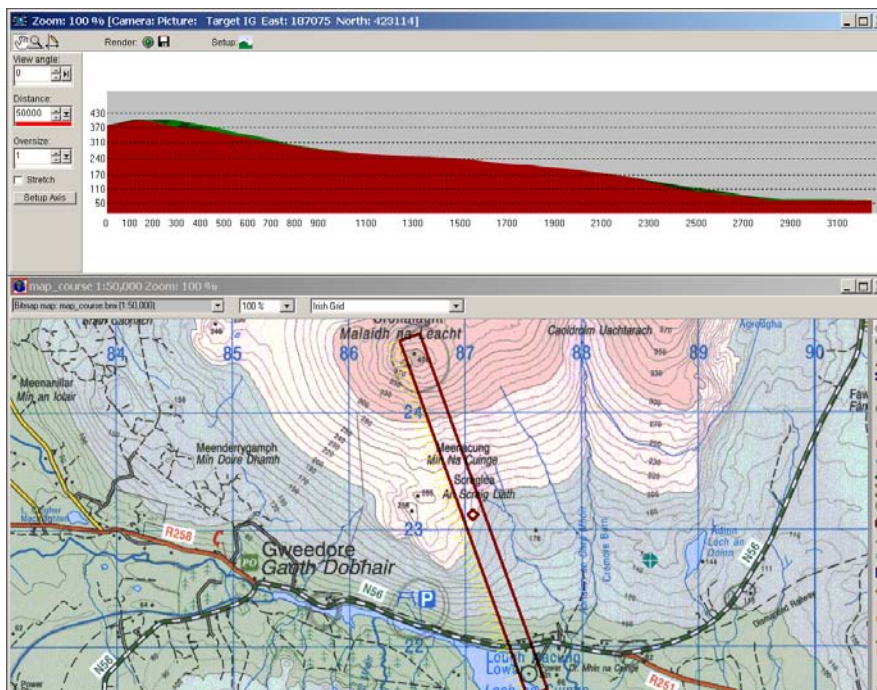
2.15.1 How to use the Terrain Profile



Using the Shape Object (right Object Bar) you first create a rectangle to define the profile cut for which you want to view the terrain profile.



The Terrain Profile tool is activated with the Terrain Profile icon (left tool bar). Note that there must be a TIN calculation based on a Line Object with height contour lines in order to use the Terrain Profile tool.

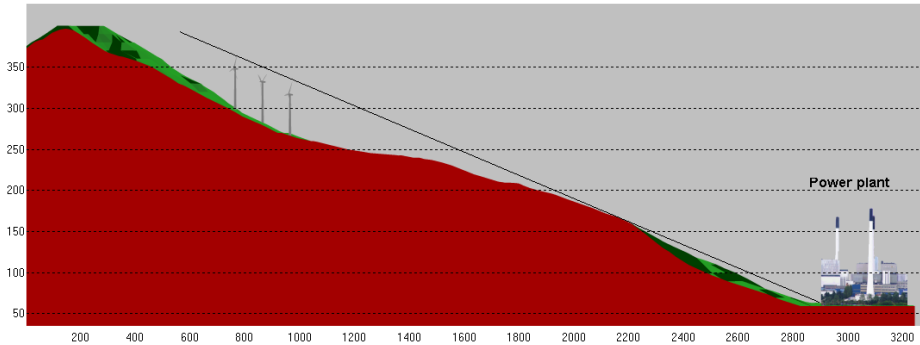
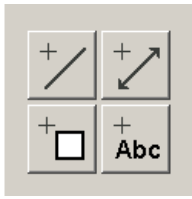


When you click on the Terrain Profile icon, a terrain profile for the selected profile-cut rectangle is rendered. The yellow arrows indicate the viewing direction for which the profile is being shown. The profile is always seen from the longer side of the rectangle. In order to view the terrain profile from the opposite side, the rectangle object must be rotated 180 degrees by dragging the corners.

The terrain profile can be over-sized and stretched, or just over-sized. The difference between stretching and over-sizing will be in the way that objects such as WTGs are shown on the terrain profile. If stretched, all objects shown will be stretched in the over-sizing operation. If "stretch" is not chosen, the objects, such as WTGs, will simply be over-sized both horizontally and vertically. This makes it easier to see the WTGs in the terrain profile, but it will also over-size them in the horizontal direction.



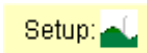
With the Draw Tool shown above, which is found in the tool menu at the top of the Terrain Profile window, lines can be drawn and text can be added to the profile view. Additional tools are available as described below.



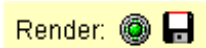
The graphic above illustrates how a bitmap (the power plant) is inserted as a 3D Object and 3 WTGs are inserted on the hill. The profile and the objects are all oversized by a factor of 3. The line from the power plant over the edge of the hill illustrates that from the left base of the power plant the WTGs will not be visible.

The part of the hill shown in red is that which would be seen on the near side of the profile-cut rectangle. The part of the hill shown in green is that which would be seen from the far side of the profile-cut rectangle. The part of the hill shown in green can also be seen from the viewpoint.

The terrain profile is ideal for analyzing local conditions and can be used for many purposes. It is especially useful for illustrating proportions between the landscape, WTGs, and other elements.



Colors can be changed with the setup button.



After any settings are changed, or any new objects are added within the terrain profile rectangle on map, the "Render" button must be clicked to update the image to include the new elements. Clicking on the floppy disc icon will save the terrain profile image as a bitmap. There is no specific report that can be generated using the terrain profile. The bitmap image is the only possible result output.

See also "quick profile" described in 2.12.2.1.

2.16 BASIS - Google Earth exporter



With a click of this button, selected objects will be exported. You can also export from the Objects List, selecting those objects to export, then right-click and select "Export to Google Earth".

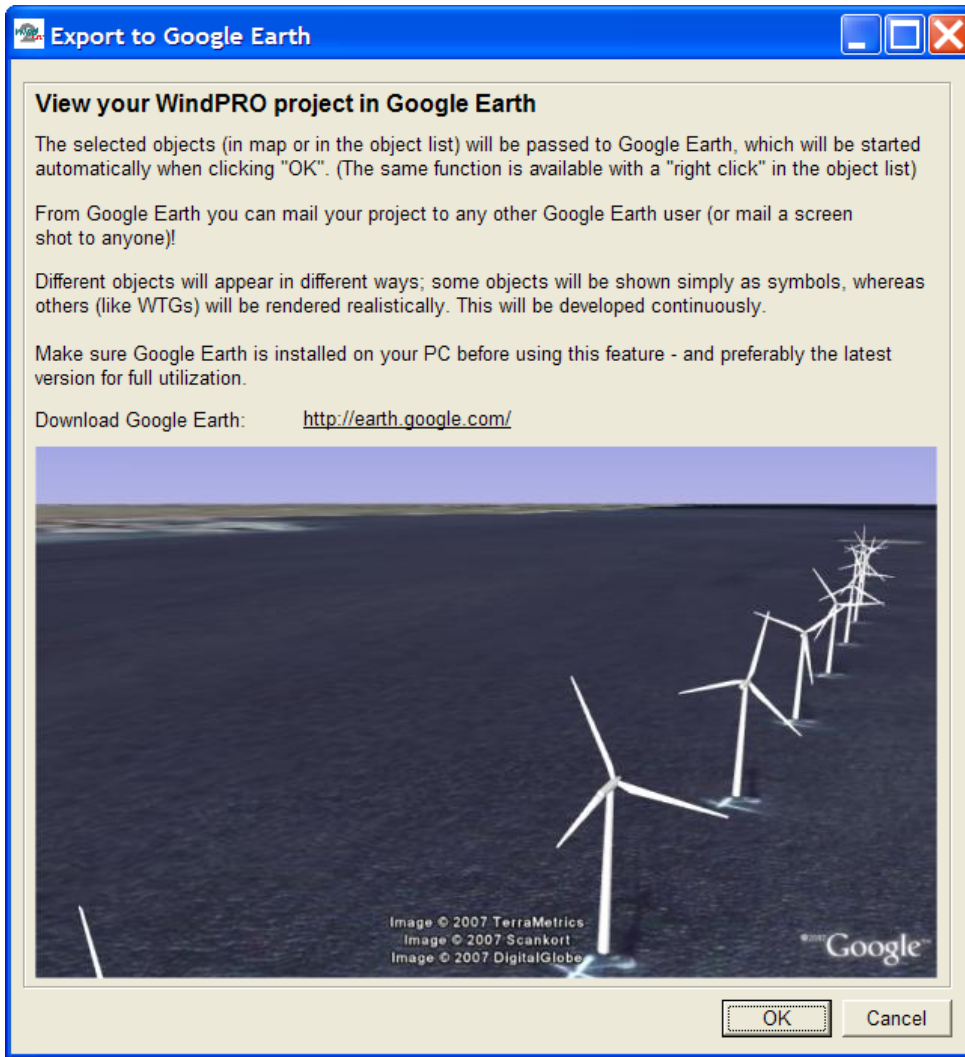


Figure 10 You need to install Google Earth before using this tool.

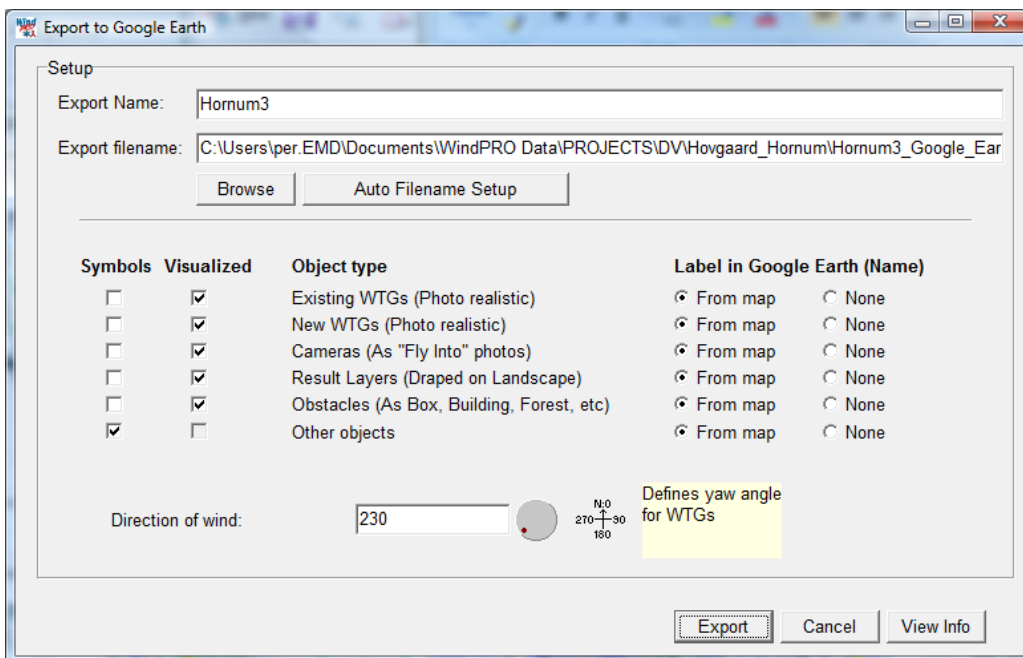


Figure 11 You can chose how some of the object types shall appear in Google Earth, including labels.

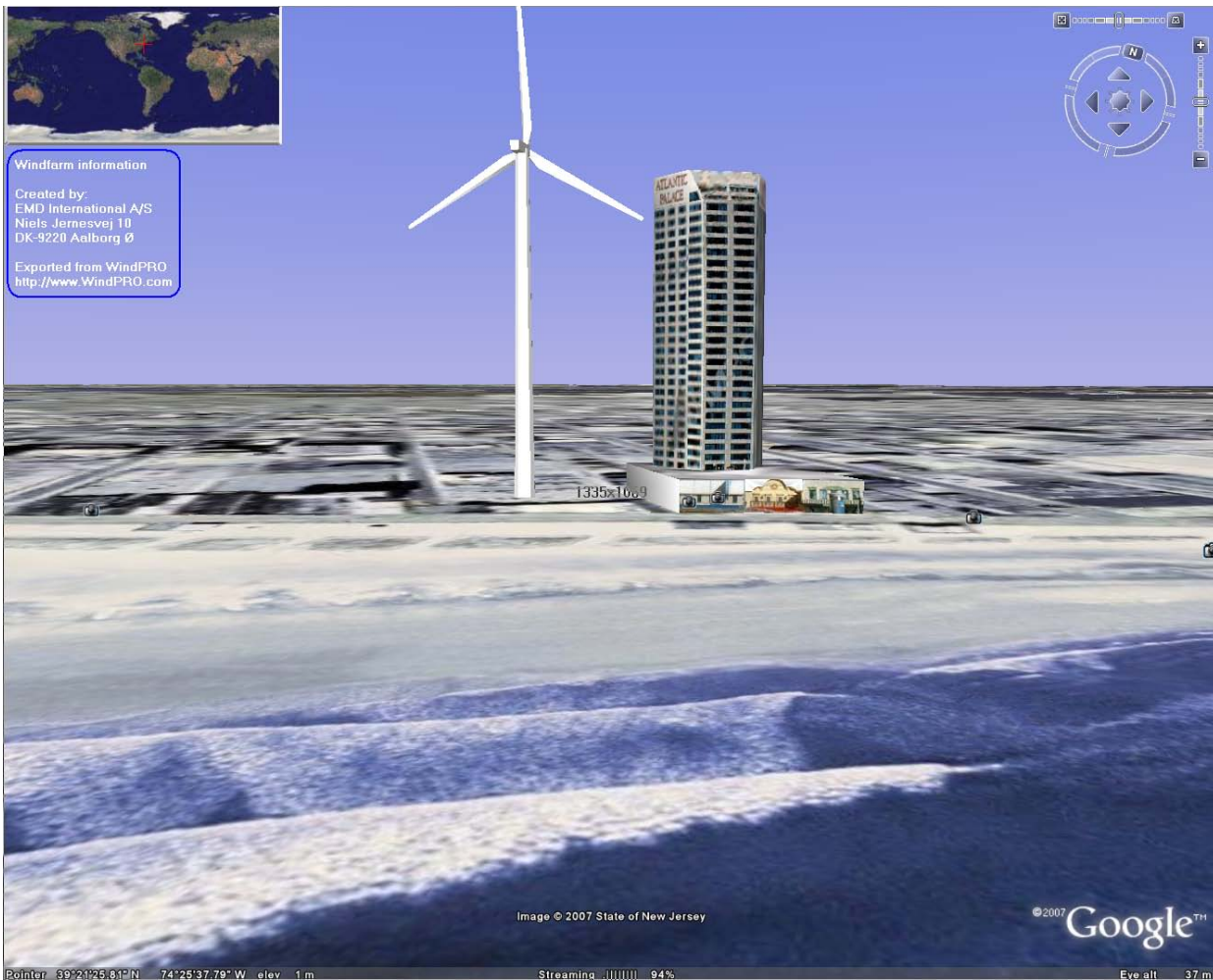


Figure 12 It has never been easier to compare a given turbine size with a known building! Or of course, to simply visualize your project.

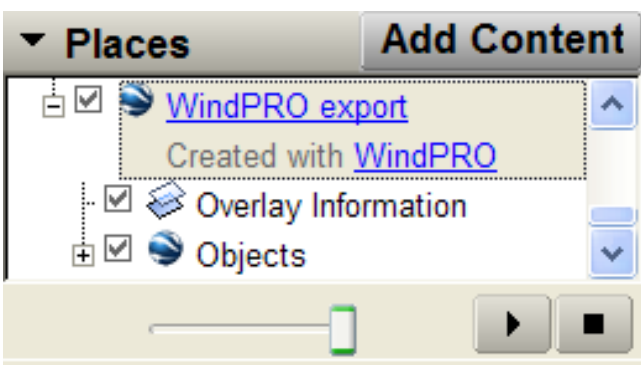


Figure 13 In the Google Earth layer structure, a WindPRO export layer is added with subfolders with object information etc. Right click at the WindPRO export and choose "Email" to send the Google Earth presentation to the chosen recipient's computer. The mail attachment is a .kmz file holding all the necessary information – this file can also be saved in your project folder (right click on the layer and choose "Save As") as part of the project documentation.

When Google Earth is closed, the file will be removed unless you perform a manual "Save As" operation. The idea is that you can "re-export" the project a number of times without getting your own Google Earth filled with several different layouts.

2.16.1 WTGs as photo realistic 3D objects

WTGs can be exported to Google Earth and shown as photo realistic 3D objects, just select the objects to export in object list and right click or click the Google Earth button.



Figure 14 Turbines exported to Google Earth.

2.16.2 Photomontages as "fly in"

Exporting cameras can give a unique test of your photomontages and a unique exporting feature, so anyone with Google Earth access can see your photomontages on a Google Earth background – creating a really impressive feature.



Figure 15 The photomontage as a "fly in" feature at Google Earth. By using the "transparency" slider in Google Earth, you can gradually increase transparency of your photo and thereby check how well it matches the Google Earth background.

2.16.3 Results layers as overlay

Result Layer objects exported to Google Earth will be draped on top of the Google Earth surface, ideal for wind resource maps, etc.

2.16.4 Other objects as symbols

All other objects will for now “just” be exported as symbols, so there is still room for improvement in future versions.

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3.0 ENERGY – Intro, modules, and step-by-step guide

3.0.1 Introduction to WindPRO energy calculation modules

Calculating the energy production for a wind energy project is one of the most important tasks. The annual energy production for a specific turbine can vary by several hundred percent depending on the site, even within a small country like Denmark. Since the installation and operation costs only vary a little between sites (expect for offshore, where the costs are much higher), the site-dependent energy production becomes crucial for the feasibility of a wind energy project. Also, within the selected site, the micro-siting is important for the expected Annual Energy Production (AEP), where factors such as utilization of higher elevated locations, distance between turbines, and turbine orientation are important in lowering the wake losses.

WindPRO offers a range of options for calculating the AEP. WindPRO is the most flexible tool of its kind when it comes to modeling combinations of wind data in varying formats, multiple types of wind turbines, combining new and existing WTGs, and handling different hub types and heights. A great deal of effort has been put into developing the capabilities of intelligently checking input data as well as checking the calculation results in order to ensure that the user is producing the most reliable results and documentation.

From version 2.7, it's possible to calculate time-dependent variations of the expected AEP within the PARK module.

The RESOURCE calculation (part of MODEL) gives you the ability to establish a wind energy resource map. This gives you the information you need for selecting suitable sites, either on a micro-siting level for best positioning of the individual turbines, or for calculation of larger regions in order to determine the bestsuited sites for wind farms. The module has unique capabilities for calculating large areas in one process and has been used for calculating the entire Country of Denmark in a 200 m grid resolution. A wind resource map presented on-screen as a background map is a valuable tool for manually optimizing a wind farm layout.

For optimizing a wind farm layout automatically, see Chapter 8.

For calculation utilizing CFD models, see Chapter 9, but note this part is under reconstruction.

For long term correction of short term measurements, see chapter 11, MCP module.

For Loss and uncertainty calculations, see chapter 12.

The various modules for performing AEP calculations with WindPRO are structured in the following modules:

- METEO – includes the Meteo object for wind data import/screening/analyze and the Meteo analyzer for like cross predictions, substitutions etc. and AEP calculation direct from wind measurements.
- MODEL – includes the “simple” ATLAS model, interface to WAsP model, RESOURCE calculation and interface to CFD models (under reconstruction).
- MCP/Statgen – for long term correction of wind measurements and generation of wind statistics based on the long term corrected wind data. This is documented in separate manual chapter (11).
- PARK – Wake loss calculation as well as time varying AEP calculations and turbulence calculations. The PARK calculations can be performed on basis of METEO for “simple terrain sites” (where the wind is assumed the same for the entire site) or MODEL, where the models extrapolate the wind to each WTG position before the wake loss calculation.

The different modules and “sub modules” are explained further below:

METEO – With this module, you can calculate energy production based on measured wind data, where you've taken exact measurements at the future WTG location (in flat, open terrain the data can usually be used for larger areas). If the measurements are taken at a height other than the proposed WTG hub height, the data can be extrapolated by giving in a wind gradient exponent, but this must be done carefully. Only in flat and simple terrain (low roughness) can the height extrapolation be expected to follow simple rules. The module gives access to comprehensive tools for importing/screening/analyzing measured wind data, which is a mix of the METEO object and the Meteo analyzer. The Meteo analyzer has features for comparing more

measurement masts, performing data substitution, and conducting a cross prediction and generation of complete 1 year time series based on data interpolation/patching etc.

The METEO module will normally be used more for importing, analyzing, and preparing measured wind data for generation of a Wind Statistic with the WAsP Interface.

MODEL (ATLAS) - With this module, you can calculate energy production based on the simple ATLAS model (Wind Atlas method), which is based on a terrain description (roughness, simple hills, and obstacles) and a Wind Statistic. The roughness model is the same as in WAsP, but the hills and obstacles are calculated with less complex flow models than in WAsP. For this reason, ATLAS should only be used for noncomplex terrain, and should never be used in mountainous terrain. The future for the ATLAS model will only be smaller projects (smaller turbines), where the model cost is an issue. For large modern turbine projects, the further refined and updated WAsP model should always be used. Nevertheless, the ATLAS model has been used for calculating more than 6.000 WTGs in Denmark, which has worked quite well.

MODEL (WAsP Interface) – With this module you can calculate the energy production using WAsP (software from RISØ, DK) as the “calculation engine”, This means that you can perform calculations for complex terrain using the Wind Atlas method with the advanced flow model incorporated into WAsP. The WAsP Interface is both a preprocessor to WAsP, for preparing and checking data, and a post-processor, for printing results in a report. It is also used for performing and printing a number of analyses, which provides the user with valuable feedback for evaluating the quality of the calculations.

3.0.1.1 Generating a Wind Statistic

STATGEN – With the METEO and WAsP Interface modules, measured wind data can be converted into Wind Statistics. The measured wind data is “cleaned” for local terrain conditions, so a regional wind climate is established for use in calculations at locations other than where the wind measurements were taken (e.g. at each turbine position).

3.0.1.2 Creating a Wind Resource Map

MODEL (RESOURCE) – This module can be used in a stand-alone fashion to generate a wind resource map based on an .rsf or a .wrg file from a WAsP calculation and an optional WTG (for an energy production map). Together with the WAsP Interface module, the RESOURCE module can calculate and generate the wind resource map for very large areas in one process. It can smoothly change the wind data used and automatically optimize digital maps for use in the WAsP calculation(WAsP can only handle limited-sized map files in a resource calculation). Lastly, local obstacles can be included, and calculations can be performed for more than one hub height at a time. These capabilities are not available when using WAsP as a stand-alone product. The RESOURCE module also provides the key input to the OPTIMIZE module based on .rsf files.

3.0.1.3 Wind farm calculations

PARK – This module is used for calculating wake losses and AEP for wind farms. The inputs for the PARK calculation are the WTG positions, types, and hub- heights, plus the wind data delivered from one of the three previously mentioned modules (ATLAS, METEO or WAsP Interface), from an .rsf file from the RESOURCE module, or from a CFD model. In order to utilize the PARK module, one of the four previously mentioned modules must be available. The PARK module can also calculate time varying AEP based on METEO data.

3.0.1.4 Optimization of wind farm layout

OPTIMIZE – This module provides access to the PARK Design Object, which is a useful tool for large-scale park design (e.g. off-shore).From version 2.4, it can run a parameter variation for auto-optimization. The other automatic energy-optimizing algorithm is based on utilization in more complex terrain (see OPTIMIZE Chapter 8). OPTIMIZE is based on the PARK module and the MODEL (RESOURCE) module, and can only be used when both modules are available.

3.0.2 Step-by-step guide for AEP calculations

3.0.2.0 PARK calculation based on local measurements, WAsP model

- ❑ Establish a map and a proposed WTG project (see BASIS Section 2.0.5)
- ❑ Establish height contour lines within approximately a 5-km radius around site in a Line Object
- ❑ Establish the roughness description within approximately a 20-km radius around site. There are three methods available:
 - 1) Roughness rose(s) (Site Data Object)
 - 2) Roughness lines (Line Object)
 - 3) Roughness lines exported from the Area Object.
- ❑ If there are local obstacles, establish them (Obstacle Object).
- ❑ Establish a Site Data Object for a WAsP calculation and select a Wind Statistic (if not available, see Calculation of a Wind Statistic, Section 3.0.2.4) NOTE: A correct Wind Statistic is extremely important to calculate correct results. Check Map data connected to the Site Data Object.
- ❑ Run PARK (if wind farm) or WAsP Interface (if single WTG or site analyses, e.g. wind profiles, additional hub heights or WTG types)

3.0.2.1 Based on measured on-site data WITHOUT a Model

- ❑ Establish a map and a proposed WTG project (see BASIS Section 2.0.5)
- ❑ Establish a Meteo Object
- ❑ Input measured data in the Meteo Object. The four acceptable types of input data are:
 - 1) Raw data logger files
 - 2) Time series from e.g. spreadsheet
 - 3) Table data (wind speed and wind direction frequency) or WAsP .TAB file
 - 4) Weibull parameters (or mean wind speed) versus direction sector (or just mean wind speed for preliminary calculations).
- ❑ Run PARK (if wind farm) or METEO (if single WTG or site analyses, e.g. additional hub heights or WTG types). NOTE: Data has to be representative of long-term wind conditions. Measurements must be at hub height or the wind shear must be known. When WTG positions are more than 50 m away from the mast, this method should only be used if the terrain is very simple (flat, without local obstacles or changing surface roughness), otherwise, see Section 3.0.2.4.

3.0.2.2 Based on Wind Statistic and terrain description, ATLAS model (simple)

- ❑ Establish a map and a proposed WTG project (see BASIS)
- ❑ Establish a Site Data Object for use in an ATLAS calculation and select Wind Statistics (if not available, see Calculation of a Wind Statistics, Section 3.0.2.4).
- ❑ Enter roughness rose information (20-km radius), local obstacles, and local simple hills. This is done graphically by using the options that appear on the pop-up menu when right-clicking on the Site Data Object.
- ❑ Run PARK (if wind farm) or ATLAS (if single WTG or site analyses, e.g. additional hub heights or WTG types)

3.0.2.3 Based on Wind Statistics and terrain description, WAsP model

- ❑ Establish a map and a proposed WTG project (see BASIS)
- ❑ Establish height contour lines within approximately a 5-km radius around site in a Line Object
- ❑ Establish the roughness description within approximately a 20-km radius around site. There are three methods available:
 - 1) Roughness rose (Site Data Object)
 - 2) Roughness lines (Line Object)
 - 3) Roughness lines exported from the Area Object.
- ❑ If there are local obstacles, establish them (Obstacle Object).
- ❑ Establish a Site Data Object for a WAsP calculation and select a Wind Statistic (if not available, see Calculation of a Wind Statistic, Section 3.0.2.4) NOTE: A correct Wind Statistic is extremely important to calculate correct results. Check Map data connected to the Site Data Object.
- ❑ Run PARK (if wind farm) or WAsP Interface (if single WTG or site analyses, e.g. wind profiles, additional hub heights or WTG types)

3.0.2.4 Calculation of a Wind Statistic (WAsP required)

- ❑ Establish a map for the measure mast site (see BASIS)
- ❑ Establish height contour lines within approximately a 5-km radius around the measure mast in the Line Object
- ❑ Establish the roughness description within approximately a 20-km radius around measure mast. There are three methods available:
 - 1) Roughness rose (Site Data Object)
 - 2) Roughness lines (Line Object)
 - 3) Roughness lines exported from the Area Object.
- ❑ If there are local obstacles, establish them (Obstacle Object).
- ❑ Establish a Site Data Object for STATGEN purpose and add data.
- ❑ Establish a Meteo Object (see Section 3.0.2.1)
- ❑ Run STATGEN from the calculation menu (takes data from the Meteo and Site Data Objects.)
- ❑ Use Wind Statistic (see Section 3.0.2.2 or 3.0.2.3).

3.0.2.5 Calculation of a Wind Resource Map (WAsP required)

- ❑ Establish a map and a proposed WTG project (see BASIS)
- ❑ Establish height contour lines within approximately a 5-km radius around the calculation map area in the Line Object
- ❑ Establish the roughness description within approximately a 20-km radius around the calculation map area. There are two methods available:
 - 1) Roughness lines (Line Object)
 - 2) Roughness lines exported from the Area Object. Using the Area Object, information can be imported from e.g. .dxf files
- ❑ Establish a Site Data Object for use in a RESGEN calculation and select Wind Statistics (if not available, see Calculation of a Wind Statistics, Section 3.0.2.4). Check MAP files and input region that you will calculate within.
- ❑ Run a RESOURCE calculation and set grid size, height(s) etc.
- ❑ Establish a Result Layer Object on the map for viewing the resource map layer and for manual or automatic optimization of the wind farm layout (OPTIMIZE module).

3.1. ENERGY – Fundamentals in Calculations

3.1.1 Basic data for energy calculations

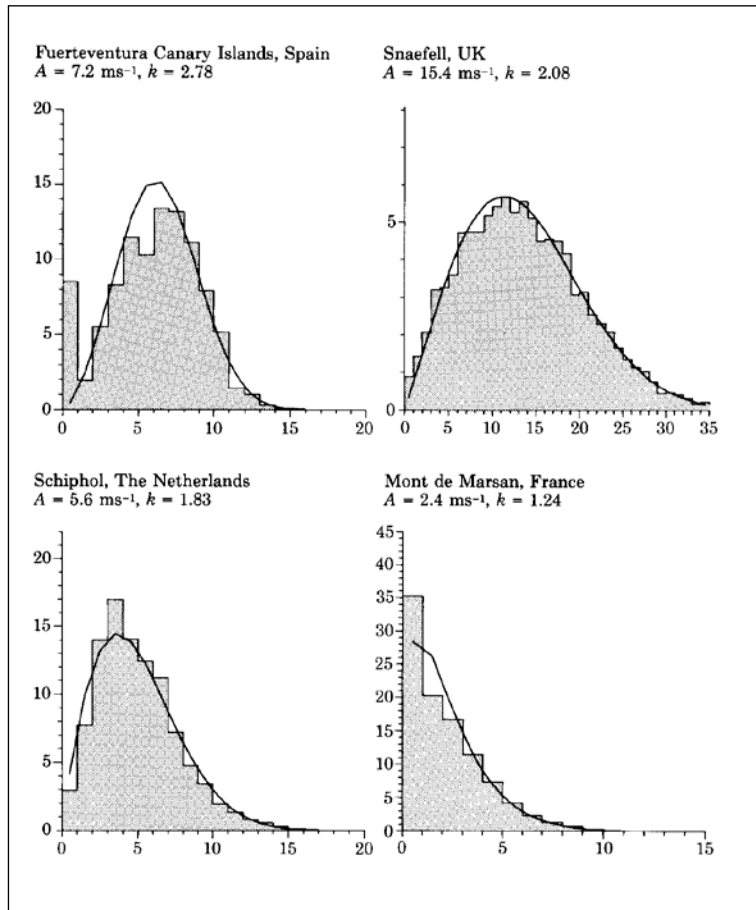
Two basic sets of data are needed in order to estimate the AEP for a WTG:

- 1) The wind speed distribution at hub height
- 2) The power curve(s) for the turbine(s) – air density corrected and eventually turbulence/shear corrected

If more WTGs are placed together and form a cluster or a wind farm, the directional wind speed distribution, the precise micro-siting of the WTGs, and their C_t curve(s) must also be known.

3.1.2 Wind speed distribution

The wind speed distribution describes the probability for a specific wind speed versus the wind speed. The mathematical, two-parameter Weibull distribution is often used to describe the wind speed distribution. The figure below shows examples of measured distributions and corresponding Weibull curve fits.



The two Weibull distribution parameters are defined by:

$$f(u) = \frac{k}{A} \left(\frac{u}{A}\right)^{k-1} \exp\left[-\left(\frac{u}{A}\right)^k\right]$$

Where:

u = the wind speed

k = the Weibull form factor

A = the Weibull scale parameter (for typical distributions, $A \approx$ is approx. equal to $1.126 \cdot u_{\text{mean}}$)

A special variant of the Weibull distribution is the Raleigh distribution where $k = 2$. This distribution is often assumed when only the mean wind speed is known.

3.1.2.1 Methods for establishing a wind speed distribution

The wind speed distribution can be established by one of the following methods:

A: Measurements at the WTG site

B: One or more Wind Statistics for the region and a terrain description for the WTG site (for simple terrain use the Wind Atlas method, ATLAS or WAsP)

C: One or more Wind Statistics for the region and a terrain description for the WTG site (for complex terrain use the Wind Atlas method, WAsP)

D: Measurements for the region (or on-site, where more WTGs with different terrain conditions will be sited), transformed to Wind Statistics for the region by WAsP (WindPRO module STATGEN). After establishment of a Wind Statistics, go to C:

A precise wind speed distribution is crucial. One reason for this is the fact that the energy content of the wind increases cubically with the wind speed. The wind power output from a WTG is calculated with the following equation:

$$P = \frac{1}{2} \cdot \rho \cdot u^3 \cdot A \cdot C_e(u) \quad (\text{W})$$

Where:

ρ = the Air Density

u = the Wind Speed

A = the Area Swept by the Rotor

$C_e(u)$ = the total efficiency, from wind energy to electric output of the WTG as a function of the wind speed.

An example:

At a wind speed of 10 m/s, with a 150 kW WTG with a 23-m rotor diameter that has an efficiency of 40% at an air density of 1.125 kg/m³.

Then the power is calculated as follows:

$$P = \frac{1}{2} \cdot 1.125 \text{ kg/m}^3 \cdot 10^3 \text{ (m/s)}^3 \cdot 23^2 \cdot \pi/4 \text{ m}^2 \cdot 0.4 = 93,434 \text{ W}$$

This means that the power is 93.4 kW and the energy production is 93.4 kWh in one hour. If the wind speed always is 10 m/s during an entire year, the AEP will be 8760h x 93.4 kWh = 818 MWh – but conditions are never this ideal, therefore the number of hours with all the varying wind speeds must be known (the wind speed distribution).

At half the wind speed (5 m/s), assuming the same WTG efficiency (which, in practice, will be lower), the power is 11.7 kW or only 12.5%.

NOTE: The formula above cannot be used to calculate annual energy production based on the annual mean wind speed. The wind distribution and the power curve must both be known.

Method A) Measurements at the WTG site

The measurements must correspond to the long-term wind conditions. Typically, this calls for continued measurements over a minimum period of three years. If at all possible, measurements of shorter periods must be controlled and correlated to the long-term measurements by utilizing a station within the same region.

The data should be available in one of the following formats:

- Time series from a data logger or spreadsheet, normally with records of both wind speed and direction
- Table or histogram with observations per wind speed interval (and normally by direction interval)
- Weibull parameters, possibly given per wind direction sector
- Mean wind speed, possibly given per wind direction sector

Data that is available in one of the above formats can be entered or imported into a Meteo Object in WindPRO (see also Sections 3.2.2 and 3.3.2).

Method B) One or more Wind Statistics for the region and a terrain description for the WTG site (simple terrain)

The wind speed distribution in a relatively simple terrain can be calculated with ATLAS, e.g. as for most of Denmark (except those areas with large hill formations or industrial areas with many dominating local obstacles). ATLAS requires a Terrain Data Object and one or more Wind Statistics. The Wind Statistics should be based on measurements made within a maximum radius of 200 km from the site (see also Sections 2.1.x and 3.1.x).

Method C) One or more regional Wind Statistics and a terrain description for the WTG site (complex terrain)

For sites in more complex terrain, i.e. with many hills, mountainous terrain, or terrain with dominating local obstacles, the calculation of the wind speed distribution can be carried out by using the energy calculation software WASP. WindPRO calls WASP (which must be purchased from RISØ separately as the calculation module once a Terrain Data Object has been created, WASP has been selected as the calculation module, and one or more Wind Statistics have been selected. The Wind Statistics should be based on measurements made within a maximum radius of 100 km from the site. Please notice that Wind Statistics in mountainous terrain may only be valid within a very short distance (down to as little as a few hundred meters) from the measurement station (see also Sections 2.1.x and 3.1.x).

Method D) Measurements for the region transformed into Wind Statistics for a region by WASP

The comments that were made under Method A are valid here too. The only difference is that the data cannot be used directly, but instead, must be transformed into a set of regional Wind Statistics which are based on the measured data combined with a terrain description as outlined under Method C.

In other words, first a Meteo Object must be created in WindPRO, and then a Terrain Object for the measuring station must be created and used to generate a set of Wind Statistics for the measuring station (the regional Wind Statistics). The regional Wind Statistics can then be used as described under Method B or C (see also Section 3.2.1).

3.1.3 Fitting Weibull Parameters for Wind Energy Applications

A number of different methods exist for estimating the distribution parameters in an arbitrary distribution. Among the most common methods are procedures using: 1) estimation of the statistical moments, 2) least squares methods, 3) maximum likelihood methods or 4) Bayesian methods. An introduction to these methods may be found in Ross [i]. Traditionally, it is recommended to use the maximum likelihood method for estimating the distribution parameters because of the ability of this method to estimate not only the parameters themselves but also a consistent estimate of any statistical uncertainty connected to the distribution parameters. When using the methods 1) or 2), it is possible to include uncertainty estimates on the distribution parameters using Bootstrap or Jackknife methods, see Efron and Tibshirani [ii].

3.1.3.1 The Weibull Distribution

For wind energy applications, the two-parameter Weibull distribution is used as the most common parametric distribution of the T -minutes averaged wind speed (often $T=10$ minutes):

$$F(u) = 1 - \exp\left[-\left[\frac{u}{A}\right]^k\right] \quad (1)$$

$$f(u) = F'(u) = \frac{k}{A} \cdot \left[\frac{u}{A}\right]^{k-1} \exp\left[-\left[\frac{u}{A}\right]^k\right] \quad (2)$$

where k is the Weibull form parameter
 A is the Weibull scale parameter
 $f(u)$ is the Weibull density function
 $F(u)$ is the Weibull cumulative distribution function

The statistical moments, a_v , are related to the Weibull distribution parameters as follows:

$$\text{Mean value:} \quad \mu = a_1 = A \cdot \Gamma[1 + 1/k] \quad (3)$$

$$v\text{-th order statistical moment:} \quad a_v = \int f(u)u^v du = A^v \cdot \Gamma[1 + v/k] \quad (4)$$

3.1.3.2 Estimating Moments in the Sample (Measured/Observed) Distribution

In the sample distribution, the statistical v -th order moments, a_v , are given by [iii, Chapter 27]:

$$a_v = \frac{1}{n} \sum_i x_i^v \quad (5)$$

where a_v is the v -th order statistical moment
 n is the number of samples
 x_i is the sample with the index i

Note: The sample moments should be determined directly from the available time series/samples. However, it is also possible to estimate the sample moments from histograms – even if this procedure is slightly more inaccurate.

3.1.3.3 The Wind Power Density

The available wind power density is proportional to the mean cube of the wind speed. This may be expressed using the Weibull parameters:

$$\begin{aligned} E &= \int 0.5(\rho u)u^2 f(u)du = 0.5\rho a_3 \\ &= 0.5\rho A^3 \cdot \Gamma(1 + 3/k) \end{aligned} \quad (6)$$

When dealing with the sample distribution, the wind power density is:

$$E_{\text{sample}} = 0.5\rho \frac{1}{n} \sum_i u_i^3 \quad (7)$$

3.1.3.4 Estimating the Weibull Parameters for Wind Energy Applications

This section describes how to estimate the Weibull parameters using the method described in The European Wind Atlas [iv]. When using the 2-parameter Weibull distribution for wind energy applications, the requirements for the estimated 'optimum' distribution parameters may not be as specified in the four methods above. Indeed, The European Wind Atlas [iv] specifies two criteria quite different from the ones specified in the 'traditional' methods:

- The total wind energy in the fitted Weibull distribution and the observed distribution are equal.
- The frequency of occurrence of the wind speeds higher than the observed average speeds are the same for the two distributions.

These two requirements lead to an equation in k only. It is important to notice, that the average wind speed in the requirement in 2) is the sample wind speed. This leads to the required equation in k only. The equations (6) + (7) is used in order to determine the A parameter as a function of k :

$$E = E_{sample} \Leftrightarrow A = \left[\left(\frac{1}{n} \sum_i u_i^3 \right) / \Gamma(1 + 3/k) \right]^{1/3} = [a_3 / \Gamma(1 + 3/k)]^{1/3} \quad (8)$$

Now, the requirement 2) is used with equation (8):

$$P[u > \mu_{sample}] = 1 - F(\mu_{sample}) = \exp \left[- \left(\frac{\mu_{sample}}{A} \right)^k \right] = \exp \left[- \left(\frac{\mu_{sample}}{[a_3 / \Gamma(1 + 3/k)]^{1/3}} \right)^k \right] \quad (9)$$

A standard root finding algorithm is utilized in order to determine k from eq. (9), as the probability of exceeding the mean value, $P[u > \mu_{sample}]$ is calculated directly from the sample distribution (time series or histograms). Now, when k is known (calculated from (9)), A is easily determined from (8), assuming that E or a_3 are also determined from the sample distribution.

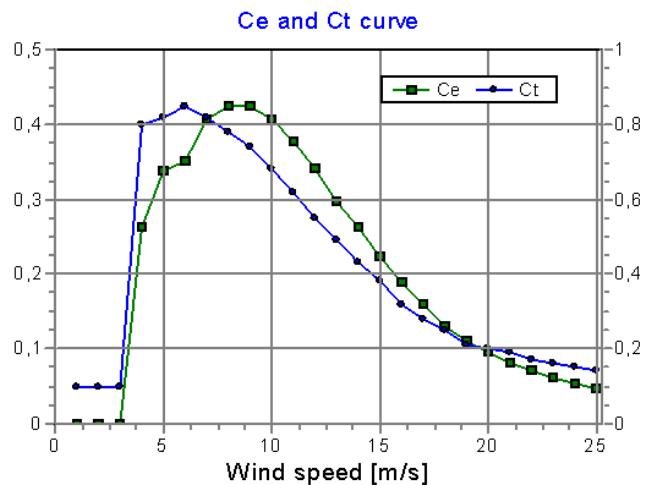
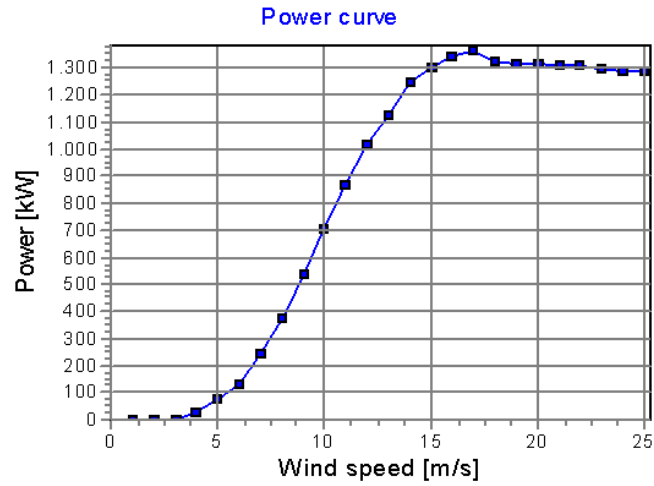
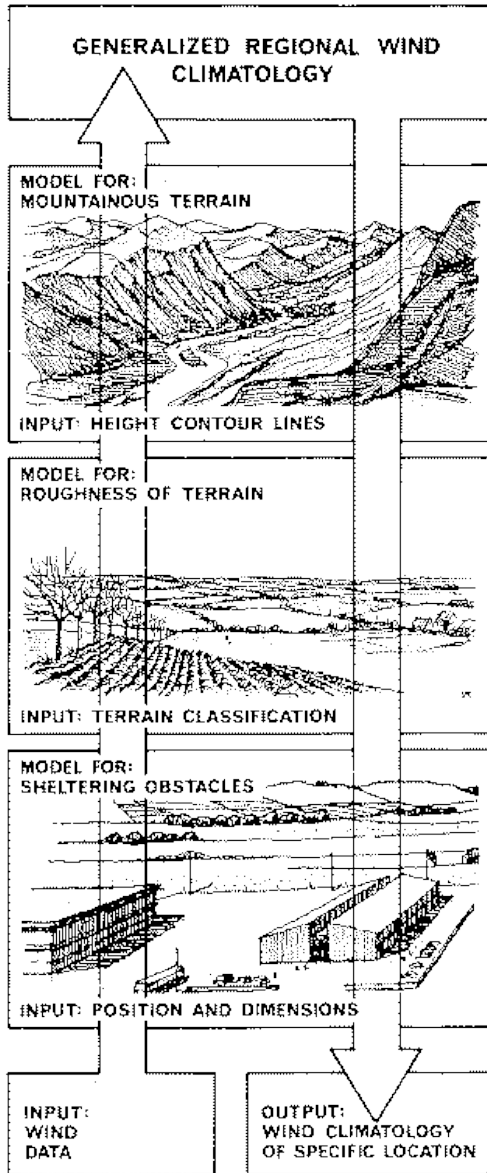
Example – samples with histograms and time series data

Using time series data in a section between degrees = [255;285[from a Danish wind farm at Torrild, then the first and third order moments may be calculated to $a_0 = 5.593$ m/s and $a_3 = 321.88$ (m/s)³ (using eq. 5). The probability of exceeding the mean wind speed is 0.45421 in the sample distribution. The k parameter may be determined to $k = 2.0444$ and $A = 6.2801$ m/s using equations (9) and (8).

Estimating the moments from a histogram using a 1 m/s bin width yields $a_0 = 5.654$ m/s and $a_3 = 332.15$ (m/s)³ and the probability of exceeding the mean is 0.4511. The Weibull parameters can be determined to $k = 2.0267$ and $A = 6.3275$, i.e. a slightly different result than the one obtained using time series. The current implementation in WindPRO differs slightly from the specifications stated in the European Wind Atlas (using the distribution density function instead of the distribution function), but it also uses histograms in estimating the Weibull parameters. Here, an $A = 6.316$ and $k = 2.0340$ is found. WASP reports $A = 6.3$ and $k = 2.04$. The histogram values that were used are stated below:

```
Wind [m/s] <1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Count [o/oo] 11 62 121 155 122 120 97 84 77 73 41 22 8 4 2 1 1 0 0 0
```

Please note that when calculating the mean value from the Weibull A and k parameters (see eq. (3)), then the mean value is slightly different from the one found directly from the sample values. This is due to the fact, that the fitting criteria assures only that the energy in the sample and fitted distributions are equal, and furthermore that the probability of exceeding the sample mean are the same. The means calculated from the Weibull A and k parameters are 5.564 m/s for the time series data and 5.606 m/s for the histogram data.



3.1.4 The power curve and the C_t curve

The power curve describes the electric power output from a specific WTG versus the wind speed at hub height. The power curve is typically measured by installing wind monitoring equipment close to a WTG, and measuring the coincident values of the wind speed and the electric power output. Alternatively, the power curve can be calculated using aerodynamic computer models.

Power curves for a large number of the WTGs are already available in the wind turbine catalogue in the WindPRO BASIS module (WTG catalogue). The power curves are generally based on measurements or calculations. The reliability of the power curves may vary. Therefore, it's important to check the power curves. Please refer to Chapter 2.6 for further information on this subject.

The C_t curve, which is used in PARK calculations, is usually just a standard curve for either stall-regulated or pitch-regulated WTGs. Experience indicates that this is sufficient, but more detailed scientific work on the subject is lacking.

Further information about the power curves can be found in the chapter 2.6 in WindPRO BASIS. A typical example of power curve, C_e and C_t curves for a stall-regulated 2-speed generator WTG are displayed in the above figures.

3.2. ENERGY – Calculation Methods

3.2.0 Introduction to calculation methods

In this chapter you will find a short description of the various calculation methods that can be used from WindPRO. The following methods will be described:

- Wind atlas method (modules: ATLAS, WAsP Interface and RESOURCE)
- Direct use of measurements (module: METEO with Weibull or measure option)
- PARK - this calculation is used in conjunction with one of the methods mentioned above.

3.2.1 Wind Atlas method (ATLAS, WAsP and Resource)

All calculation methods are based on the Wind Atlas method.

The Wind Atlas method assumes that you use a set of Wind Statistics for a specific area (the local Wind Atlas). Combined with a terrain assessment of the area within 20-km radius around the site, the program calculates the actual mean site-specific wind conditions at any specified height above the site terrain. These wind data can then be compared with the power curve of a specific WTG, after which the expected mean annual energy production for that WTG at the chosen site can be calculated.

Hence, three sets of information are required for an energy production calculation based on the Wind Atlas method:

- The governing Wind Statistics for the region
- A terrain assessment (roughness, orography and local obstacles)
- Power curves for the WTG (s) in question

3.2.1.1 Method description – ATLAS as opposed to WAsP

The WindPRO program module ATLAS complies with the algorithms that are described in the “European Wind Atlas” with the following limitations:

- Only one obstacle per wind direction sector can be entered. Also, the obstacle model is simplified compared to the WAsP model.
- The hill model is simplified and is not based on a flow model, as is the WAsP model. The hill model is based on a simple mathematical model, which only calculates with the height and the length of one hill in each directional sector.
- The stability model, which is described in the “European Wind Atlas” and which adjusts the wind profile at sites within 10 km from a coastline, is not included in the ATLAS program. However, sensitivity analyses carried out by EMD indicate that only marginal errors may occur if the stability model is not included.

One of the key elements in the Wind Atlas method is the terrain assessment. The terrain must be described as follows:

- Roughness classification of the terrain - detailed within approximately a 5-km radius from the site, or coarser within a 20-km radius from the site.
- Hills (orography) - within approximately a 5-km radius if you use digital maps.
- Local obstacles - within approximately a 1-km radius from the WTG position.

Usually, a terrain assessment requires both good quality maps and a field survey.

3.2.1.2 Method description – Regional Wind Statistics

The governing regional Wind Statistics (Wind Atlases) for most of the European countries (1989) are mapped in the “European Wind Atlas” from RISØ. A number of other countries, e.g. the new EEC members Sweden and Finland, have made similar maps. It’s not possible to explicitly point out exactly which Wind Atlas to use for a specific site (in Denmark, one should generally choose DANMARK ‘92). But one should generally use a Wind Atlas which is based on the measuring station closest to the site, and then control the result by comparing the result with Wind Statistics from one or two adjacent measuring stations.

Another approach would be to specify a number of Wind Atlases in the same calculation, weighted by the reciprocal distance to the site.

The regional Wind Atlas constitutes a complete description of the governing wind conditions for the region in question, and consists of a table that contains the following default WAsP setup (the parameters can be changed manually in the WAsP parameter file):

Weibull A and k parameters for:

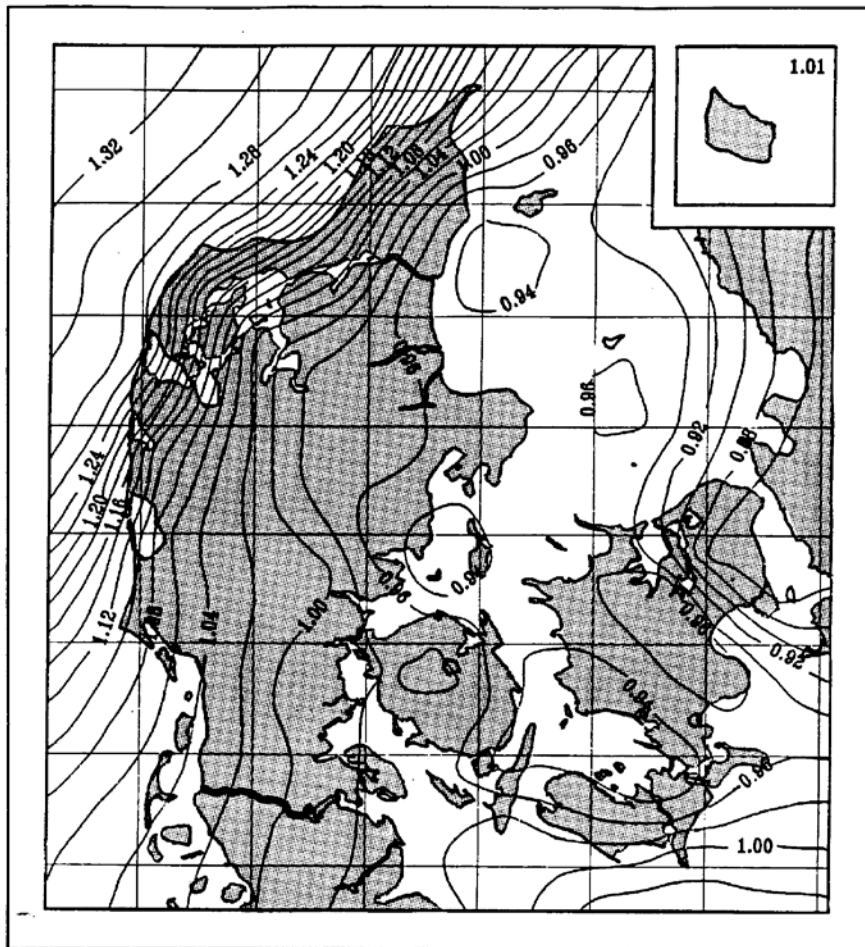
- Each of the roughness classes: 0, 1, 2, 3 (4 in total)
- Each of the heights: 10, 25, 50, 100, 200 m above ground level (5 in total)
- Each of the directions: N, NNE, ENE, E, ..., NNW (12 in total)

This gives a total of $4 * 5 * 12 = 240$ wind speed distributions.

The most critical aspect of the Wind Atlases is their quality, which may vary significantly. An error margin of 50% in the estimated energy production is easily generated simply if a Wind Atlas of poor quality is used. It’s, therefore, important to crosscheck the applied Wind Atlas with other neighboring Wind Atlases, and preferably make test calculations for other WTGs in the region, which have been operating for some years.

Recommendations for Site Calculations in Denmark

When calculating the wind energy potential for sites in Denmark, the “Danmark ‘07” Wind Atlas is recommended. It includes a set of correction curves that scales the wind speed according to the geographical position (the correction for differences in the geostrophic wind conditions (~1000m agl.) over Denmark is based on comprehensive studies and production validation for a large number of Danish WTGs). The map below (EMD/InterCon I/S) shows the energy correction factors when one uses the “Danmark ‘07” Wind Atlas (which is based on the “Beldringe” Wind Atlas included in the European Wind Atlas). Ask for detailed documentation of the Danish ‘07 wind statistic (or find it at www.windpro.com).



Recommendations for site calculations outside Denmark

In general, the data from the European Wind Atlas seems to be reliable. When other Wind Statistics are used, it's recommended to always include at least two Wind Statistics from the region, and to make sure that the differences between these data are acceptable, or to include the production from existing WTGs as control elements in the calculation.

WindPRO can work simultaneously with several Wind Atlases. The program automatically calculates weighting factors for the individual Wind Atlases proportional to their reciprocal distances to the site. These factors can, if needed, be edited afterwards based on more detailed information. For example, if the site is placed in a coastal area, it would often be more accurate to give coastal Wind Statistics a higher weighting, even if closer inland statistics are available.

The use of several Wind Statistics in the same calculation can reduce the uncertainty factor (see also Chapter 3.5 regarding the quality control of data).

For larger projects (>5 MW), it is, in most cases, recommended to establish local wind measurement masts. This pertains to all countries except Denmark and Germany, where the many existing turbines can provide detailed knowledge of the wind regime.

3.2.1.3 Method description – Roughness classification

Roughness classification can be performed in three different ways:

- A. Roughness rose: Description from site for each separate sector (one or more different roughness classifications per sector)
- B. Digitizing a roughness line map (Line Object)

C. Export of roughness lines from land-use polygons. Land-use polygons can be digitized with the Area Object or imported into the Area Object from other information sources.

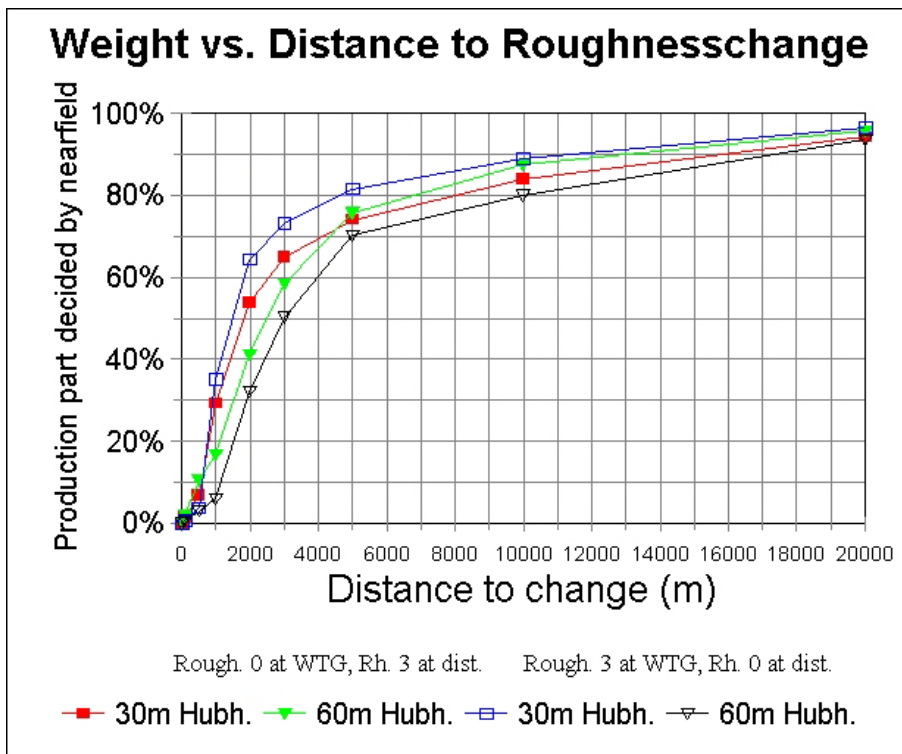
WindPRO makes it easy for the user regardless of which of the three methods is chosen. For method B, a Line Object must be used. For method C, an Area Object must be used. For more information on how to use these objects see Chapter 2, BASIS.

Proper classification of roughness is very important. This is illustrated below using method A, the roughness rose.

The terrain is divided into 8, 12 or more sectors depending on the available Wind Statistics. Most of the Wind Statistics available today are specified in 12 30-degree sectors with the following center angles:

- 0 degrees: (345 degrees to 15 degrees) (N)
- 30 degrees: (15 degrees to 45 degrees) (NNE)
- 60 degrees: (45 degrees to 75 degrees) (ENE)
- 90 degrees: (75 degrees to 105 degrees) (E)
- Etc.

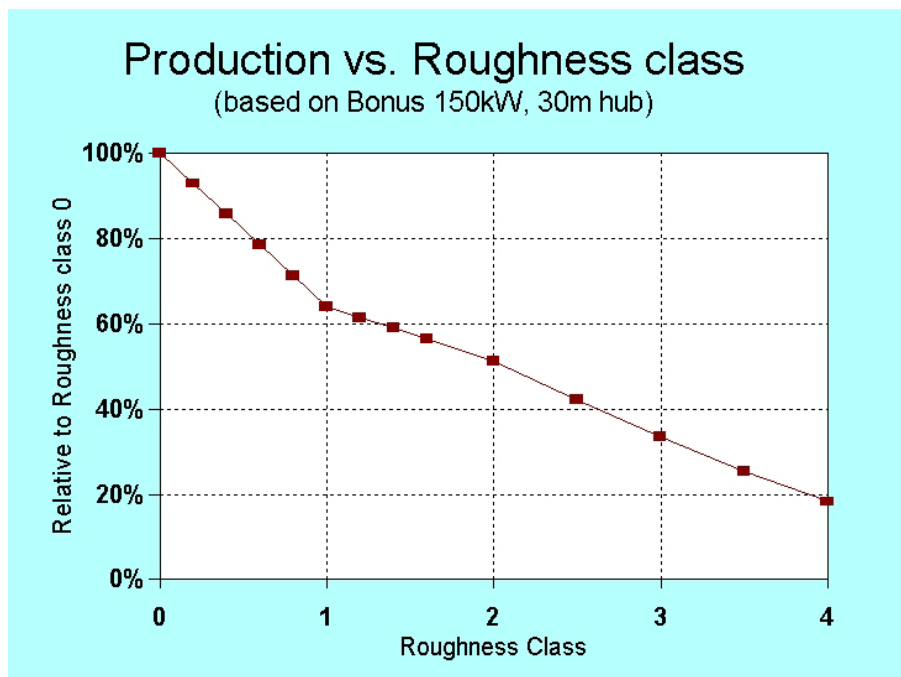
The roughness of the terrain should be described in each sector for a distance of at least 10 km from the site. Depending upon the hub height and terrain conditions, a longer distance may be relevant. Whatever distance is chosen, it's recommended to use this distance in every sector of the terrain description. You can include up to 10 roughness changes in each sector in case the terrain changes its character with the distance from the WTG.



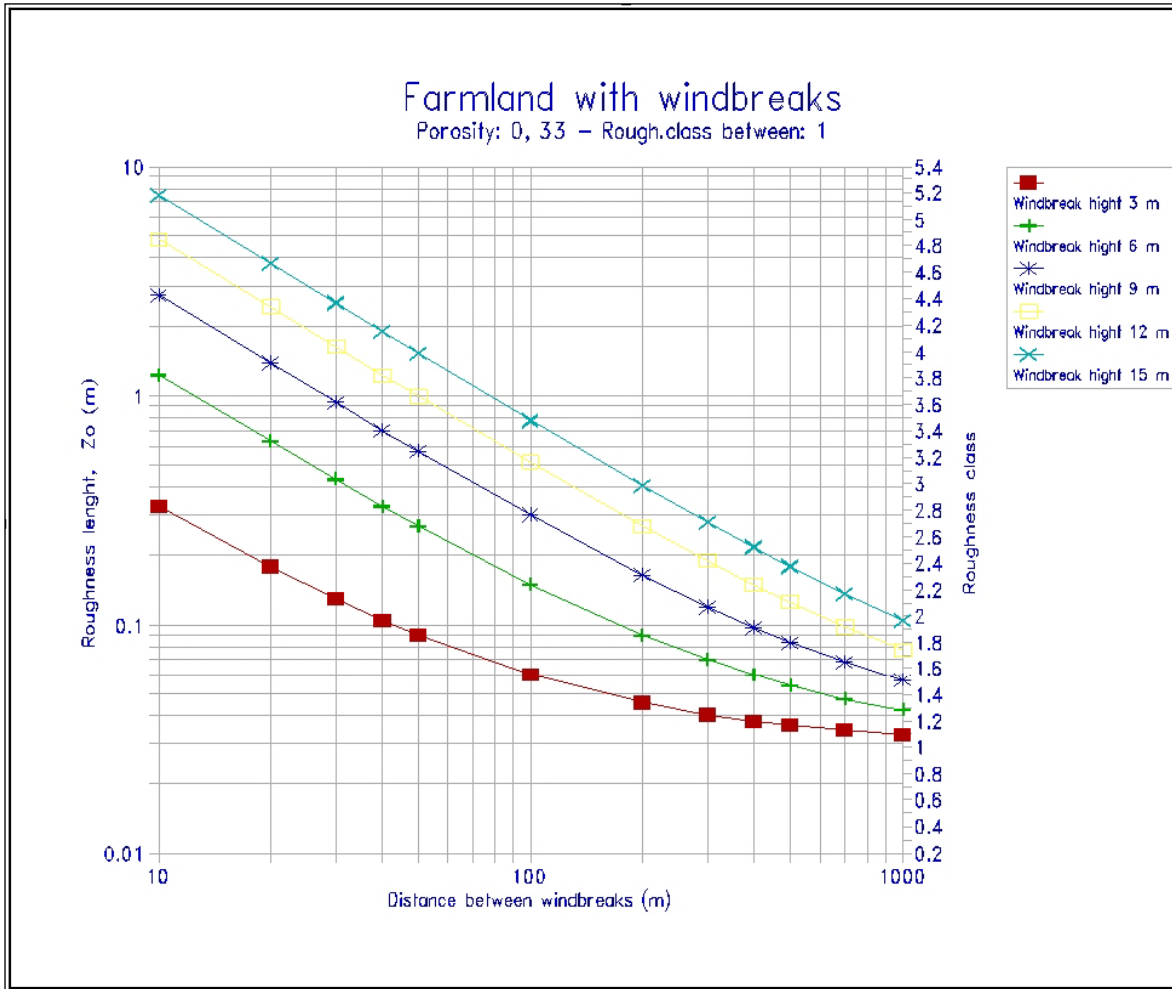
In the figure shown above, the impact of a roughness change at different distances from the WTG is illustrated. The figure illustrates, for example; that with an inner roughness class = 3, an outer roughness class = 0, and a change in 3000 meter distance; 72% of the production will be determined by the inner roughness class when the hub height is 30 m, while only 50% of the production will be determined by the inner roughness when the hub height is 60 m.

You can choose to use either roughness classes or roughness lengths (see next table).

Roughness class	Roughness length	Relative energy %	
0	0,0002	100	Water areas.
0,5	0,0024	73	Mixed Water and land area or very smooth land.
1	0,03	52	Open farmland with no crossing hedges and with scattered buildings. Only smooth hills.
1,5	0,055	45	Famland with some buildings and crossing hedges of 8 m height and about 1250 m apart.
2	0,10	39	Famland with some buildings and crossing hedges of 8 m height and 800 m apart.
2,5	0,20	31	Famland with closed appearance and dense vegetation - crossing hedges of 8 m height and 250 m apart.
3	0,40	24	Villages, small towns, very closed farmland with many or heigh hedges, Forrest, many abrupt orographic changes, etc.
3.5	0,80	18	Large towns, cities with extended build-up areas.
4	1,6	13	Large cities with build-up areas and high buildings.



In areas with hedges, the graphs in the following figure can be used to estimate the roughness class or length. Notice the non-linear impact of the hedge height on the roughness class. Normal farmland is assumed to lie between the hedges. This is incorporated into the figure by adding 0.03 m to all specified roughness lengths. A porosity of 0.33 is assumed.



In an area with many buildings, the roughness length can be estimated by using the following equation:

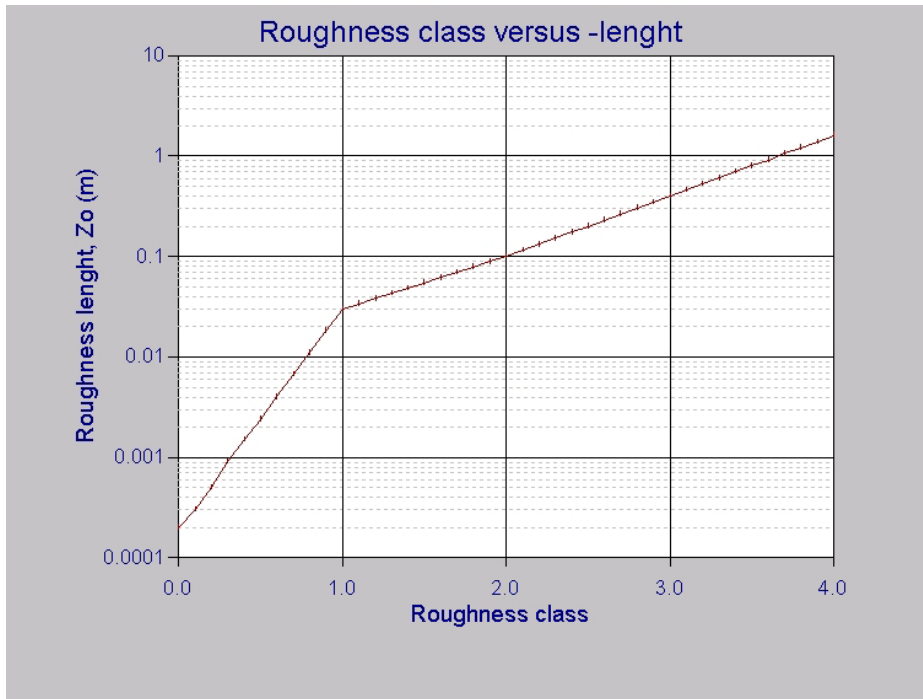
$$z_0 = 0.5 * h^2 * b * n / A$$

Where:

- h** = height of building
- b** = width of building
- n** = number of buildings
- A** = total area within which the n buildings are situated

NOTE: The roughness length of the area between the buildings must be added to the roughness length which has been determined on the basis of the above equation, e.g. add 0.03 m to the calculated roughness length for normal farm land.

The correlation between roughness classes and roughness lengths is indicated in the next figure.



If a sector between two roughness changes consists of more than one roughness class, a simple weighting of the roughness classes in the area is recommended.

For example, if the area consists of 1/2 Roughness Class 2, 1/4 Roughness Class 1 and 1/4 Roughness Class 3, the resulting Roughness Class becomes: $(2 \cdot 2 + 1 \cdot 1 + 1 \cdot 3) / 4 = 2$.

It's important that a roughness classification covers an entire roughness area (belt), i.e. a roughness belt with a width 1000 m with one crossing hedge of 10 m heights should be assessed to the roughness class 2. It's often seen that such an area has been classified as roughness class 1 all the way to the hedge, with a shift to roughness class 3 for a few meters along the width of the hedge, and with a final roughness class of 1 just after the hedge. This is incorrect! The "European Wind Atlas" recommends doubling the width of every new roughness belt when moving outwards from the WTG.

Another important rule: Even if an area is located at a ground level which is lower than the turbine site, the roughness classification is not affected by this fact. *The differences in terrain heights are included in the hill model.*

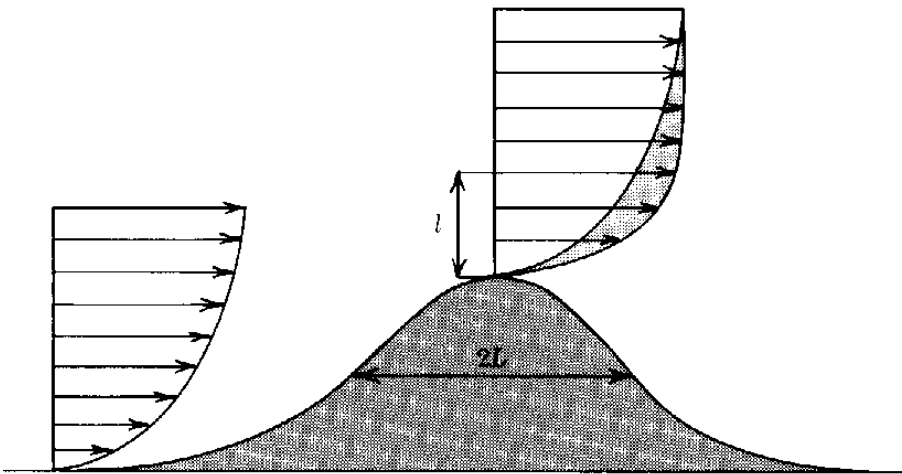
In practice, it's important to visit the site and take preliminary notes regarding the roughness classes and the distances between the roughness changes. Furthermore, notes should be taken regarding local obstacles and their dimensions. Having completed the site visit, the exact distances between the roughness changes and the final design of the roughness classifications can be determined at your desk by using the map and the above-mentioned tools. However, much of the measuring work can be avoided by using digital background maps in WindPRO (see the description of this feature below).

It's important that you carry the map with you when you visit the site. It allows you to verify the map information and to evaluate the size and porosity of the local obstacles.

3.2.1.4 Method description – ATLAS Hills

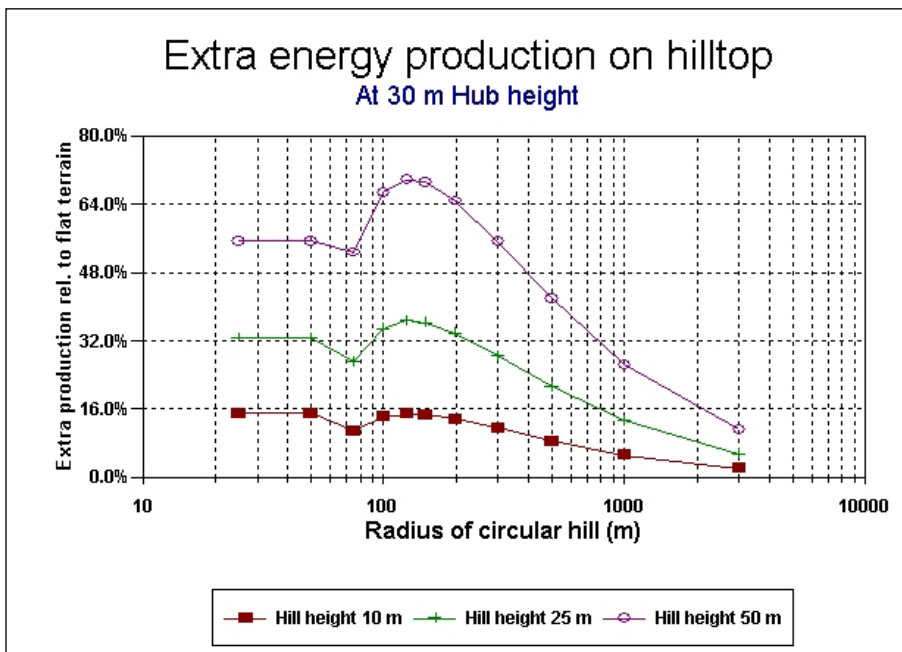
By siting the WTG on the top of a hill you will usually be able to exploit the above-mentioned increase of the wind speed. During the visit to the site, it's necessary to judge whether or not the streamlines of the wind flow will be compressed at hub height and result in an increase of the wind speeds there. The same theory applies in a negative sense, if the WTG is placed on the leeward side of a hill. If the terrain is very complex, e.g. mountainous, an analysis using WAsP should be considered (see the description of this feature in the next chapter).

In the ATLAS model, a simple numerical calculation of the hill influence is carried out on the basis of information about the sector wise hill length (the length from the WTG to the hill base) and hill height. One set of data can be entered in each of the 12 sectors.



In the above figure you can see how hills usually increase the wind speed because of the compressed streamlines (the same amount of air per time unit passes through a reduced cross-section resulting in higher wind speeds).

Cliffs and other abrupt orography changes should not be included when using the hill model as there is no method available today which allows you to calculate the effects of such orography changes. Great precaution should be taken when siting WTGs close to cliffs or other abrupt orography changes.



To illustrate the influence of siting a WTG on a hill, the above figure shows the production increase for a WTG situated on a hill with a circular base. Please notice that even for very small hill radius, the model changes so that it calculates the influence from the hill as if the hub height had been increased instead. If the mathematical model from “Vindatlas for Danmark” is used, the calculation would result in a negative change in the wind speed.

3.2.1.5 Method description – ATLAS Local Obstacles

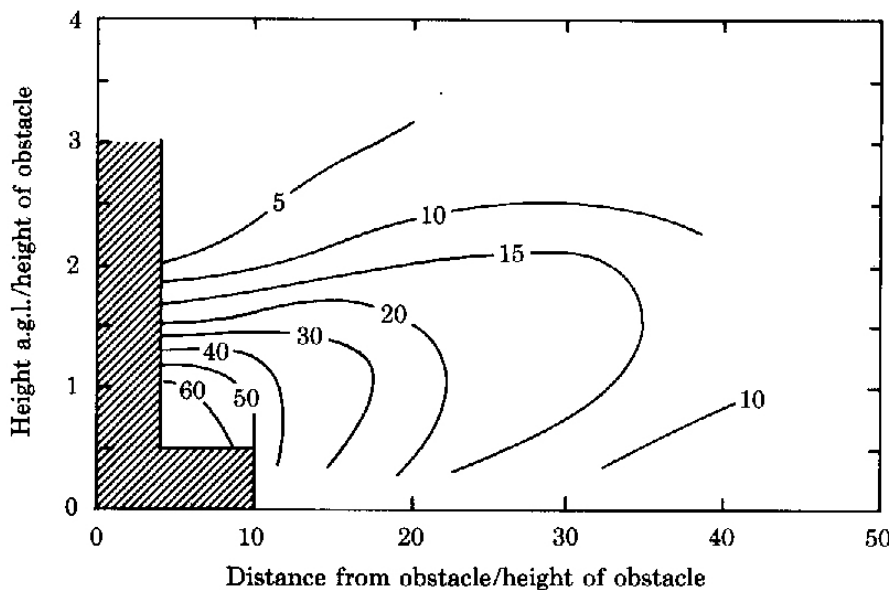
Single obstacles, e.g. buildings, hedges etc. (of more than $\frac{1}{4}$ of the hub height) near the WTG (within approximately 1000 m of the turbines) should be treated as local obstacles and not as roughness elements.

An obstacle is measured by eye during the site visit and the accuracy of this measurement is purely based on the experience of the person. The exact distances are later on found by measuring the distances on the map.

If the obstacle is lower than $\frac{1}{4}$ of the hub height or farther than 1000 m away, it should not be included in the calculation as an obstacle as it will have little or no influence on the calculation result. However, it must be included as a roughness element in the roughness classification.

In addition to the dimensions of the obstacle, its porosity must also be estimated.

The following figure shows how the program handles obstacles.



3.2.1.6 Method description – WAsP Orography and Local Obstacles

The WAsP program from RISØ can be used as the calculation model from WindPRO's WAsP Interface module. With this method, the effects of hills and local obstacles are calculated by means of a flow model. This requires a much more detailed description than the less detailed ATLAS model. Hills are described through digital height contour maps. Local obstacles are described as rectangular boxes. Any number of local obstacles can be freely distributed in the same sector, and both the rotation and the depth of the local obstacle can be specified (see the WAsP user's manual for further details).

3.2.1.7 Method description – RESOURCE

The RESOURCE module is basically a series of WAsP calculations performed automatically for a grid. The advantage of using the RESOURCE module in WindPRO relative to using only the WAsP software alone is that WindPRO allows you to include local obstacles and to use additional Wind Statistics in the same calculation. This allows the wind climate to be changed smoothly from one part of the calculated grid to another.

3.2.2 Method description – Weibull and Measure

When calculating with the METEO module, two different options (Weibull and Measure) are available. The difference is that when choosing the Measure option, the raw measured table values in the Meteo Object are used instead of the Weibull data (normally this is the best Weibull-fit of the METEO table values).

If measured data for a representative period (see Section 1.1) is available for the actual site, the energy production can be calculated by simply integrating the bin-separated products of the wind speed distribution and the power curve.

Please notice that the program will automatically convert measurements, which have been made at a height other than the hub height, into hub-height data based on the user-entered wind gradient exponent by means of the following equation:

$$v_{new} = v_{old} \left(\frac{h_{new}}{h_{old}} \right)^\gamma$$

Where:

γ = the wind gradient exponent
 h = the height

Conversions over major height differences (more than 20-30%) are associated with large uncertainties.

The following general guidelines can be used if the wind gradient is not known. These guidelines are based on data from “Vindatlas for Danmark”, and are not necessarily applicable worldwide (in complex terrain or even simple hills). You should not rely on these guidelines for any conversions other than marginal height differences.

Roughness Class	Roughness Length	Wind Gradient Exponent
0	0.0002	0.1
1	0.03	0.15
2	0.1	0.2
3	0.4	0.3

If only one set of Weibull parameters are available, an average wind gradient exponent should be specified. For example, you could use a weighting based on the distribution of wind directions.

When wind data are available in the form of frequencies that have been sorted into wind speed intervals (a histogram), you can use the data directly or you can use a Weibull curve fit of the data. The latter choice is usually recommended, since the curve-fitting procedure will filter the measured data and the effect of outliers is reduced or eliminated. The Weibull fit follows the procedure specified in the “European Wind Atlas”, where low wind speed frequencies are weighted with lower values than wind speed frequencies within the normal operation range of the WTGs.

3.2.3 Method description – PARK (Wake loss calculations)

The PARK module calculates the wake losses due to the shadowing effects between WTGs sited close to each other (wind farms or clusters). PARK offers three different methods for calculating array losses. All are discussed in the appendix on wake and turbulence models. The standard method recommended by EMD follows the model that was created by N.O.Jensen from RISØ, but with small modifications that enables one to work with different WTG types and Hub Heights in the same layout.

The basic equation for calculating the wake loss behind a rotor is:

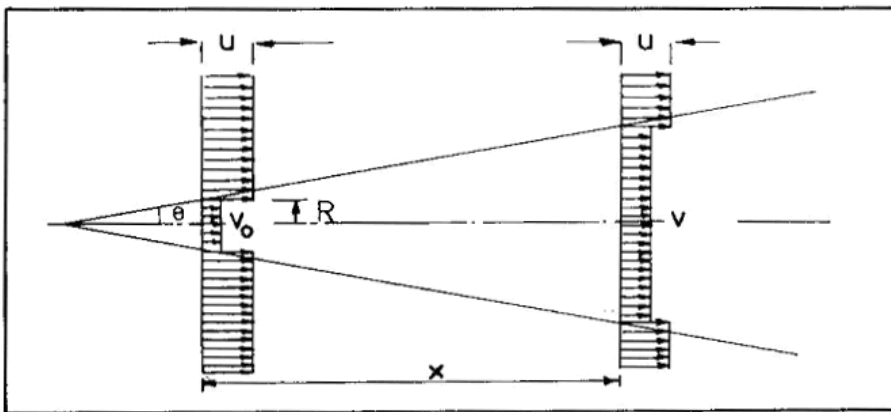
$$v = u \left[1 - \frac{2}{3} \left(\frac{R}{R + \alpha x} \right)^2 \right]$$

Where:

- v = the wind speed at a distance x behind of the rotor
- u = the free wind speed just upstream from the rotor
- R = the rotor radius
- α = the wake decay constant.

$2/3$ is an approximation of the C_t value. In calculation model, the actual C_t value is used for each wind speed interval.

The figure below shows the basic idea behind the simplified wake model for wake losses behind a turbine. The wake decay constant is a measure of the down-stream widening of the “shadow cone” behind the wind turbines. The constant is specified as widening in meters per meter downstream of the rotor. A constant of 0.075 m, corresponding to an opening angle of approximately 4 degrees is usually recommended.



Measurements by RISØ on different wind farms indicate that the wake decay constant depends on the turbulence and therefore on the roughness class, varying from 0.04 for a roughness class of 0, to 0.1 for a roughness class of 3. The use of the default value of 0.075 for all calculations on land is judged to have only marginal impact on the results. For offshore applications, a value of 0.04 should always be used.

NOTE: For very large wind farms (more than 50 WTGs), recent measurements indicate that the wake model used in PARK may not predict the array losses accurately. The wind farm itself changes the roughness, and the free wind speed inside a large wind farm might not follow the assumptions in the N. O. Jensen wake model. This knowledge might lead to an improved PARK module in the near future. A way to account for this in the current version is to increase the roughness inside the wind farm area, e.g. for an offshore wind farm, to a roughness class of 1.5 (a roughness length of 0.055 m).

As of version 2.5, the PARK module is able to perform calculations based on additional wake models as well as wake-induced turbulence. For more information on these features, please refer to the appendix on wake and turbulence models.

3.2.3.1 More than one wind data set in a wind farm calculation

When carrying out a PARK calculation, one must always judge whether one overall wind speed distribution represents the site conditions correctly, or if several terrain descriptions or measured sets of data are needed for an accurate calculation of the entire park layout. No guidelines can be specified, as the choice will depend on the complexity of the terrain, the size of the wind farm, and the accuracy required. If more than one set of data are specified, PARK will always use the data set closest to the individual WTG in the calculation.

Another way to get an individually calculated wind distribution for each WTG in a wind farm is by using a link to digitized roughness and height contour lines.

3.2.4 Generating a Wind Atlas (a set of Wind Statistics)

If measured wind data is available for the site or for the region in question (within a maximum of approximately 100 km from the site depending on the complexity of the terrain), you can choose to generate a regional Wind Atlas that can be used for both ATLAS and WAsP calculations as described in Section 3.2.1.2. This requires that the WAsP program be installed on the hard disk, and that you are familiar with processing wind data. The METEO module and WAsP Interface provide automatic access to the STATGEN module for generating Wind Statistics. But the “natural place” for generating wind statistics is the MCP/Statgen module, where the basis is the long term corrected wind data, as it should be.

In addition to generating Wind Atlases, WindPRO can also import Wind Atlases that have been generated in WAsP (.lib files; see the WAsP manual for further information).

3.3 ENERGY – Input data for AEP calculations

3.3.0 Introduction to data input for AEP calculations

In this section, the procedures for entering the necessary information for performing AEP calculations in WindPRO are described (see also step-by-step guide, Section 3.0.2).

Please, refer first to the WindPRO BASIS description on how to create the basic project before entering the specific data for energy calculations.

The objects which can be entered specifically for AEP calculations are listed below:



Site Data Object – “the basket” that holds all information on the terrain data and wind statistics to be used in a MODEL or PARK calculation. Also used for STATGEN (generating of wind statistic), where only terrain data then is specified.



Meteo Object – measured wind data as Time series, Tables and/or Weibull distributions.

A Wind Statistics (Wind Atlas or .lib file) can be generated when you have both a Site Data Object (purpose STATGEN) and a Meteo Object along with WAsP.

A PARK calculation (array loss calculation) can be performed based on a Site Data Object, a Meteo Object, or a wind resource file (.rsf file).



WAsP Local Obstacles - NOTE: This object has no effect in an ATLAS Calculation.

The other relevant objects (described in Chapter 2, BASIS) are:



New WTG



Existing WTG



Line Object (for height contour lines and roughness lines)



Area Object (for polygon roughness)



Result Layer – for presentation of wind resource map on screen.

3.3.1 Input for MODEL calculations

Using a model to extrapolate the wind data from one position (measurement mast) to the planned turbine position(s) is the most common way to calculate the wind speed distribution at the turbine. The most common model for this is the WAsP model. After the WAsP model has calculated the wind speed distribution at each turbine, a wake loss model (PARK model) is used to find the reduction in wind speed distributions at each turbine (if more turbines). Finally, the wind speed distributions and the power curves multiplied including air

density correction for calculation the AEP. Other models than WASP can be handled for extrapolation of the wind speed distribution. The “simplified” version of WASP is the ATLAS model that is a “built in” model in WindPRO. Finally, any model, like CFD, can be used, which requires this model deliver the extrapolation output as a wind resource map (.rsf or .wrg file).

In case wind resource maps being used for input, no further terrain or wind data input is required, go directly to chapter 3.6. (Although you should include elevation data for helping giving the right air density correction).

3.3.1.1 Siting and Setting Up Site Data Objects

A Site Data Object can be created by:

- Selecting the object from the toolbar
- Positioning it on the map at the location of the terrain assessment
- With a mouse-click, it is established and the input form appears

Normally, the Site Data Object will be located in the middle of the wind farm. But, please read the following carefully:

If a roughness rose is used as the roughness description method, all WTGs in a wind farm will be calculated with the exact same roughness description. To compensate for this, you can add additional Site Data Objects and thereby specify different roughness roses.

Each WTG in the wind farm will then use the nearest roughness description. The same applies to obstacles and hills when the simple ATLAS model is used.

If you use roughness lines or areas (only when using WASP), all WTGs in a wind farm will be assigned a unique roughness description. (For more detail on roughness lines, see Section 3.6.1.1, Digitized Roughness Map. For more details on roughness areas, see Section 2.9.4, Area objects).

When using height contour lines (only when using WASP), the energy production for each WTG in a wind farm is calculated individually with respect to orography.

Once the Site Data Object has been created, a window appears as shown below, where the use for the object is defined.

For more information about coordinates, description, labels, layers etc., see Section 2.5 in BASIS.

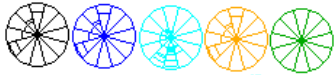
NOTE: The Z-coordinate of site data object has no influence on the calculations.

If WASP is installed and linked to WindPRO, you can choose to use the Site Data Object in the ATLAS module or in the WASP module exclusively, or in both modules. In the latter case, you have to select which to use

when setting up the calculation. Another option is to use the site data object to generate a Wind Statistic (see Section 3.3.4) or to calculate a wind resource map (see Section 3.6).

The selection of the above purposes determines which data you can enter on the following tab sheets. ATLAS and WAsP have a simple and a detailed terrain description of the hill and local obstacles conditions respectively. STATGEN and RESGEN can only work with the more detailed WAsP data formats.

Depending of the use, the object will change color on the map. The different colors are:



Black – for Atlas

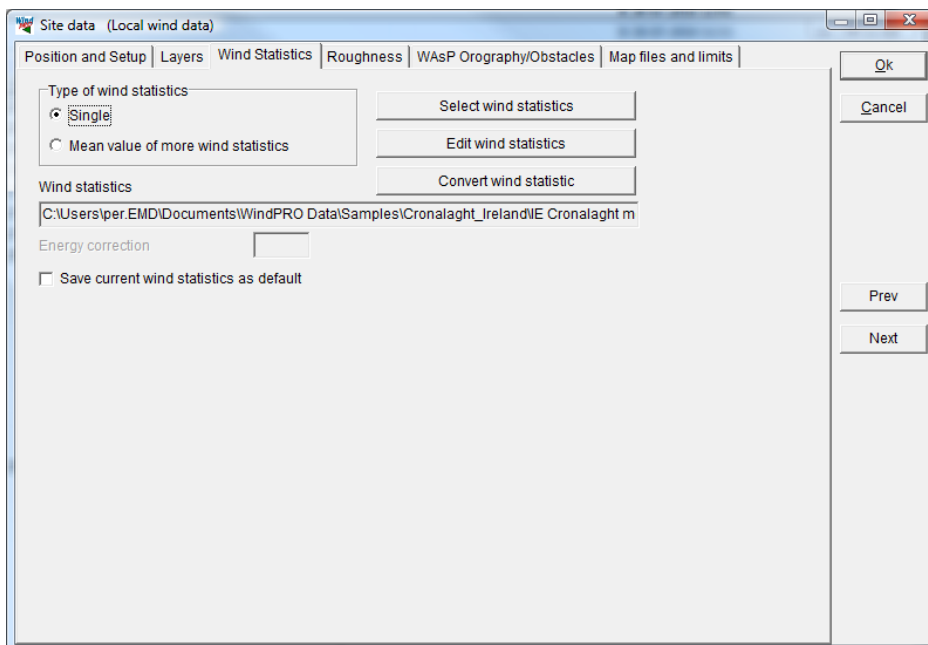
Blue – for WAsP

Cyan – for both Atlas and WAsP

Orange – for STATGEN

Green – for RESGEN

3.3.1.2 Tab sheet Wind Statistics (Wind Atlas) in Site Data Object

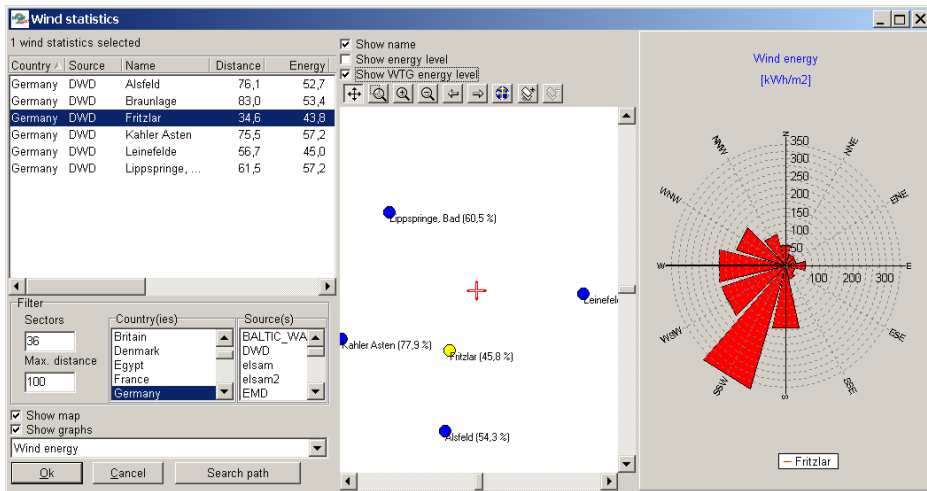


Regarding “Convert wind statistic”, see chapter 3.4.5 - Wind index correction level conversion to wind speed

The “Edit wind statistics” button leads to a maintenance window, where, for example,.lib files can be imported and assigned coordinates, so that that they will appear on the map shown in the selection window.

Selecting wind statistics

One (select “Single”) or more (select “Mean..”) Wind Statistics can be selected for the same calculation.

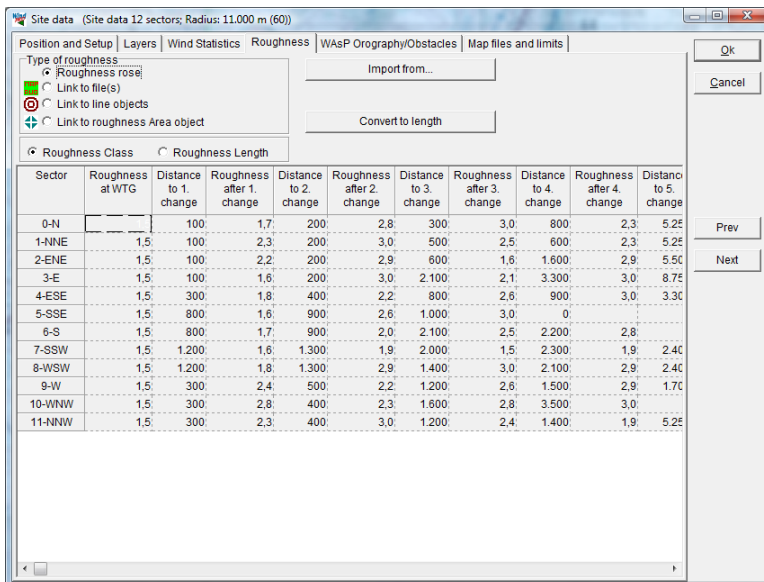


When “Select wind statistics” is chosen, there are several optional search filters available. If no country or source has been marked, then all Wind Statistics will be shown. You can also click on additional countries, sources etc.

NOTE: For calculations in Denmark the “Danmark ‘07” Wind Atlas should always be selected due to its special status. Regional correction curves have been linked to the Wind Atlas based on comprehensive investigations of a large number of Danish WTGs. Therefore, this Wind Atlas is judged to be significantly more accurate than other available Wind Atlases for Denmark.

NOTE: One of the most important things in an energy calculation is to evaluate the energy level of the Wind Statistic. There are so many possibilities for mistakes that a final evaluation of the energy level by comparison with the level for other Wind Statistics in the region may be a good way to discover fatal mistakes. From the Wind Statistics selection window, both the absolute as well as the power-curve-filtered power curve level is shown as a percentage compared to the Beldringe Wind Statistics (in the middle of Denmark).

3.3.1.3 Tab sheet Roughness in Site Data Object



The roughness classification can be entered directly if you don't have a digital map or, if you've already received the roughness classification from another source.

The input tab sheet shows the input fields for the roughness classification, i.e. enter the information for one sector at a time and shift to a new sector either by double-clicking or pressing the <Enter> key.

In addition, you can import and edit digital roughness maps (from a WAsP .map file) or read .rds files (WAsP roughness description) from previous WAsP calculations (see the explanation below).

One of the very powerful features in WindPRO is the ability to create and edit a roughness classification directly on the digital map.

Three other ways to define the roughness are:

Link to file(s) – define the roughness line file(s) in the tab sheet “Map files and limits”.

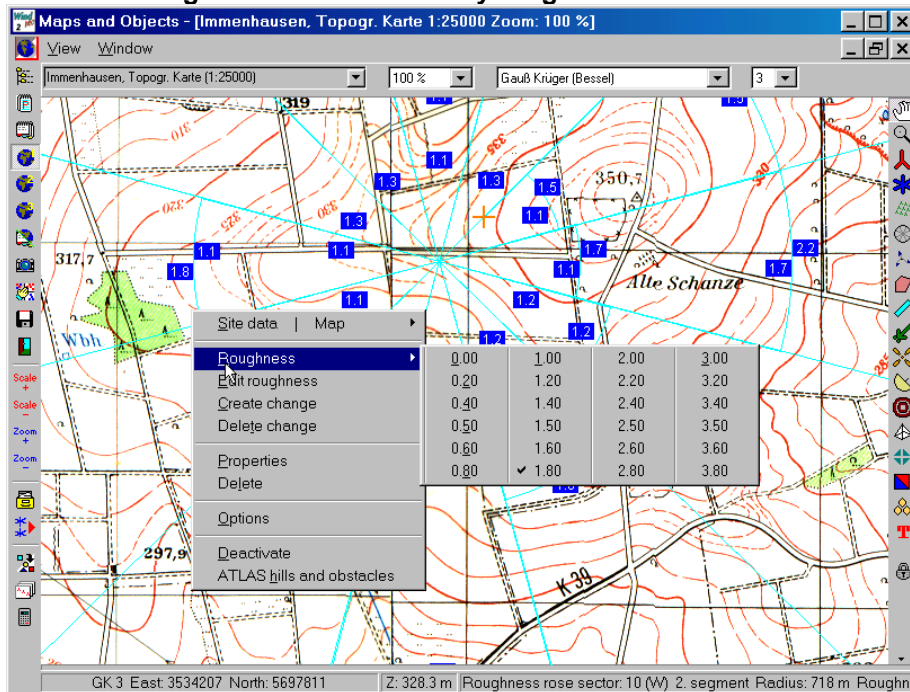
Link to line objects – automatically use line objects in your project with roughness lines.

Link to area objects – automatically use area objects in your project with roughness areas.

Each of these three methods has the advantage that each WTG in a wind farm will get its own unique roughness classification. For more details on roughness lines, see Section 3.6.1.1, Digitized Roughness Map. For more details on roughness areas, see Section 2.9.4, Area objects.

NOTE: When changing between Roughness Class and Roughness Length, the values previously entered are not converted automatically. To convert Roughness Class values to Roughness Lengths, use the “Convert to length” button.

On screen roughness classification by roughness rose



When the map has been rendered on the screen, you can drag the map around by moving the hand icon while holding down the left mouse button.

When the roughness rose is activated you gain access to the features listed below by clicking on the right mouse button:

- Roughness - the roughness class is selected from the table for the area where the cursor was placed at the time you right-clicked.
- Edit roughness - option for entering actual roughness classes.
- Create change - creates roughness changes in the area that was activated by the cursor at the time you right-clicked.
- Delete change - erases the roughness change closest to the cursor in the direction of the roughness rose center.
- Properties - activates the input window for the Terrain Data Object.
- Delete - erases the Site Data Object.
- Options - changes the setup for the size of the automatic roughness step size when they are moved.
- Deactivate/Activate - changes the status for the actual Terrain Data Object so that only its position is marked. This option is useful when entering other objects, including other Terrain Data Objects.

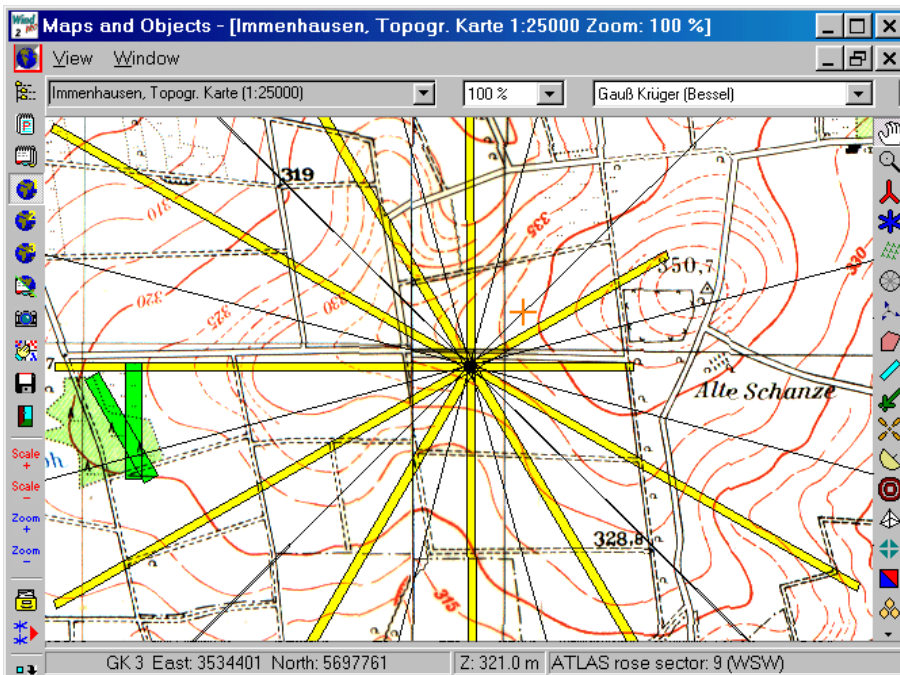
- ATLAS hills and obstacles - shifts the object status from input of roughness to input of hills and local obstacles (see the next section).

NOTE: The roughness-change lines can be dragged around by holding down the left mouse button when the cursor is positioned on a line.

3.3.1.4 Tab sheet ATLAS Hills/Obstacles in Site Data Object

Regarding the roughness classification, both hills and local obstacles can be entered either via the object list or directly on a digital background map. Please refer to the previous section for information on how to activate the graphic input menu.

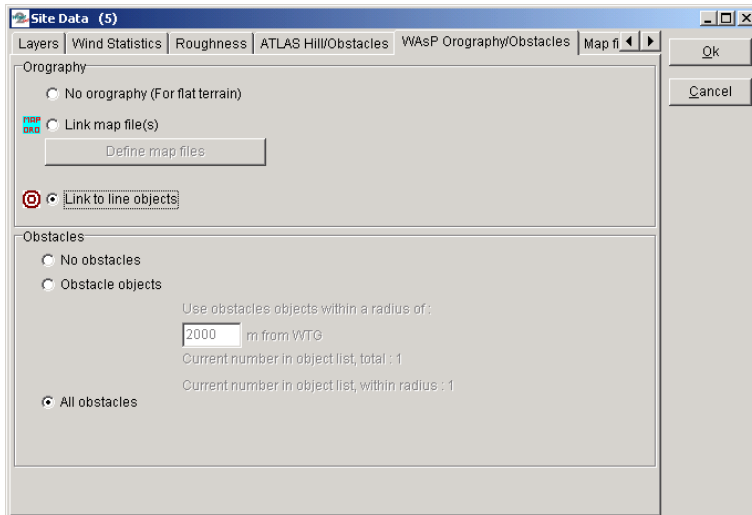
For each sector you can create one hill and one local obstacle.



The program automatically calculates the distance from the center of the Site Data Object to the hill base or local obstacle and the obstacle width or width in the sector. The objects can be dragged to desired positions with the mouse when it's activated. The hill height (the distance from the base to the top) and the obstacle height and porosity must be entered in a table (select this option by right-clicking under "Properties").

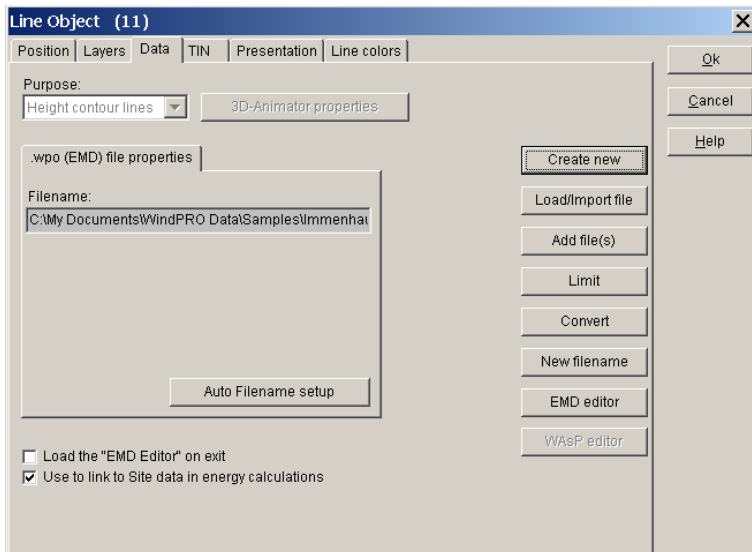
NOTE: Entering the elevation of the hill base can also be used to enter the hill height. To use this method it's necessary to enter the Z-coordinate for the Terrain Data Object under the tab sheet "Position".

3.3.1.5 Tab sheet WASP Orography/Obstacles



If WASP is chosen as the calculation module, you can use digital maps with height contours (digital orography maps) and local obstacles in WASP format.

If you select “Link to line objects”, then one or more line objects with height contour lines which are marked “Use to link Site data in energy calculations” will be used automatically (see the check box in the bottom of line object properties shown below).

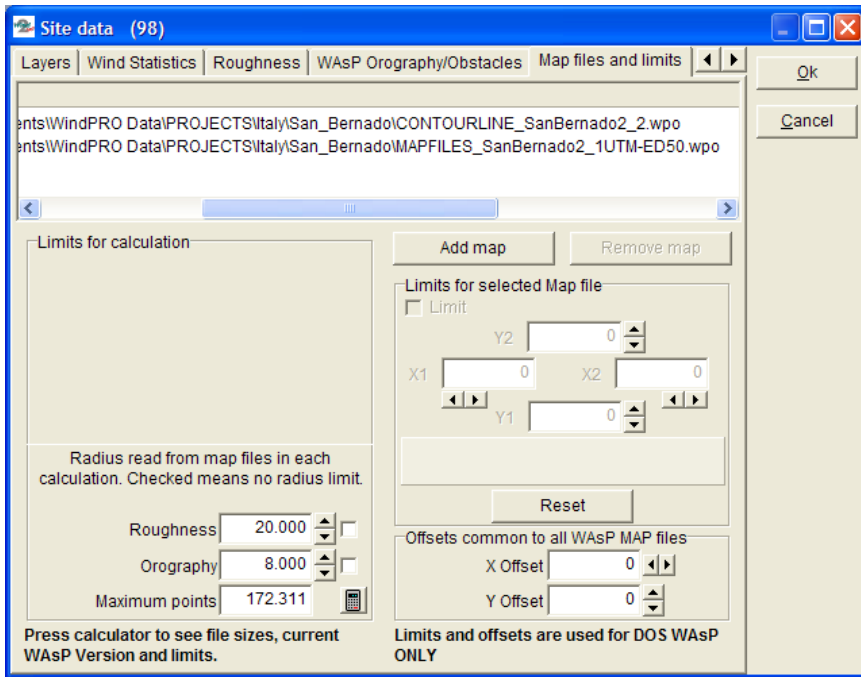


If digitized height contour line maps exist only in files (not loaded into line objects), they can be linked (see next section).

Once a series of local obstacles has been created (see Section 3.3.1.7), you can define which local obstacles are to be included in the calculations via the Site Data Object menu. Then, only those obstacles which are situated within a certain radius of the individual WTGs will be included in the calculation.

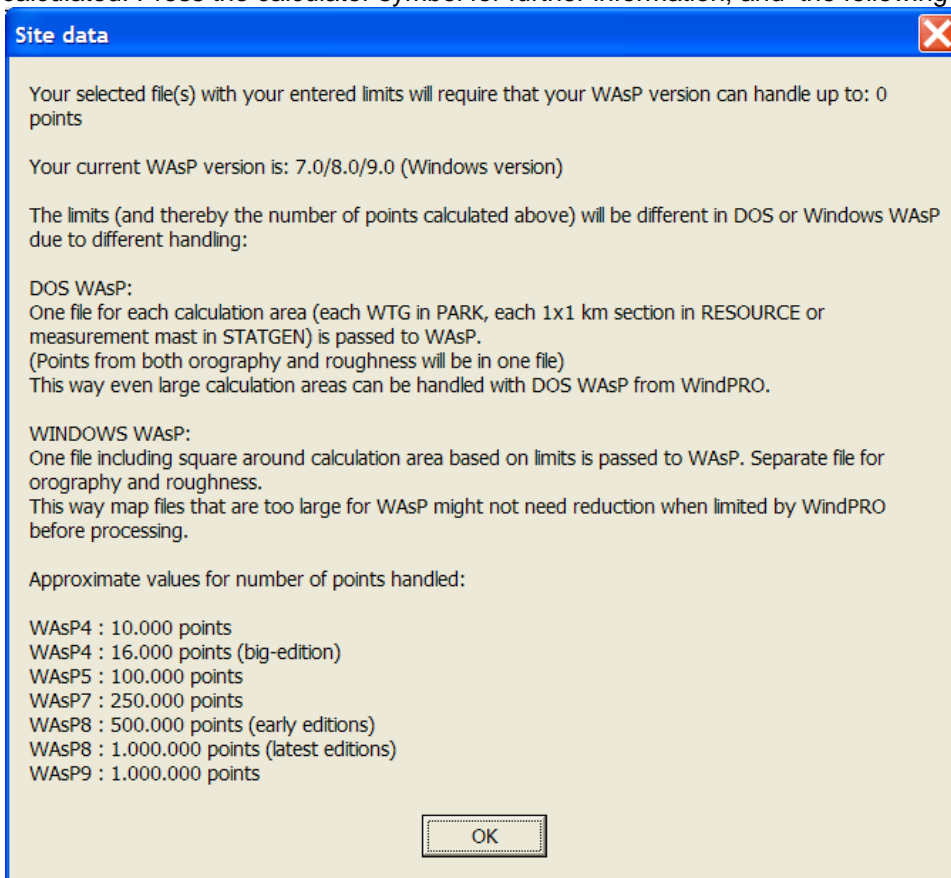
3.3.1.6 Tab sheet Map files and limits

If there are no height or roughness data assigned to Line Objects, but the data exists in files, these files must be added to the Site Data Object map list before they will be included in the energy calculation.



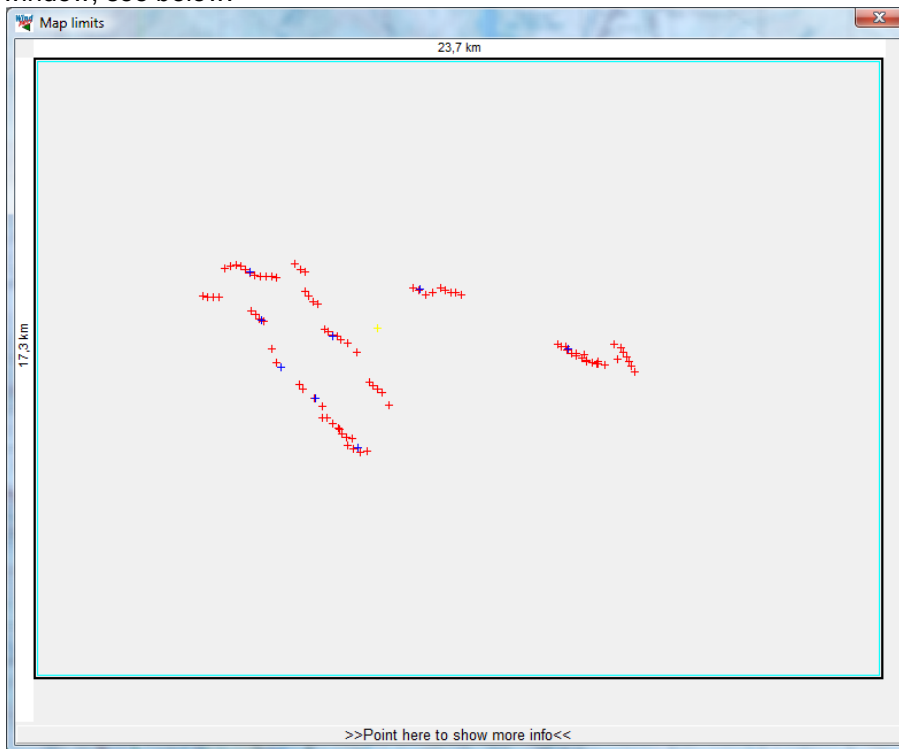
The list shows the .map and .wpo files to be used in calculation. If it shows some files (from line objects) that are not intended files, you must deselect “Use this object for energy calculation” on the line objects.

Once the .map files have been selected, you can define the area of the .map files to be included in the calculations, or you can define a radius around each of the WTGs to be included in the calculations. The indicator “Maximum points” shows the number of digital points which are included in the boundary file and calculated. Press the calculator symbol for further information, and the following screen will show up:



NOTE: The “Map limits” window in the lower right part of screen shown above indicates the position and size of the maps relatively to the project. This is an important check to make sure that the maps cover the appropriate

area and that they are in the right coordinate system. If they are not, it will be easily seen in the “Map limits” window, see below.



Pointing at the bottom part gives more precise information on the distances from relevant objects to map borders, see below.

Distances in used maps from "outmost point" to closest WTG or calculation point:

	Orography	Roughness	Distances used for validation:
North	6,0 km		Orography: 5,0 km (recommended value: 7 km)
East	6,7 km		Roughness: 20,0 km (recommended value: 20 km)
South	6,0 km		Red values indicates too low distances
West	4,8 km		

NOTE: Test is performed based on highest/lowest point in map files. The test does not verify if terrain is described properly within these points. For some sites, if there e.g. is a mountain 8 km from site, or a roughness change from land to sea at 21 km, recommended distances might be too low. For other sites, where the terrain only changes slightly at distance, less distance is needed. Note also that larger hub heights requires larger distances, recommendations are for round 100m

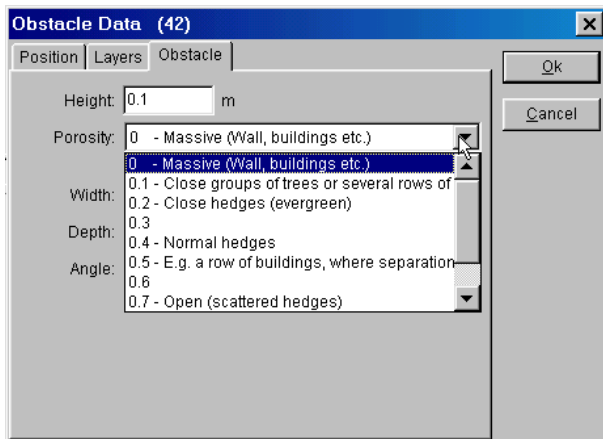
3.3.1.7 Input of WAsP Obstacles



Local Obstacles are created on a background map with the WAsP Obstacles icon.

Dimensions are defined by dragging the corners of the object to the desired size.

Once the object has been positioned, the following window appears where you can specify the height and porosity:



The porosity determines how much wind will pass through the obstacle and is seen as an average throughout the seasons.

3.3.2 METEO object; Input of wind data, screening, analyzing

The meteo object is the input object for wind data. Input can be from the very simplest form;

- input manually one wind speed (annual mean) in one sector together with Weibull $k=2$, and you can calculate.

To the very advanced form:

- You import measurements from a Sodar or Lidar export file with 25 different heights for a long measurement period with high time resolution. The data files might even have changed format or units during the measurement period, which also are handled efficient. The Meteo object importer can also read from compressed files, like zip are read direct.

The measurements can be used “direct” (without use of models) for AEP calculations in the calculation module METEO. But, the most common way is to generate a wind statistic based on the data in a meteo object and terrain information from a site data object and then use the wind statistic in a site data object for calculation of AEP with ATLAS, WAsP interface or (most common) with PARK module. NOTE: Remember in-between the long term correction (MCP, see chapter 11).

3.3.2.0 Compatibility to version 2.5 or older

The Meteo data object in v2.6 is completely changed relative to v2.5. This also includes the data structure, so data stored in v2.6 will no longer be backward compatible, meaning that v2.5 cannot read v2.6 Meteo object data. But v2.6 can load v2.5 Meteo object data.

Some major changes to mention:

- Import filter now works on the entire data file, meaning that all measurement heights in a data file are set up in one process.
- No limits in number of signals in graphic view
- All measurement heights are handled together including new profile features
- Disabling can be performed in for all heights in one process
- Expanded/generalized statistics
- New efficient implementation of NCAR data download (+ more) via Online button

VERY IMPORTANT when recalculation of ver. 2.5 projects:

Time series, table and Weibull data are now fully linked meaning that changes in time series AUTOMATICALLY lead to a change in Table/Weibull data. If you have manually modified Table or Weibull

data from version 2.5, these will, per default, NOT exist in version 2.6. You will get a warning if this is so when loading the data first time.

Workaround: If you wish to transfer table or Weibull data from 2.5 to 2.6, you can copy the data to excel from 2.5 and then create a new measurement height in the new meteo object (or a new meteo object), only activated with Table and/or Weibull data and paste the data from Excel.

3.3.2.1 Guide

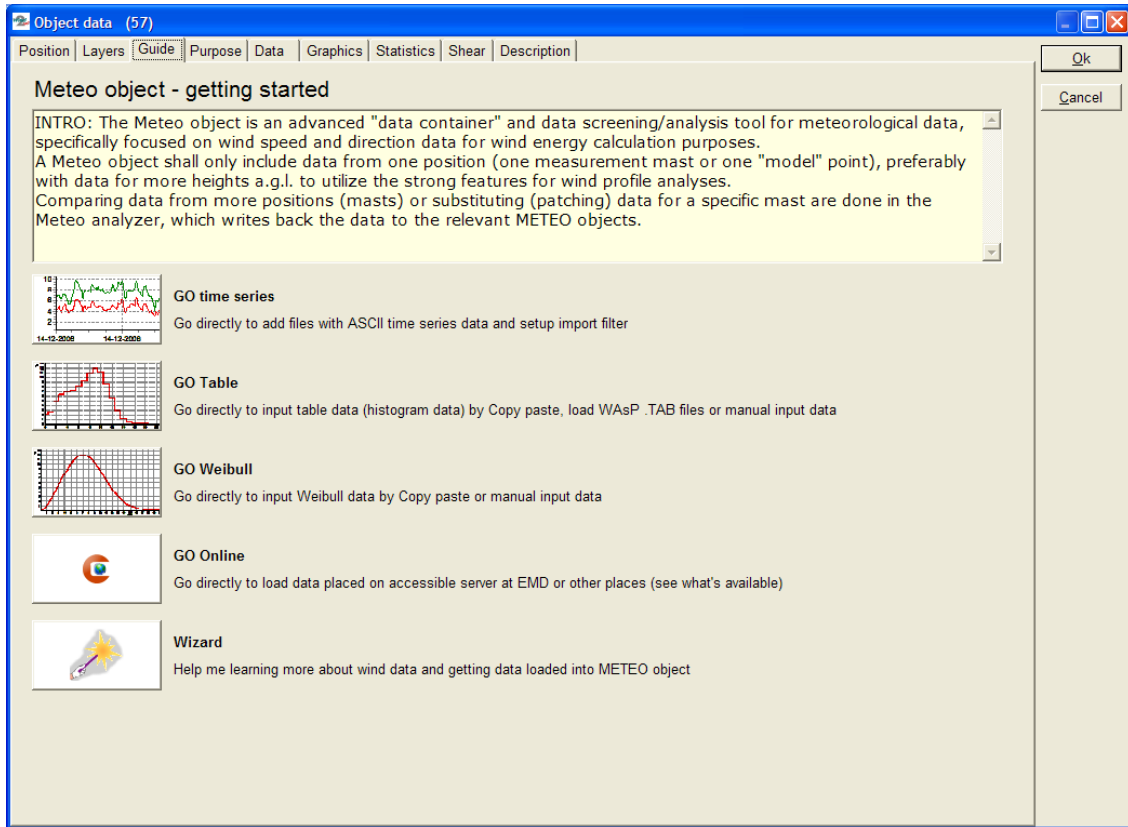


Figure 1 This is the first screen users will see when creating a new meteo object. This is “self explanatory”.

Typically, time series will be the most common format in which data is made available – if users have any doubts about reading them, start with the Wizard.

Online data gives access to data on EMD On-line server, where EMD adds free data for fast and easy download. Also, data for purchase is available, where the EMD server relinks to commercial data servers. To download these requires a coupon code, which can be purchased through EMD. Press the On-line button to see your current options. These are expanded regularly. If a meteo object with On-line data is reopened, the Online button changes to “refresh online”.

3.3.2.2 Purpose

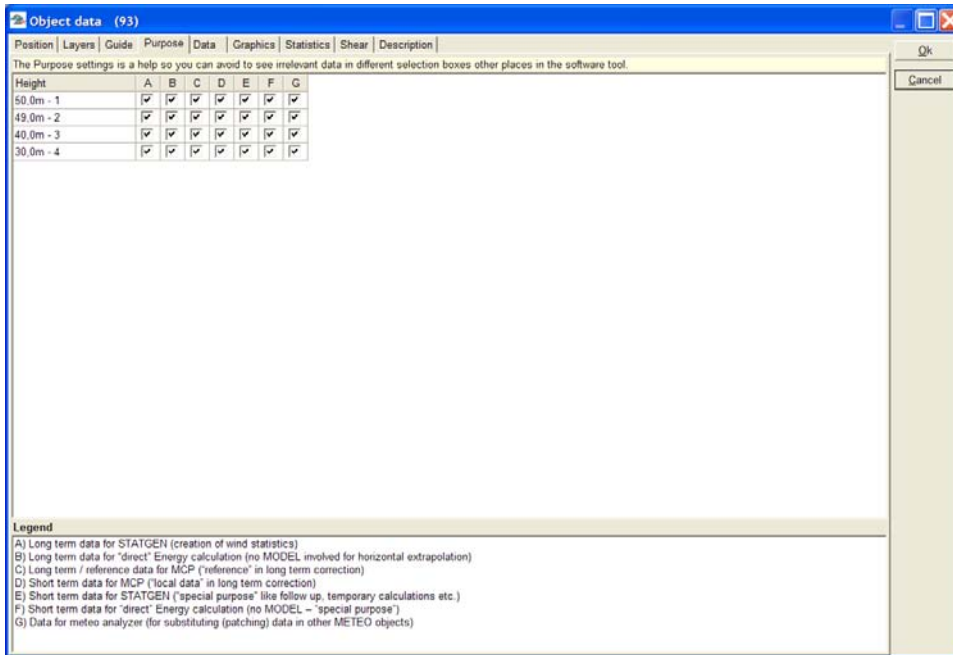


Figure 2 Purpose settings helps to structure the data.

If there are many wind measurement data in a WindPRO project, it can be difficult to keep an overview. Giving the data different purpose settings can improve the overview. Only the relevant data based on purpose settings will be selectable from different forms in the software.

3.3.2.3 Data

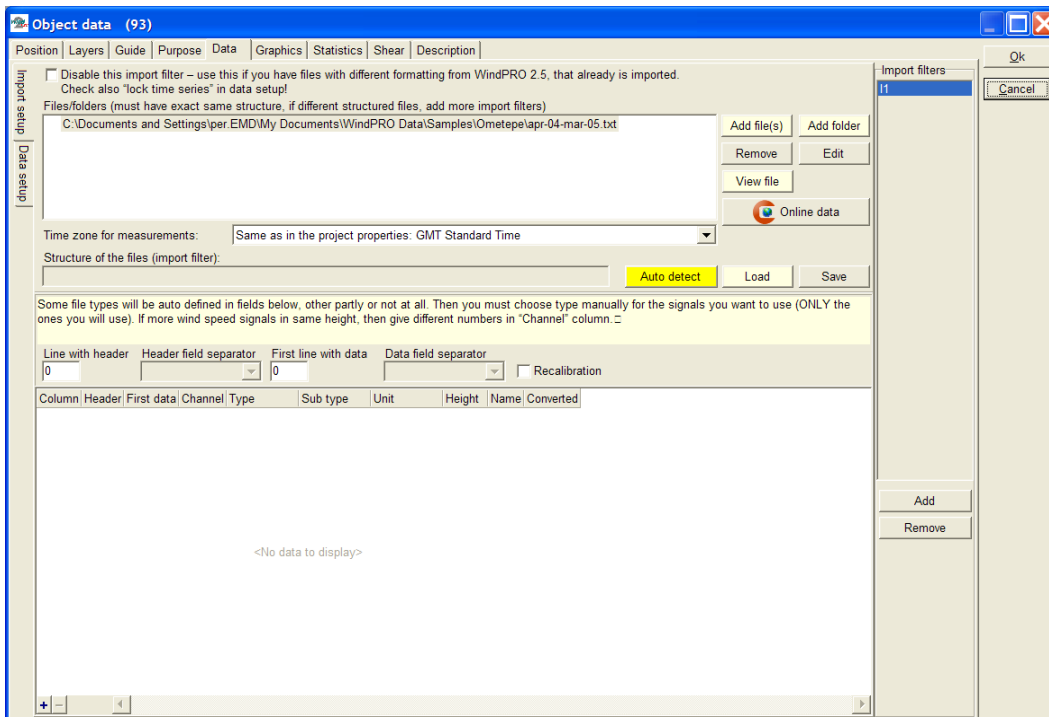


Figure 3 The data tab - import setup

The Data tab controls:

- Import setup (identifying file structure(s)),
- Data setup (setting up the signals wanted for each height)

and after importing data:

- Time series (view, analyze, flag time series data)
- Table data
- Weibull data
- Turbulence data

Below, each function in this form is explained.

Data; Import setup

Top line: [] **Disable this import filter.** This feature shows how data imported from a v2.5 project was set up,. The reason for this feature is that in v2.5 data might have been added with a different import filter setup that has not been stored for each setup. Therefore it cannot be restored fully. But, you might still wish to see how it was set up (e.g. which columns were used).

If additional files with different structures were added in v2.5, you also need to “lock time series”, see “Data setup”.

File types supported: Only ASCII files can be imported at present. This means that raw logger files, Excel files or database files must be converted to text files before data can be imported. Compressed text files are supported, so it is ok to have the text files in .zip, .rar or other compressed files.

Add file(s); point out the files with the data to import. Note, these **MUST** have the same structure – if not, add more import filters.

Add folder; point out the folder with the files that contains the data to import. Note, these **MUST** have the same structure – if not, add more import filters. When specifying a folder, and adding new data files after the initial set up, the Meteo data object can be updated. Simply choose “load new” in the data setup tab (see later). If there are data from more masts or more different files in the folder, it is possible to set a mask, eg. “*.txt” so only relevant files is used.

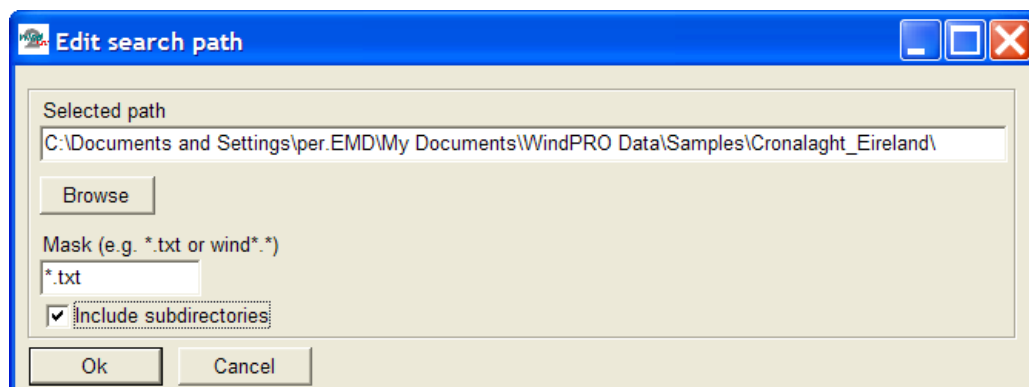


Figure 4 Adding folders gives high flexibility and fast import of new data subsequently placed in the folder.

Remove; Remove the selected files in the list from the import filter

Edit; Edit the import setting, like the file mask in “Add folder”.

View file; View the selected file with current import settings applied. This is very useful to identify the structure of the file and to see if the import settings are working.

Online data; (requires an active license for the MCP/Statgen module) - start a communication with EMD server, to see which data are available for the region (NCAR always at present).

Time zone; If data is in UTC (same as GMT) time, which often is seen for “general purpose data”, or your data files are not in your local time zone, they will automatically be transformed to the local time zone set in the project properties. For the individual heights, you have the further option to time shift the data series

individually. This is needed, for example, when importing NCAR data where 10m data is forecast data (6 hour ahead) while the other data is “normal”.

Structure of the files (import filter); A file giving the structure can be loaded and saved. This helps save time if the same type of files is often used in different projects. If you do not have an import filter saved, use the “auto detect” feature.

Auto detect; is a very powerful feature, that can recognize the “base structure” of many types of wind data files. There will often be “manual work” to do – this can be avoided for subsequent files by saving the structure.

Line	Column	Header	First data	Channel	Type	Sub type	Unit	Height	Name	Converted
1	Date & Time Stamp	04-04-2004 19:00:00			Time stamp	Date&Tin		0		
2	CH1Avg	10.8	1	Wind speed	Mean	m/s	50.00	1_CH1Avg_Mean	10.80 m/s	
3	CH1SD	1	1	Wind speed	StdDev	m/s	50.00	1_CH1SD_StdDev	1.00 m/s	
4	CH1Max	13.4	1	Wind speed	Max	m/s	50.00	1_CH1Max_Max	13.40 m/s	
5	CH1Min	8.4	1	Wind speed	Min	m/s	50.00	1_CH1Min_Min	8.40 m/s	
6	CH2Avg	10.6	2	Wind speed	Mean	m/s	49.00	2_CH2Avg_Mean	10.60 m/s	
7	CH2SD	1	2	Wind speed	StdDev	m/s	49.00	2_CH2SD_StdDev	1.00 m/s	
8	CH2Max	13	2	Wind speed	Max	m/s	49.00	2_CH2Max_Max	13.00 m/s	
9	CH2Min	8	2	Wind speed	Min	m/s	49.00	2_CH2Min_Min	8.00 m/s	
10	CH3Avg	10	3	Wind speed	Mean	m/s	40.00	3_CH3Avg_Mean	10.00 m/s	
11	CH3SD	1	3	Wind speed	StdDev	m/s	40.00	3_CH3SD_StdDev	1.00 m/s	
12	CH3Max	13.3	3	Wind speed	Max	m/s	40.00	3_CH3Max_Max	13.30 m/s	
13	CH3Min	7.3	3	Wind speed	Min	m/s	40.00	3_CH3Min_Min	7.30 m/s	
14	CH4Avg	9.4	4	Wind speed	Mean	m/s	30.00	4_CH4Avg_Mean	9.40 m/s	
15	CH4SD	1.2	4	Wind speed	StdDev	m/s	30.00	4_CH4SD_StdDev	1.20 m/s	
16	CH4Max	13	4	Wind speed	Max	m/s	30.00	4_CH4Max_Max	13.00 m/s	

Figure 5 After “auto detect” the lower part of the form is filled. In the example above an NRG Symphonie™ logger file is used, and everything is auto detected. Several other standard logger output files can be auto detected and new types are continuously added. Some file formats although must be manually setup, if it e.g. are user defined excel exports, the software has no chance to auto detect.

Import setup; Manual adjustment of “auto detections”

There has to be an entry for each data signal which is to be used in the object. The signals not to be used will just be “ignored”, like “min” which is often not used. Signals can at a later stage be set up and used.

1. Chose “type” in drop down, like “Time stamp” or “wind speed” (note that the standard deviation (StDev) of a wind speed signal is also classed as a wind speed).
2. Chose “sub type”, like “year” or “mean” etc.
3. Chose “unit” – note that wind speeds in non-metric units (e.g. mph, knots) will be auto converted to “m/s” in the object.
4. Chose “height” – must be in “meters” – eg. NRG Symphonie™ files set to “feet” will be auto converted to meters. Always check that height is correct as it might be wrong in the data file!

When all signals are set up, go to the “data setup” tab.

Data; Data setup

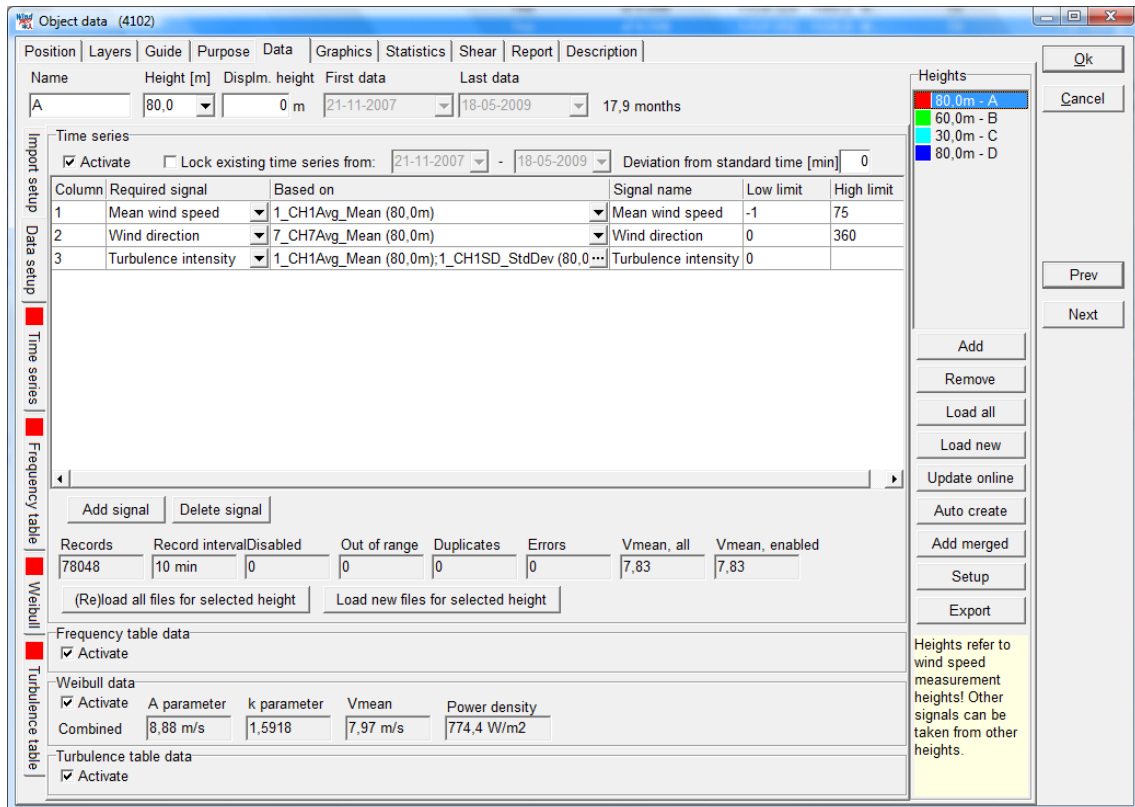


Figure 6 In "data setup" each wind speed height is defined.

Auto Create are by default yellow while this will be the typical "start". This will automatically create all the wind speed measurement heights from the import setup. The signals created by default are:

Wind speed
Wind direction
Turbulence intensity

Wind direction is taken from nearest height to wind speed height.

Add/Remove signal; is used for adding other signals to measurement height, e.g. temperature or "max. wind speed". There is fully flexibility.

(Re)load all/new files for selected signal; loads the data from the files via import filter into a time series. The right button (new) only loads new files added after last load operation.

Buttons to the right:

Add/remove; add or remove (selected) measurement height

Load all/new; loads all heights in one process. The "new" only loads new files added after last load operation.

Update online; Refresh data previous loaded as EMD On-line data (update with recent months)

Add merged; Flexible way to merge two or more measurements, typically used to take out the tower shading when two sensors in same height. See example at the end of this part.

Setup; Color theme, rules for concurrency, disabling of turbulence and rules for use of data for turbulence table.

Export; Export all or selected data in flat text file format. The flagging of the data is included in the export, see explanation in the text file, example below where 80m and 60m data are exported:

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Geographical Coord	Longitude:	-87,22	Latitude:	13,9									
Local Coordinates:	Longitude:	475798	Latitude:	1536185									
Description:		4108											
User label:													
StatusValues:													
Ok		0											
Disabled		1											
Below limit		2											
Above limit		4											
Duplicate		8											
Null value		16											
Missing		32											
Other error		128											
Note that SampleStatus takes precedence over DataStatus which means that DataStatus is only relevant if SampleStatus is OK.													
	MeanWindS	Direction			TimeSta	SampleSt	DataStatus_Me	DataStatus_	DataStatus_		MeanWind	Direction	TurbIntUI
TimeStamp_80,0m	peedUID_80	UID_80,0	TurbIntUI	Commen	mpStatus	atus_80,0	anWindSpeed	DirectionUID	TurbIntUID_	TimeStamp_60,0m	SpeedUID_	UID_60,0	TurbIntUI
	,0m	m	D_80,0m	t_80,0m	_80,0m	m	UID_80,0m	_80,0m	80,0m		60,0m	m	D_60,0m
	[m/s]	[Degrees]									[m/s]	[Degrees]	
11-06-2008 13:10	4,4	53	0,0682		0	0	0	0	0	11-06-2008 13:10	4,3	53	0,0698
11-06-2008 13:20	4	56	0,15		0	0	0	0	0	11-06-2008 13:20	3,7	56	0,1622
11-06-2008 13:30	4,3	57	0,2326		0	0	0	0	0	11-06-2008 13:30	4,1	57	0,2195
11-06-2008 13:40	4,7	55	0,1702		0	0	0	0	0	11-06-2008 13:40	4,6	55	0,1739
11-06-2008 13:50	4,2	48	0,2143		0	0	0	0	0	11-06-2008 13:50	4,1	48	0,2439

Status values are binary coded so the sum in the status columns can be decoded for precise identification of the flagging (means that more flags can be applied to the same data point. There is, as well, a status column for all signals as well as one for each signal. The headers are exported uncoded (UID) meaning that the same text will appear no matter from which language is exported. Thereby it is easy (only one WindPRO meteo importer needed) if a company wishes to maintain a large database with exports from many different users round the world.

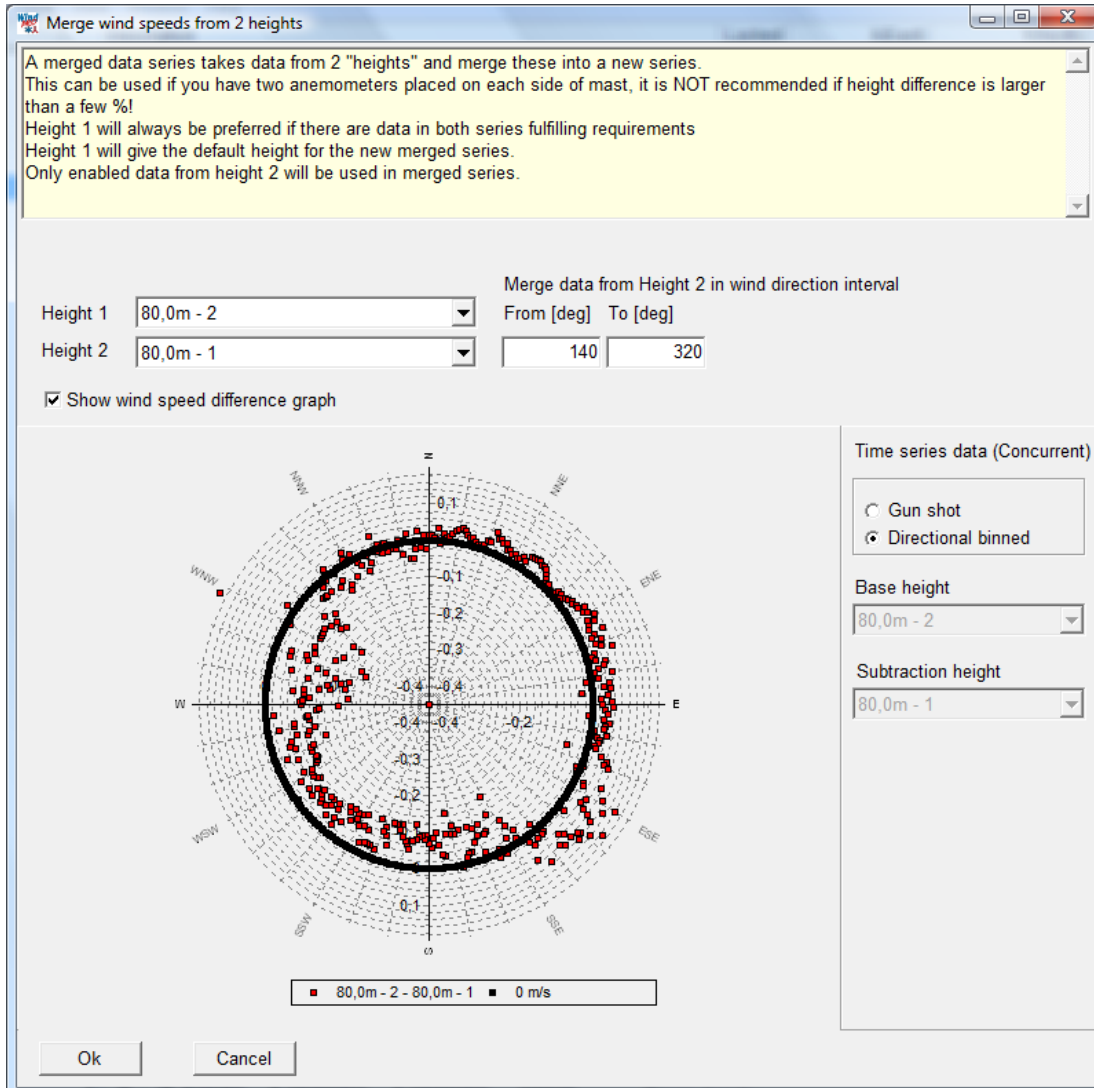
Features in top of form:

Activate; The different types of data presentation can be activated/deactivated. If you have no intention of using the Weibull distribution, or you have table data but no time series data, this feature is useful.

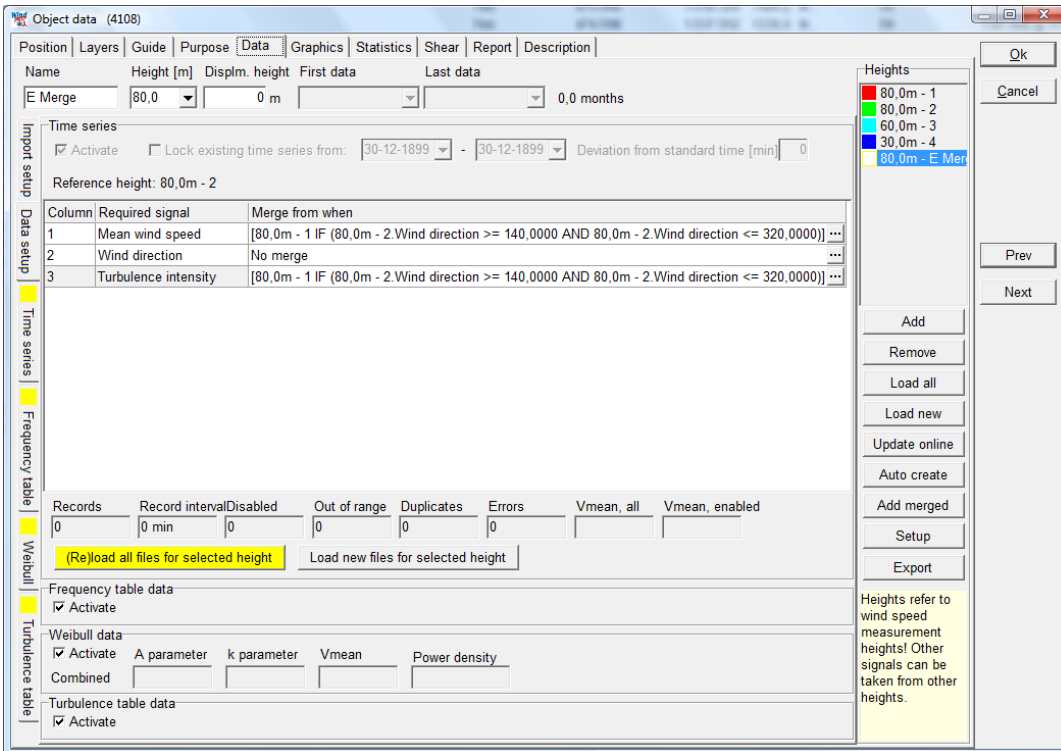
[] **Lock existing time series;** is used when new data is added, but the older previous data loaded does not exist as data files on the PC or they have been added with different import settings in v2.5. Basically, adding new data requires intact import filters and files for all data except when older data series are locked.

Low/high limit; is used to flag the data record “out of range” data in the time series. Note wind speed low limit by default is “-1”. Sometimes calibration of the raw measurements makes the “0” or very low wind speeds negative. To avoid these being “flagged” as “out of range” it is important not to set this to “0”. If “0” wind speeds are not included in the data set, the Weibull distribution will be wrong and the calculations will be wrong.

Remove tower shading – add merged



When two wind speed measurements are at the same height, the purpose often is to be able to remove the influence of tower shading and thereby get the "clean" signal by taking the wind speed from the "free" sensor at any wind direction. A typical setup is shown above. Here sensor 2 is used as "base" and there are merged data from sensor 1. Looking at the data it is obvious that sensor 1 measure higher values from 140 degrees to round 320 degrees (the difference sensor 2 – 1 is negative). This example is not as obviously clear as is often seen, probably while both sensors are close to top-mounting. Click on OK and the following screen appears:



The rules established for the merged series are shown. Before loading the merged data the rules can be edited by clicking the small dots to the right of each rule, and any rule based on any signal can be created.

When data are loaded, the tabs with the different data presentations will be added.

Time series;

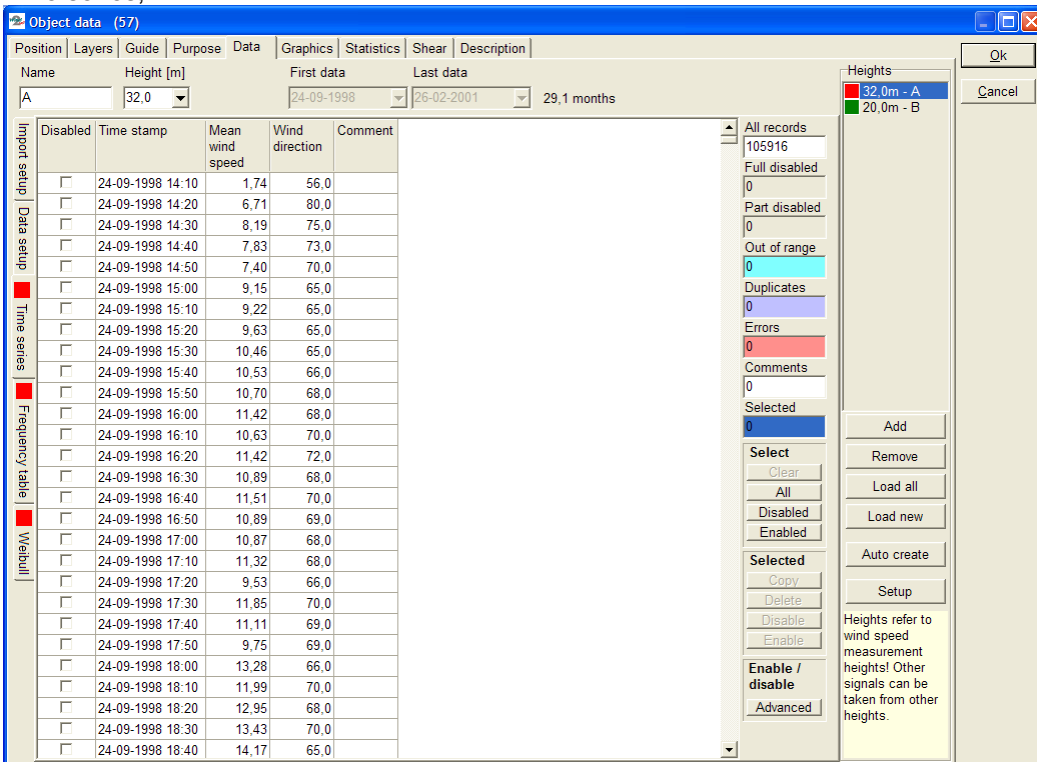


Figure 7 With color background, data characteristics like “Out of range” data are clearly shown. Click in the color field and the cursor jumps to the first event. Data can be sorted by clicking on the header, this is very efficient for like finding the highest measured wind speeds.

Select; can select “enabled” data – selection can also be performed “manually” by dragging with mouse in the list.

Selected; data can e.g. be copied to clipboard and pasted to other programs, e.g. Excel.

Enable/disable; can be performed manually in the list checking the checkbox, or the “Advanced” feature can be used.

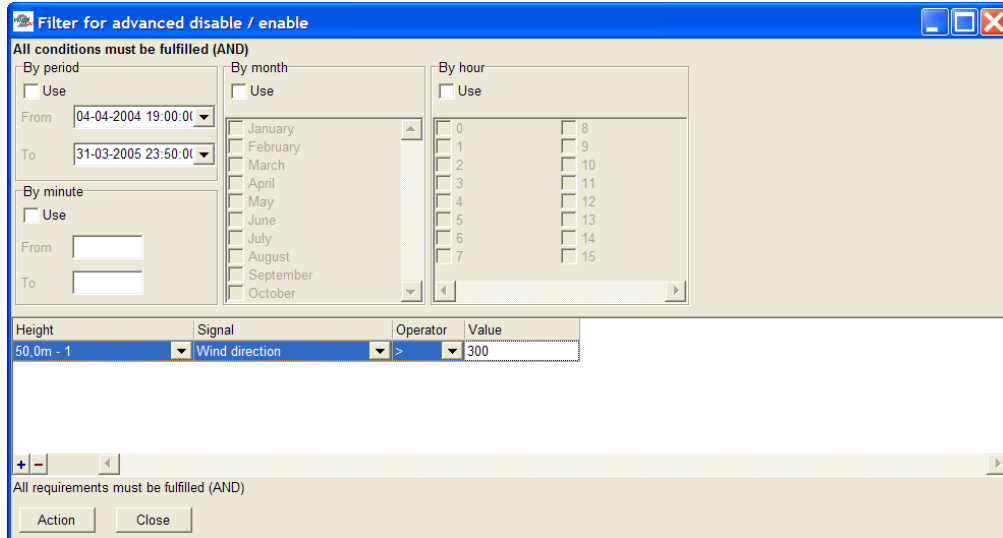


Figure 8 With “advanced” enabling/disabling, flexible data selection can be performed, e.g. based on the value of any signal in the data files.

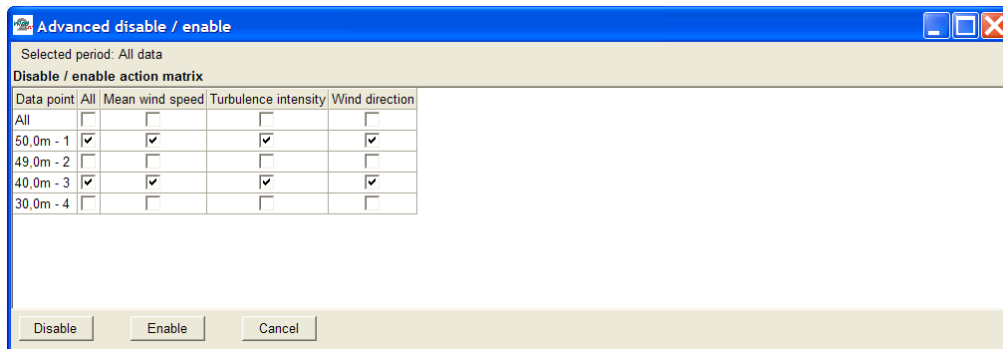


Figure 9 Pressing the “Action” button (shown in previous Figure) gives access to the Advanced disable/enable feature for ALL heights (with same time stamps within +/- 5 min.) that fulfill the conditions in the filter settings.

Only the Enabled data that is NOT out of range or duplicated is used in the aggregated data described in following. The aggregated data is automatically updated if changes in the original time series data are performed.

Data; Frequency table

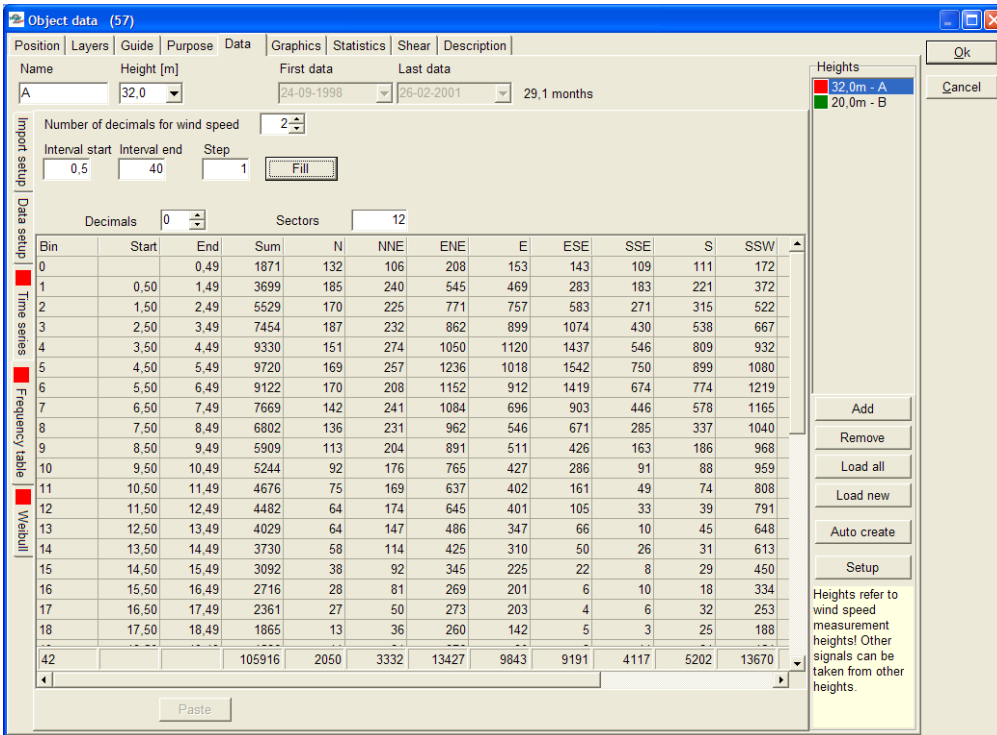


Figure 10 Frequency table shows the binned data by direction and wind speed.

Data; Weibull

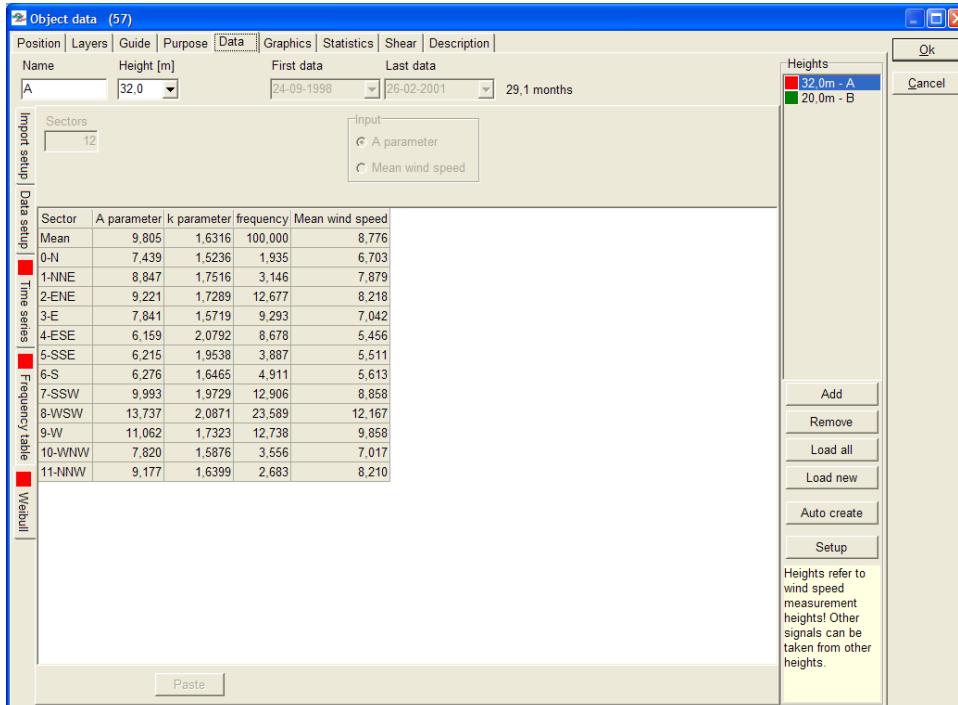


Figure 11 The Weibull fitted data.

The method for Weibull fit is energy weighted, by the same method as Risø's WASP uses, as described in "European Wind Atlas". The Weibull distribution is used as input if the Meteo object data is used for further calculation, e.g. within the WASP model.

Data; Turbulence

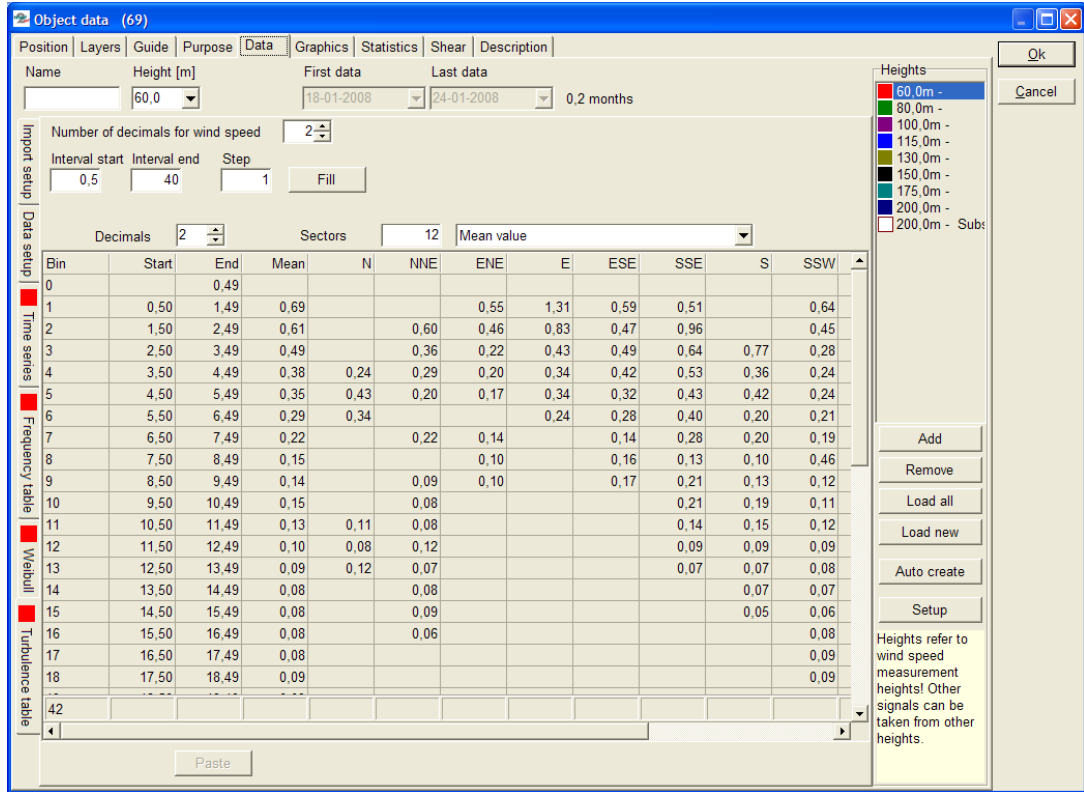


Figure 12 Turbulence data can be shown as mean values and as standard deviations. By copying these two tables to Excel, any combination of mean and standard deviation can be made for turbulence evaluations (e.g. Characteristic values as defined in IEC 61400-1 ed.2 = mean + 1 x StDev and ed. 3 as mean + 1.28 x StDev).

3.3.2.4 Graphics

The Graphic tab holds advanced features for evaluation of the measurements. Also included are features for disabling erroneous data found by the graphic evaluation of the data.

There will be the following main graph windows, each with different view options:

- Time series
- Weibull/table
- Wind speed difference
- General X-Y graph
- Profile

Only a selection of the graphs within each option will be shown below while the others should not need any further explanation.

Graphics; Time series



Figure 13 The time series view is efficient for finding erroneous data – simply right click in graph at start and end of erroneous data for disabling those. You can also add comments (right click) and these can be reported in a separate report.

With the check boxes for each height and signal, viewing can be controlled.

Graphics; Weibull/table

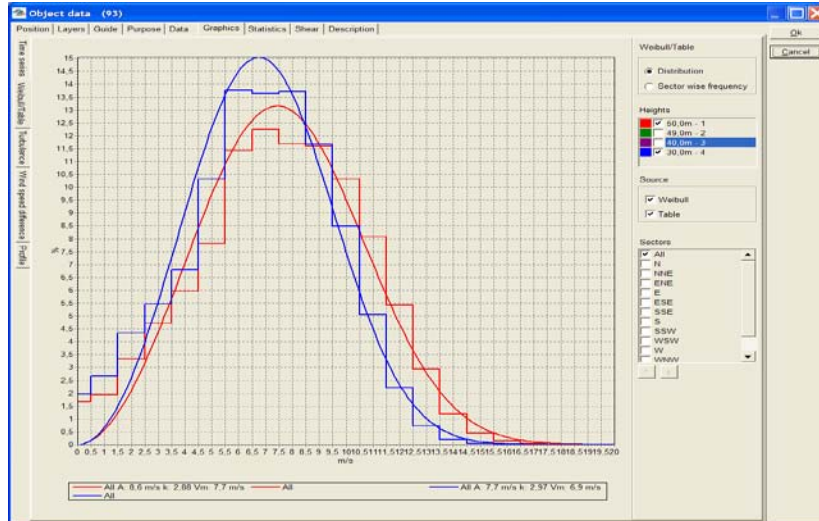


Figure 14 The Weibull/table graphs are here shown for two heights. Note that the axis can be scaled manually by the “Edit graph” feature, activated by double clicking on the graph.

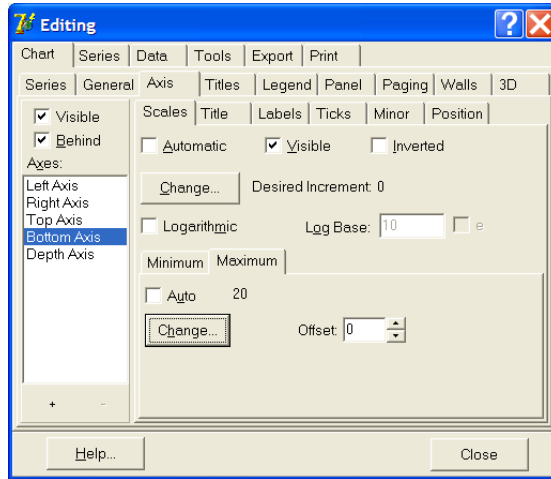


Figure 15 Double clicking on a graph gives access to advanced editing of the graph setup. Here we show the method of manually adjusting the x-axis.

Graphics; Wind speed difference

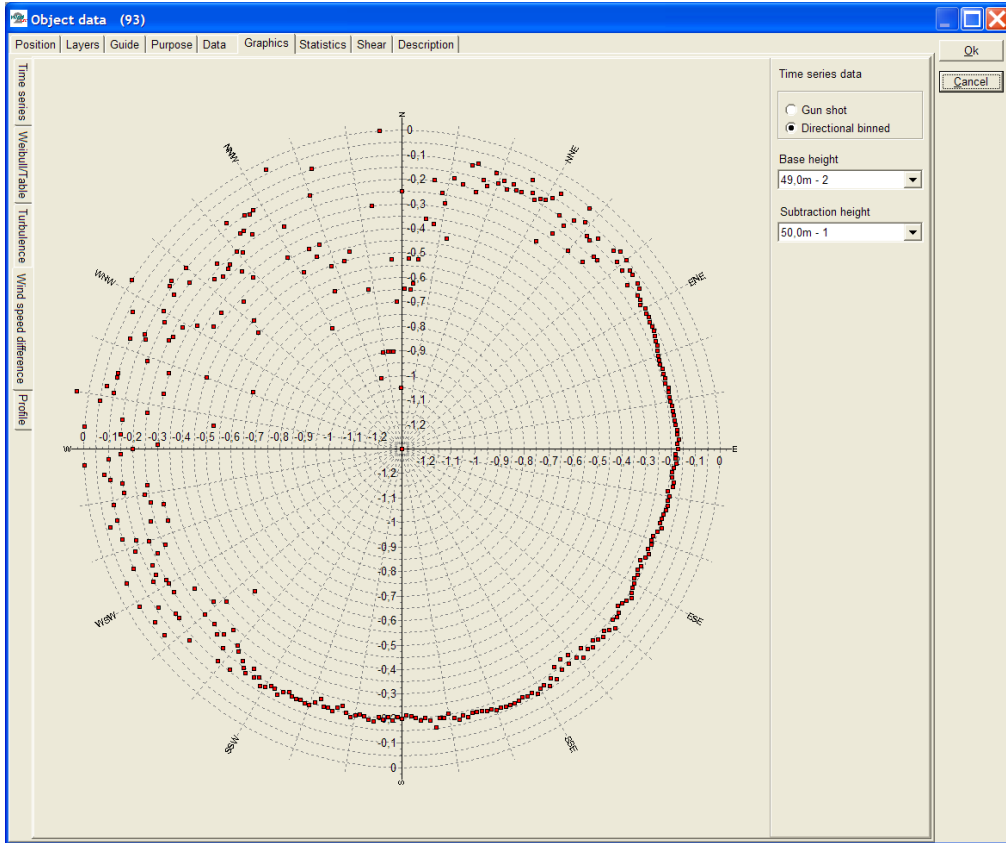


Figure 16 Based on two different wind speed sensors, a difference plot can be created. This is a useful way to evaluate boom directions and influence.

Graphics; General X-Y graph

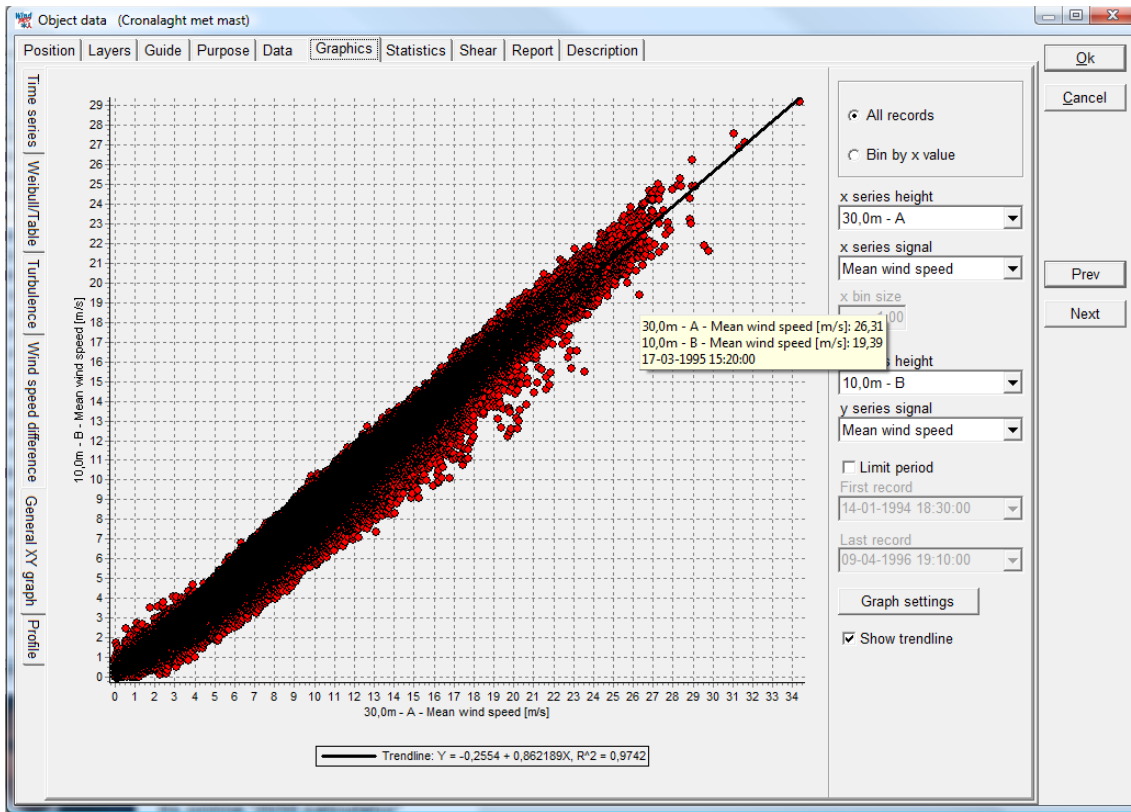


Figure 17 With the general X-Y graph you can plot any signal versus any other. When the cursor is placed on top of a point, the hint box shows the values and the date-time. This is an efficient tool to evaluate “outliers” – go back in time series to evaluate if the outliers seem reasonable or there are obvious sensor problems, which require disabling of the specific period.

Graphics; Profile

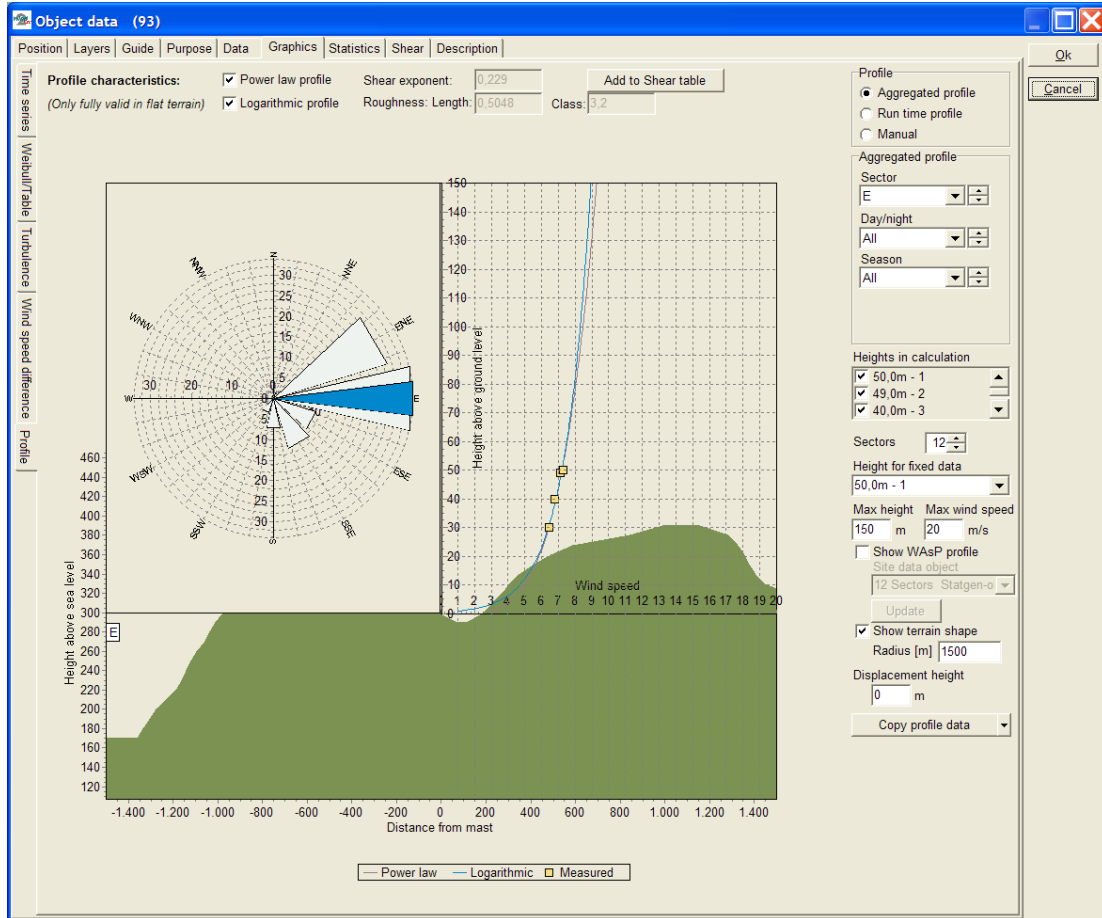


Figure 18 The profile viewer show as well the terrain profile as the wind speed profile

The profile viewer illustrates how the measured wind profile looks by showing the best fit of both power law profile and logarithmic profile. Also, a WAsP-calculated profile can be shown.

There are 3 view options;

- Aggregated (average values of concurrent data for all heights used)
- Runtime (record by record)
- Manual (aggregated, but manually controlled values for power and logarithmic profiles)

The “height for fixed data” will be used as input in WAsP calculation, if the WAsP profile is chosen. (WAsP can only calculate from one measurement height and creates the profile shape based on the flow and terrain model).

Note that only in flat terrain can the power or logarithmic profiles be extrapolated to higher levels with reasonable accuracy. If there are flow compressions due to hills, simple power or logarithmic profile extrapolations should NOT be trusted. Here the WAsP profile will be a better estimate since it will include corrections by a flow model to account for the compression effects.

3.3.2.5 Statistics

Three different tabs for statistics;

- Main statistics
- Monthly means
- Availability (data recovery)

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Signal	Unit	Count	Of total	Mean	Std dev	Min	Max	Weibull mean	Weibull A par	Weibull k par
50.0m - 1 Mean wind speed, all	m/s	52014	100.0 %	7.52		0.30	18.50			
50.0m - 1 Mean wind speed, enabled	m/s	51787	99.6 %	7.54		0.30	18.50	7.69	8.62	2.8783
30.0m - 1 Wind direction, all	Degrees	52014	100.0 %	103.7	46.8	0.0	355.0			
30.0m - 1 Wind direction, enabled	Degrees	51787	99.6 %	102.8	43.7	0.0	356.0			
50.0m - 1 Turbulence intensity, all		52014	100.0 %	0.1377	0.0764	0.0000	1.5008			
50.0m - 1 Turbulence intensity, enabled		51787	99.6 %	0.1374	0.0757	0.0000	1.5008			
49.0m - 2 Mean wind speed, all	m/s	52014	100.0 %	7.33		0.40	18.20	7.50	8.42	2.8085
49.0m - 2 Mean wind speed, enabled	m/s	51786	99.6 %	7.35		0.40	18.20	7.50	8.42	2.8085
30.0m - 2 Wind direction, all	Degrees	52014	100.0 %	103.7	46.8	0.0	355.0			
30.0m - 2 Wind direction, enabled	Degrees	51786	99.6 %	102.8	43.7	0.0	356.0			
40.0m - 3 Mean wind speed, all	m/s	52014	100.0 %	7.13		0.50	17.30			
40.0m - 3 Mean wind speed, enabled	m/s	51785	99.6 %	7.15		0.50	17.30	7.31	8.19	2.9783
30.0m - 3 Wind direction, all	Degrees	52014	100.0 %	103.2	46.3	0.0	355.0			
30.0m - 3 Wind direction, enabled	Degrees	51786	99.6 %	102.4	43.2	0.0	355.0			
30.0m - 3 Turbulence intensity, all		52014	100.0 %	0.1427	0.0688	0.0000	1.9222			
30.0m - 3 Turbulence intensity, enabled		51786	99.6 %	0.1425	0.0681	0.0000	1.9222			
40.0m - 4 Mean wind speed, all	m/s	52014	100.0 %	6.74		0.40	16.50	6.91	7.75	2.9714
40.0m - 4 Mean wind speed, enabled	m/s	51786	99.6 %	6.74		0.40	16.50	6.91	7.75	2.9714
30.0m - 4 Wind direction, all	Degrees	52014	100.0 %	103.2	45.3	0.0	355.0			
30.0m - 4 Wind direction, enabled	Degrees	51786	99.6 %	102.6	42.98	0.0000	355.00			

Figure 19 Raw views of main statistics.

Signal	Unit	Count	Of total	Mean	Std dev	Min	Max	Weibull mean	Weibull A par	Weibull k par
- Signal : Mean wind speed, all										
50.0m - 1	m/s	52014	100.0 %	7.52		0.30	18.50			
49.0m - 2	m/s	52014	100.0 %	7.33		0.40	18.20	7.50	8.42	2.8085
40.0m - 3	m/s	52014	100.0 %	7.13		0.50	17.30			
30.0m - 4	m/s	52014	100.0 %	6.74		0.40	16.50	6.91	7.75	2.9714
+ Signal : Mean wind speed, enabled										
+ Signal : Turbulence intensity, all										
+ Signal : Turbulence intensity, enabled										
+ Signal : Wind direction, all										
+ Signal : Wind direction, enabled										

Figure 20 By dragging "Signal" up into the header bar area, a more convenient view can be established.

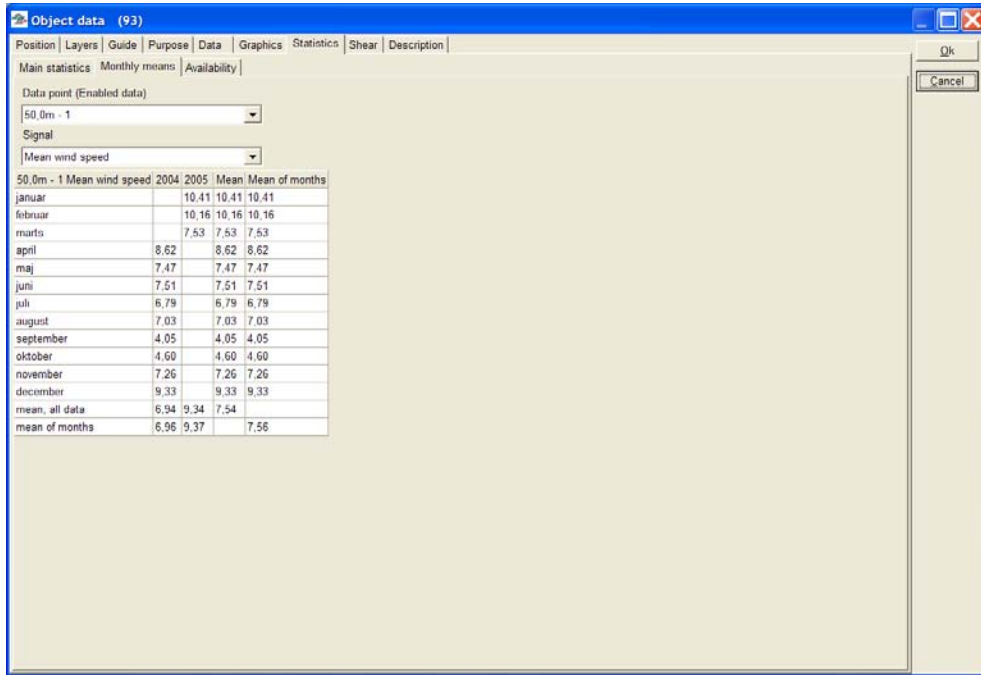


Figure 21 Monthly means can be shown signal by signal – by right click, the tables can be copied to the clipboard and easily integrated in documentation.

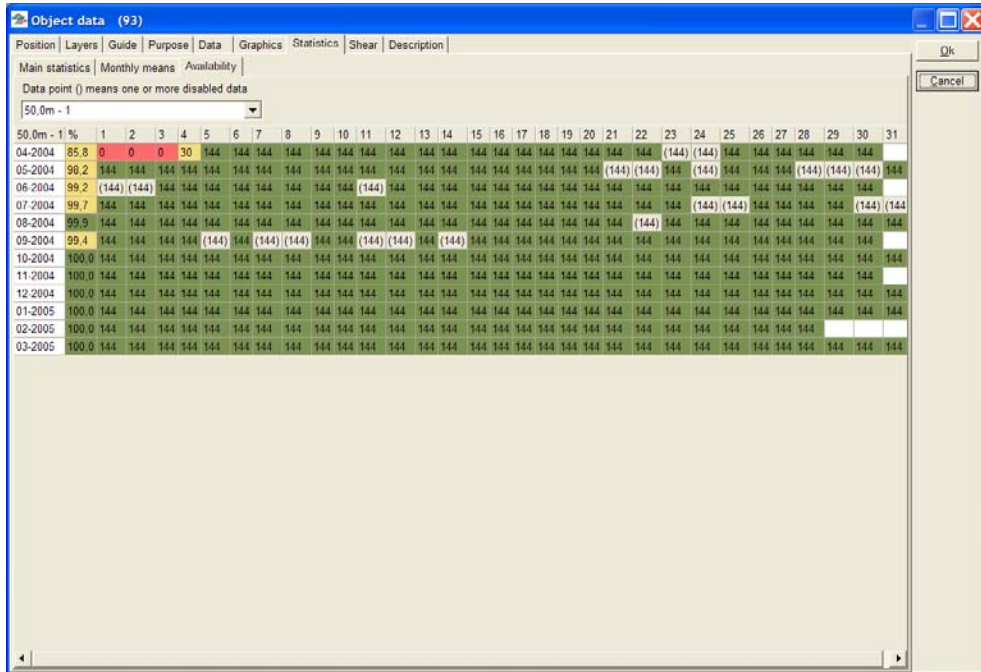


Figure 22 Availability can be shown height by height. Color coding gives a fast overview of the availability.

3.3.2.6 Shear

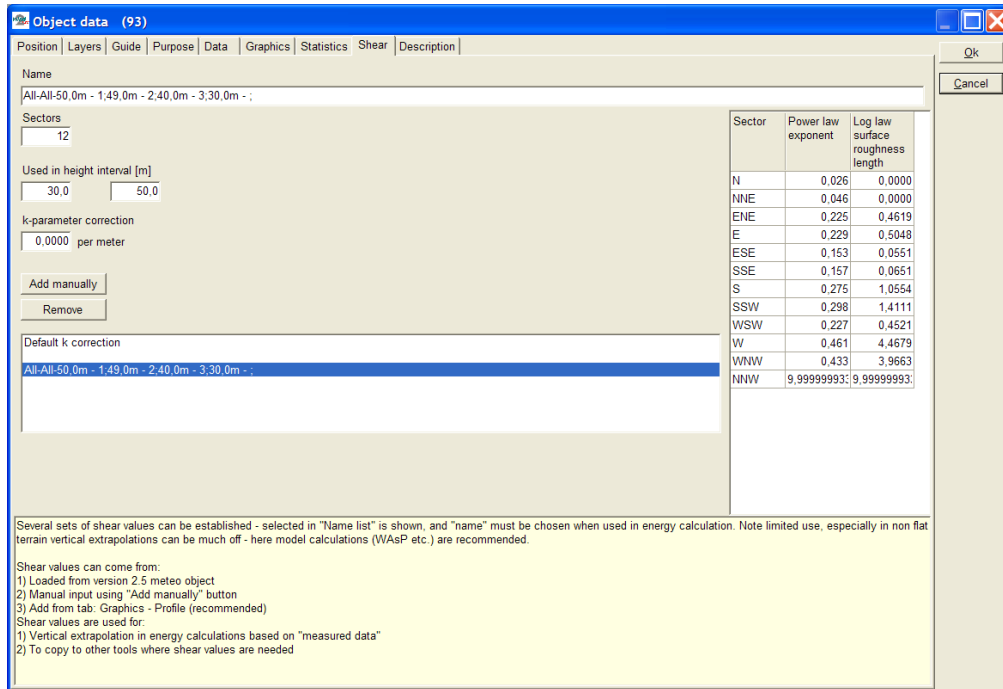
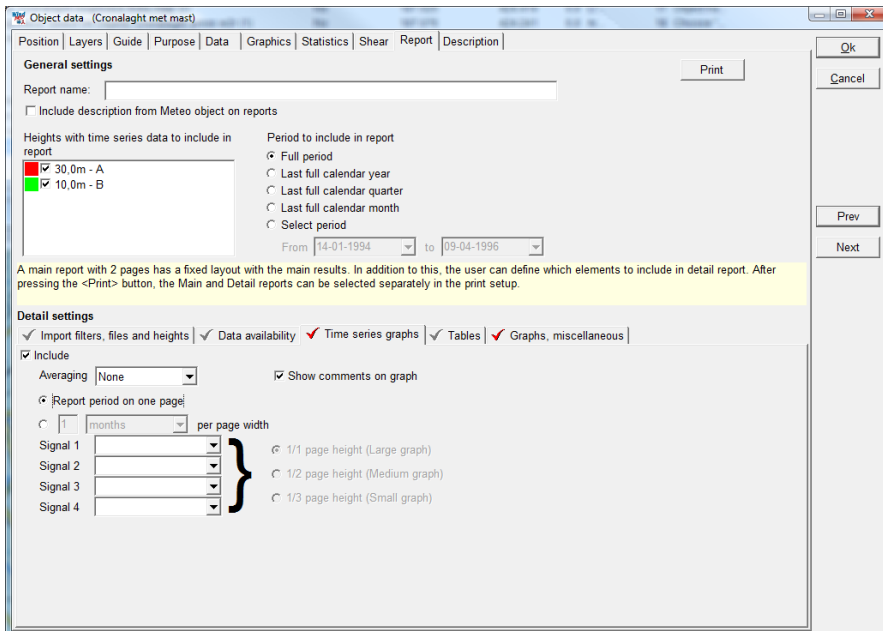


Figure 23 Shear can either come from v2.5 calculations, manual input or calculated from the graphic profile viewer.

The Shear tab can hold an unlimited number of shear calculations. The text in the yellow box explains the use of the shear tab.

3.3.2.7 Report




Figur 24 The Report tab allows for setting up a report, where a number of optional tables and graphics can be selected

To define the report should be self explanatory.

When all data are entered, and reports eventually printed for documentation, click “OK” and the data can then be used from the calculation menu. If you intend to generate a Wind Statistics using WAsP, you must enter a Site Data Object, we suggest STATGEN, with a description of roughness, hills, and obstacles around the measurement tower.

Performing a STATGEN calculation will automatically transfer the necessary data to a WAsP-calculation and create a WAsP .lib file (by default the native WindPRO format .wws, which holds additional information).

3.3.3 METEOANALYSER

The MeteoAnalyser is a tool started from the left tool bar  or the tool menu.

The MeteoAnalyser works directly on the data in the Meteo data objects. MeteoAnalyser works on data from more Meteo data objects in parallel and can therefore also perform operations that are not possible within the individual Meteo data objects, such as:

Graphic comparison of data from more Meteo data objects (measurement masts)

Disable/enable concurrent data from multiple masts

Substitute / Fill data from one signal to another – scaling optional!

Cross predictor – set up and perform a cross prediction analysis based on the WAsP model from height to height, and mast to mast (test accuracy of vertical and horizontal model extrapolation). In addition RIX correction parameters can be found with the cross predictor.

Time variation data files (.WTI) can be generated from one or more measurements by merging/interpolation/patching. The WTI files generated holds a complete 1 year data file with user defined time resolution for use in time varying PARK calculations or for detailed Loss calculations.

An example of its use:

Situation:

A user has data from two wind measurement sensors at the same height placed on the north and south sides of a mast. They may want to use the north sensor when wind is from 270°-90°, otherwise use the south sensor.

Method:

- Use “Advanced disable/enable” (available both in Meteo data object and in MeteoAnalyser) to disable all data in north sensor from 90° – 270°.
- Create a substitution data series based on this meteo height (data series).
- Substitute all disabled data from the south meteo height (data series).

Now the substituted data series holds the required data.

3.3.3.1 Compare time series graphics for more measurement masts

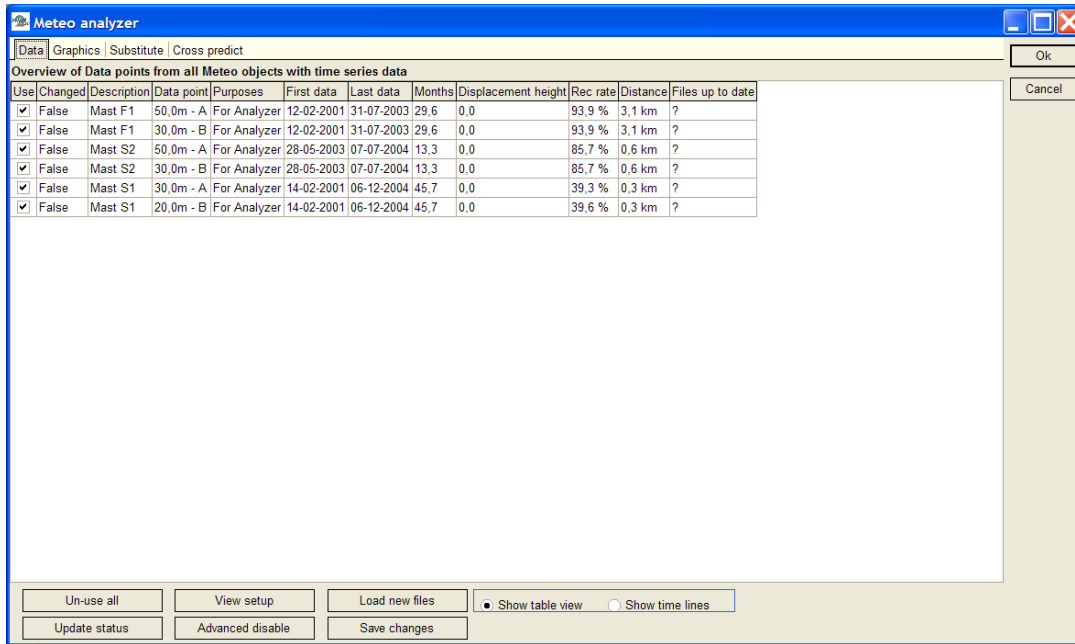


Figure 25 Selection of data - here the data you do not want to use for "analyzing" can be deselected (Unused).

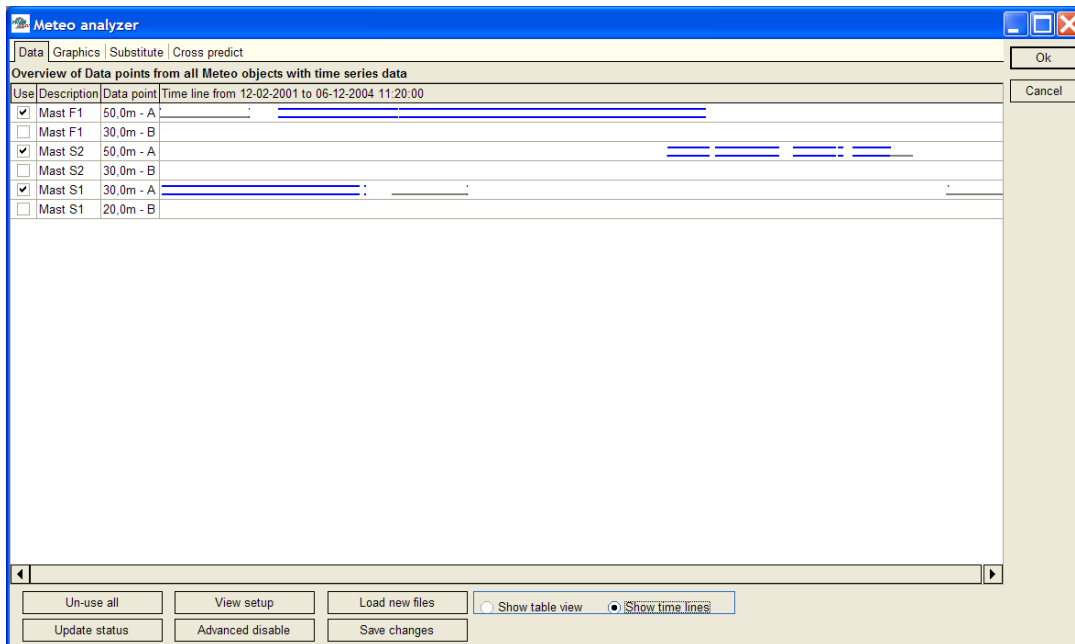


Figure 26 The "Show time lines" gives a nice overview of selected data.

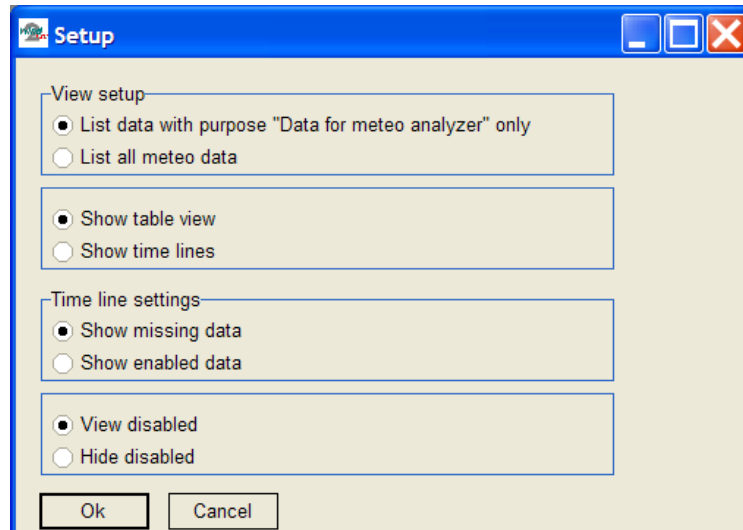


Figure 27 The view setup gives access to showing time lines with different settings.



Figure 28 In the "graphics" tab, you will see basically the same graphs as in Meteo object, only now with comparison of data from more Meteo data objects.

3.3.3.2 Perform data substitutions from other measurement signals

First a data series for substitution is created – or selected if one or more previous series have been created. The name of a substitution series will get the extension "Subst." as the last part of the name.

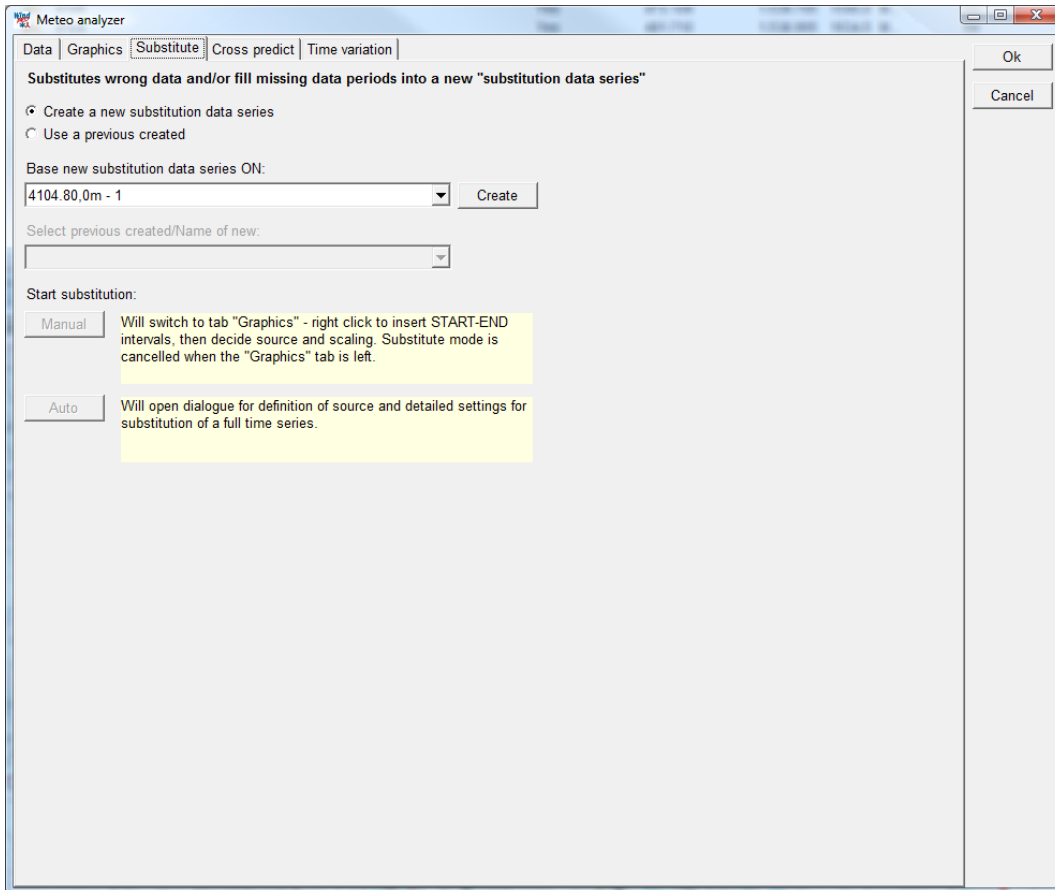


Figure 29 On the Substitute tab you can create a data series copy from one of the existing data series (heights) that will work as the new series into which substitutions/fillings from other data series can be performed.

There are two ways to perform a substitution;

- **Manual**; based on graphic view, where intervals for substitution are marked manually.
- **Auto**; where the entire time series is substituted based on the rules defined by the user.

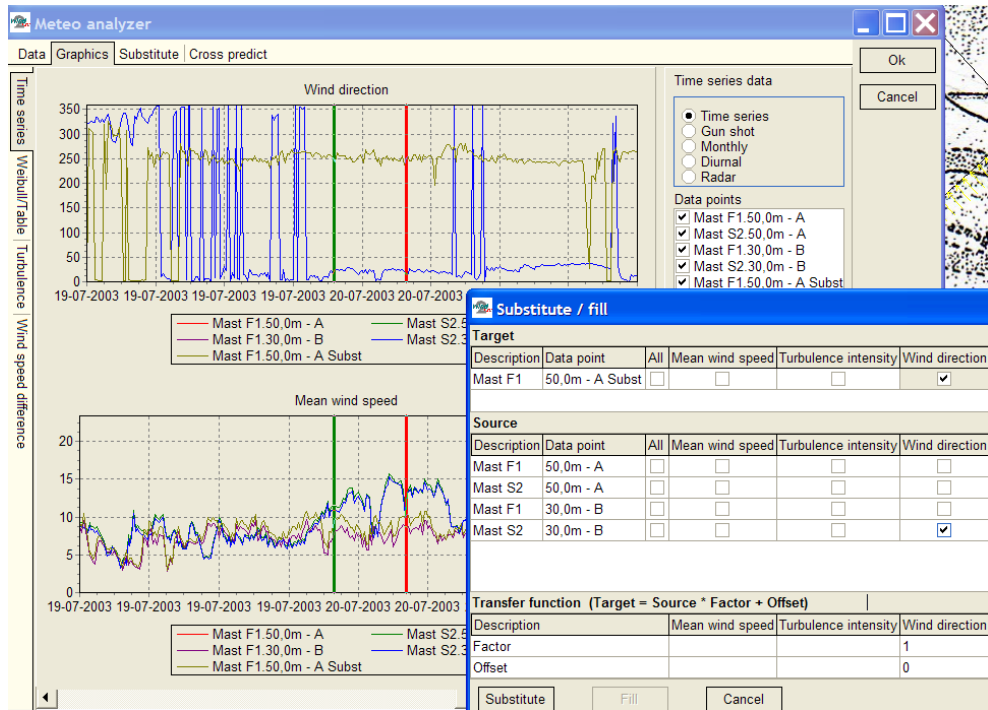


Figure 30 Manual substitution; select "start" and "end" of interval by right click, and the substitution settings appear. Here you can decide which signal(s) are to be substituted and the source and transfer function (scale and offset).

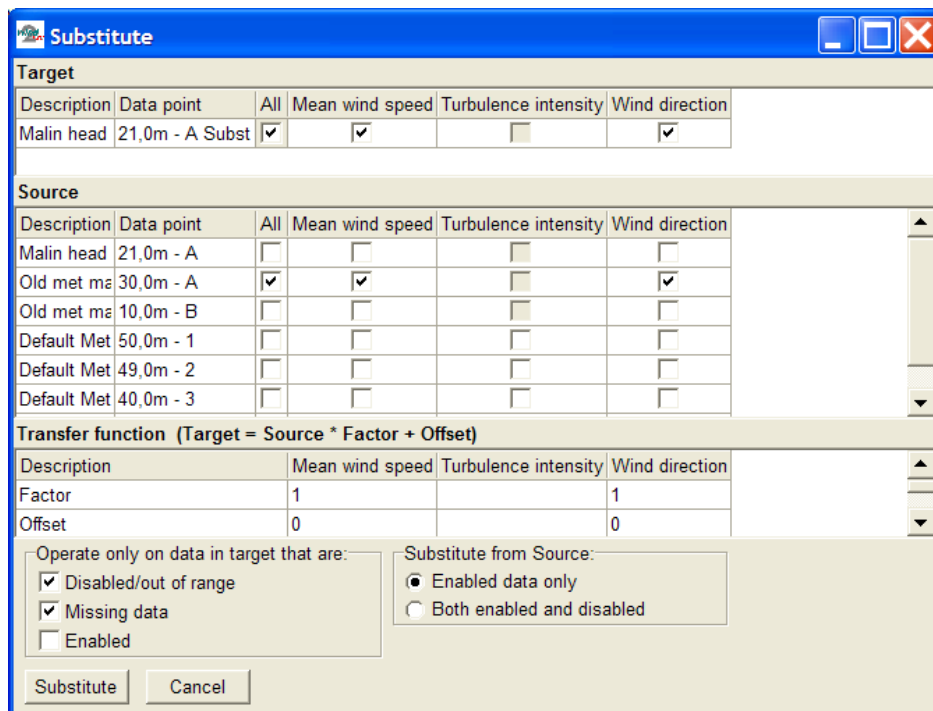


Figure 3241 Auto substitution: Set up the rules for substitution, typically only disabled and missing data records will be substituted (while disabling of "bad data" is performed first), and only enabled data used for the substitution.

3.3.3.3 Cross predict; WASP vertical and horizontal extrapolation

Cross prediction from one mast or height to another by a model based on concurrent data is the best way to find how well the model performs for the site. This is a very time consuming process in previous tools, but can now be performed with a single mouse click - and some waiting time for the calculations.

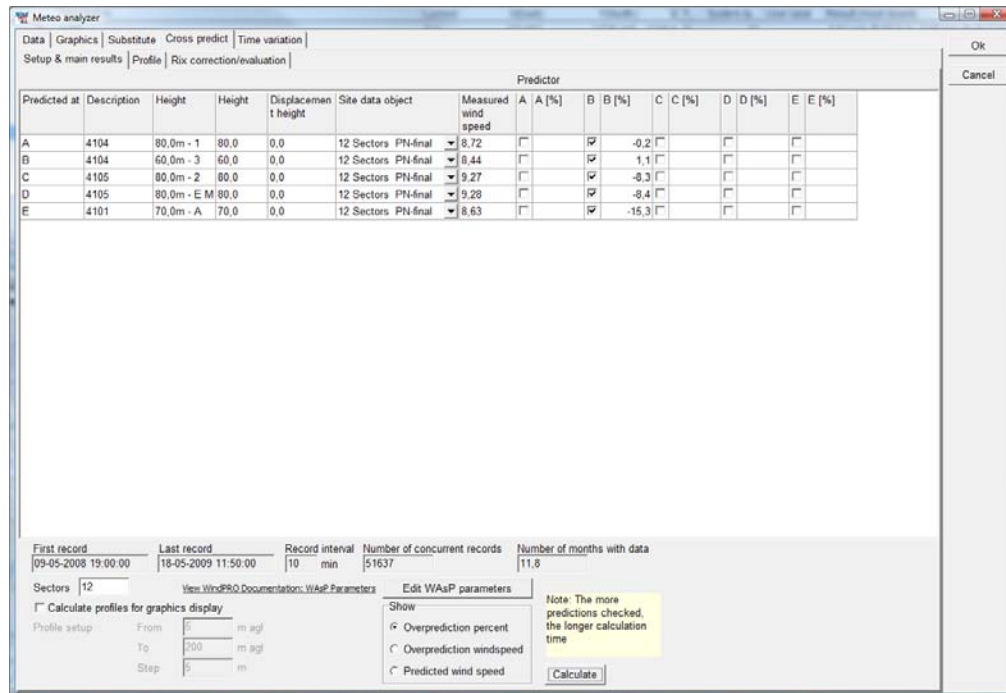


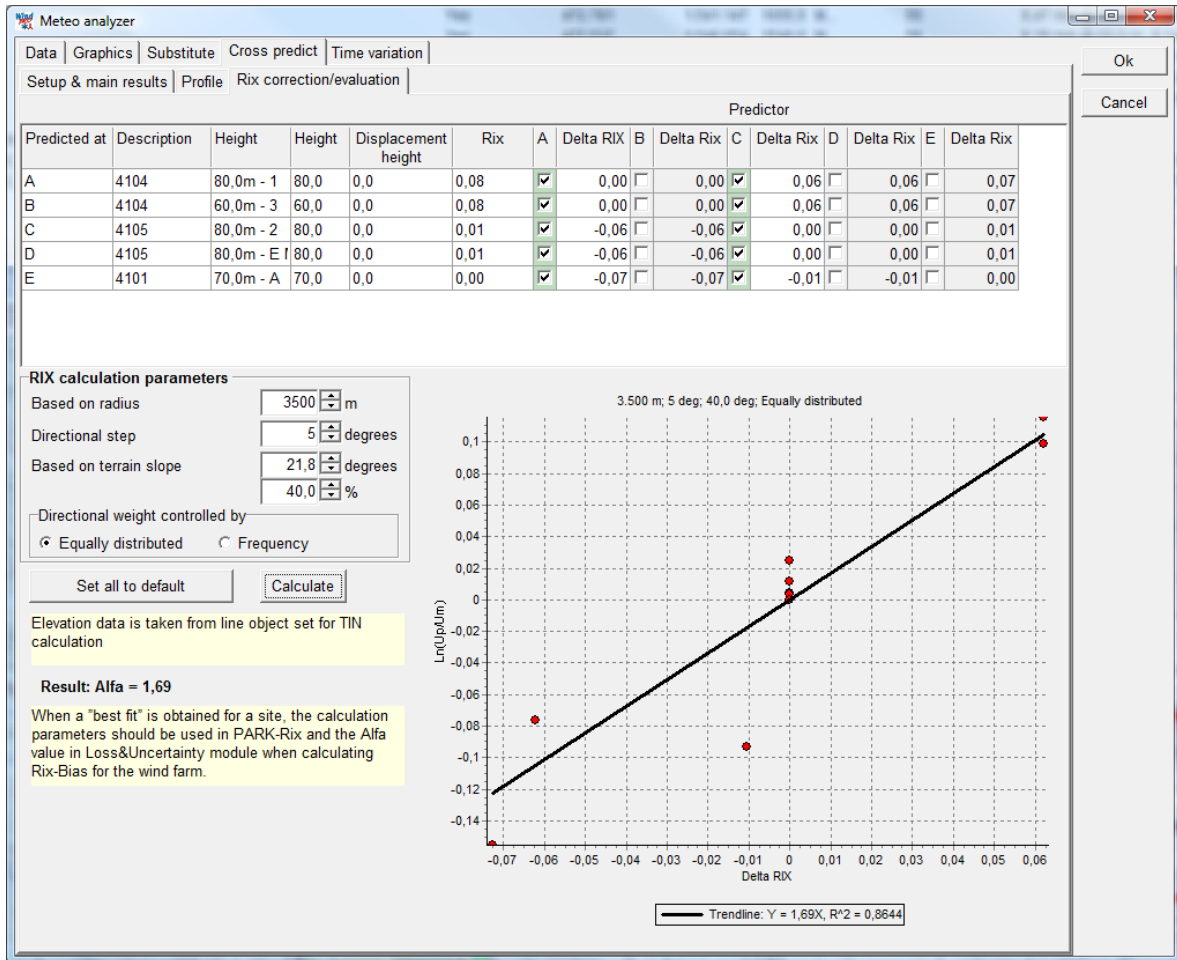
Figure 32 The WASP model capability of horizontal as well as vertical extrapolation of data is tested in one process on concurrent data. Above, a calculation where, listed as Prediction B, Mast 4104 60m predicts other heights and other masts. At Mast 4104 itself at 80m it under predicts by 0.2%, at mast 4105 it under predicts by 8.3-8.4%. So here vertical extrapolation is reasonable, while the horizontal prediction is poor. At mast 4101 it under predicts with 15.3%.

The cross predictor tool is also a very convenient tool just for extracting concurrent mean wind speeds from more data series. Data can be copied to clipboard by selecting the cells to copy and right clicking.

If cross predictions are poor, there can be several reasons like:

1. Measurement equipment is poorly calibrated
2. Masts are wrongly positioned in the terrain
3. Terrain is not described well enough (roughness, height contours, local obstacles)
4. The wind climate is not the same at the different masts (and thereby the model cannot cross predict, while this assumes the wind climate at the site is the same). This could be if one mast is close to a mountain ridge that gives meso scale wind flow modifications.
5. The steepness in the terrain is high and "known model problems" (flow separation) results in poor model handling of the wind flow transformation.

For the last one a "fix" is developed by Risø, the RIX correction. If this seems to be the problem, the tab RIX correction/evaluation can be used to find the best RIX correction parameters (end to evaluate if the RIX method seems to fix the cross prediction issue):



Figur 33 The RIX correction/evaluation tool shows the logarithmic wind speed deviation versus the Delta Rix. From the trend line based on the cross prediction errors, the Alfa value that can be used in the Rix Bias calculation in the WindPRO Loss & uncertainty module can be found. In the graph above it seems reasonable that RIX can explain the cross prediction errors (all points on a reasonable straight line). The found Alpha = 1,69 would be the choice in the RIX correction, that can be performed in the Bias part of the Loss & uncertainty module.

Only the cross predictions calculated at previous tab can be used in the Rix evaluation. See further documentation on RIX calculation in 3.4.3.1 RIX calculation or in Loss & uncertainty manual Bias part.

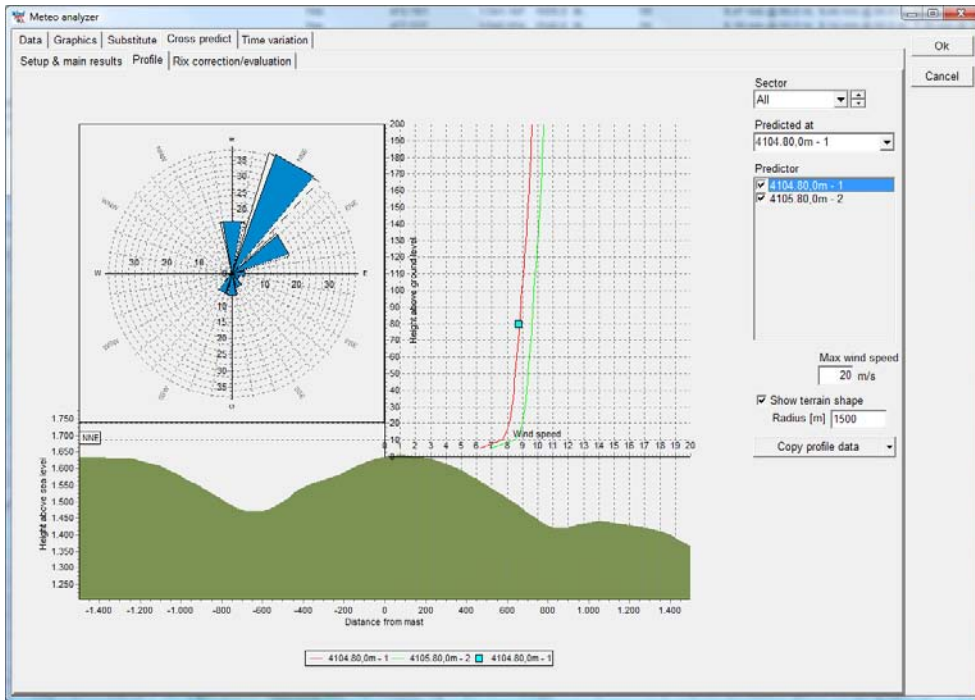


Figure 34 Finally, the prediction versus measurement can be inspected with the profile viewer. But note only one measurement point is shown, the one from the selection “predicted at”. But more profiles can be shown based on the different predictors (if more exist). For analyses of how well the vertical profile is predicted, use the meteo object.

NOTE: The profiles are ONLY shown if you have checked the “Calculate profiles for graphic display” BEFORE calculation. See form below.

First record	Last record	Record interval	Number of concurrent records	Number of months with data
09-05-2008 19:00:00	18-05-2009 11:50:00	10 min	51637	11,8
Sectors	View WindPRO Documentation: WAsP Parameters		Edit WAsP parameters	
12				
<input checked="" type="checkbox"/> Calculate profiles for graphics display				
Profile setup	From	5 m agl	Show	
	To	200 m agl	<input checked="" type="radio"/> Overprediction percent	
	Step	5 m	<input type="radio"/> Overprediction windspeed	
			<input type="radio"/> Predicted wind speed	
			Note: The more predictions checked, the longer calculation time	
			Calculate	

3.3.3.4 Time variation; Complete 1 year data from .WTI file generator

WTI (WindTimevariation) is the file extension selected for the generated file with time varying wind data (and other meteorological data). Therefore, the tool described below often is named the WTI generator.

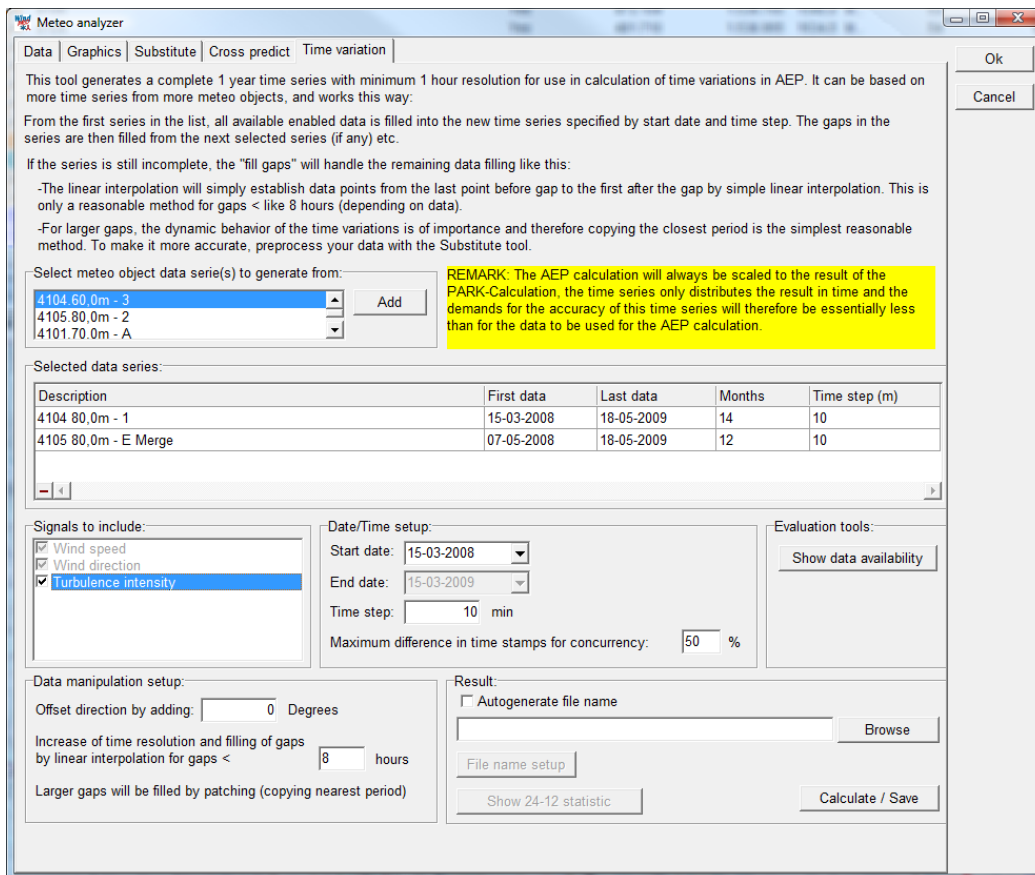


Figure 35 The setup for generation of a complete 1 year wind data file for the purpose calculation time varying AEP and/or detailed loss calculations.

The basic idea with the tool for generating a complete 1 year wind data file is that for some purposes like calculation of the expected AEP variation in time (as e.g. 12-24 tables for negotiation PPA), an often seen problem is that half a month of data is missing. There will, therefore, be no production calculated that half month. Leaving out half a month is of course, not realistic, but it might not need to be a very accurate calculation for that half month. Then the WTI generator is convenient, while this can fill in the gaps in reasonably intelligent ways and make sure that every 10-minute or 1-hour has a reasonable value for wind speed and direction (and other parameters like temperature, if selected).

Another use is in loss calculation. If e.g. the loss due to shut down below -20°C shall be calculated, a time series with both wind and temperature can be used, where the loss module finds how much energy is calculated to be produced in the time steps where temperature is below 20°C . If the temperature sensor was not working all the time (1 year) or simply not present, data can be substituted from nearby met station or NCAR data into the basic measurement, so all relevant time stamps are included after the data has been processed by the WTI generator.

Basically 3 methods are available for filling gaps:

- Take from other measurement (other height, other mast or like NCAR data)
- Fill the gap by linear interpolation (if the gap is smaller than X hours)
- Fill by patching (copying nearest period of same length into the gap)

The 3 methods can be used in combination. Data will be "resampled" to any user defined time resolution, but typically a 10 minute or 60 minute resolution should be used. NOTE: taking data from another mast does not include any scaling options. Eventually, scaling is needed to bring the two masts to the same level. This must be done up front by the substitute part in the MeteoAnalyzer.

The .WTI file is, by default, saved in the project folder and can be selected from PARK time varying calculation or from Loss & uncertainty module. The wind speed data is automatically scaled to the calculated mean wind speed for the actual site for as correct a distribution of the calculated AEP on time stamps as possible, even though the data might not be from the hub height or maybe not even from the site.

3.3.4 Extreme Wind Speed Estimator

Having imported a time series into the Meteo, object you can run an extreme wind speed calculation. This is described in the appendix in the extreme wind speed calculation section. The calculation is activated from the Tool menu in the Maps and objects window.

3.3.5 Input for a PARK calculation

It's not necessary to create WTGs as objects in order to perform an ATLAS or WAsP calculation. Instead, you can choose which WTGs and hub heights to calculate when you launch the calculation.

However, when performing a PARK-calculation you must input the WTGs on the map, since it's their inter-placement and WTG-type that is essential for the PARK calculation.

If the wind farm is extended over a wider area, you may need to use several Site Data or Meteo Objects. Each turbine will then use the nearest object (only from the ones selected in calculation setup, by default, all are selected). Using digital roughness and height contour lines is the best method. Using a WAsP calculation for each WTG in the park will calculate the effect of the orography and local obstacles individually. To calculate the roughness classification individually, you must attach a digital roughness map produced by WAsP.

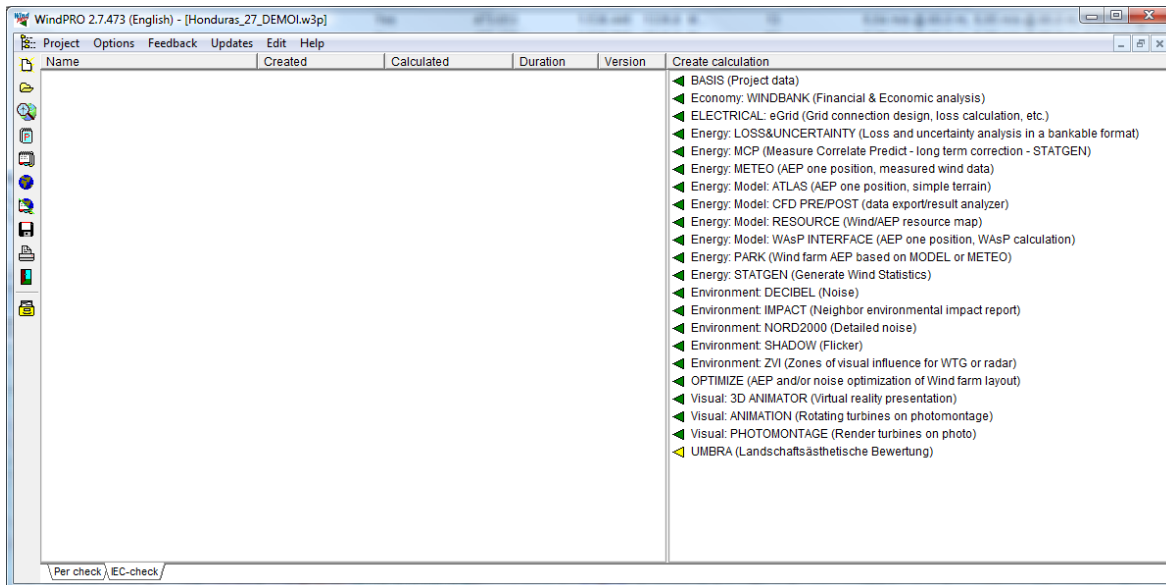
If you've created combined ATLAS and WAsP Site Data Objects, the PARK calculation will always use the WAsP calculation. However, if you want to use the ATLAS calculation as input for the PARK calculation, you must change the setting of the Site Data Object to only use an ATLAS calculation.

Details on how to input the more specific parameters for a PARK calculation are described in Section 3.4.1.

3.4 ENERGY – Calculations and Printouts



When all the objects have been created, you can return to the WindPRO main menu, e.g. by clicking on the Calculation Tree icon.



A calculation is started by clicking on the green button (arrow) beside the required calculation.

NOTE: Modules for which you have no license activated will be marked with a yellow button indicating that these will only run in DEMO mode (calculations will use standard values and not the actual values entered). If an arrow is marked with a T it means the license activation is time limited.

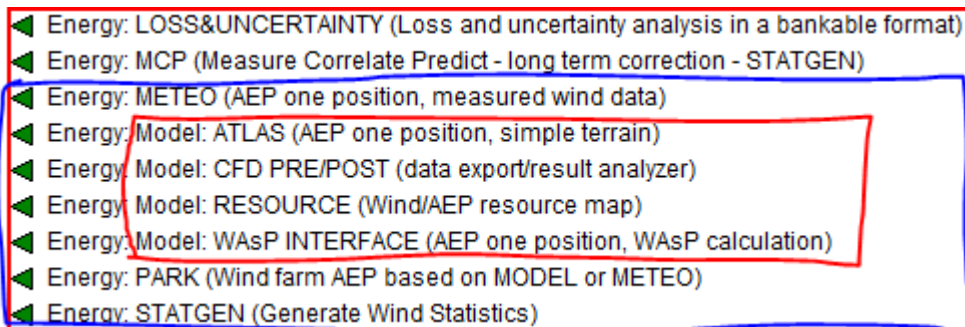


Figure 36 Zooming in on all energy related modules. The two first ones, Loss&Uncertainty and MCP have separate manual chapters. The ones in the red frame are sold as one module called MODEL. The last mentioned STATGEN is not “sold” but automatically activated if you have activated METEO and MODEL.

NOTE: The MODEL (RESOURCE) Module is described separately in Section 3.6. The different calculation modules are explained in the following; starting with PARK, while this is the normal choice for an AEP calculation, the other are more for “special purpose” calculations.

3.4.1 Calculation Energy: PARK (AEP for Wind Farm + RIX etc.)

3.4.1.1 Standard PARK calculation

Tab sheet Main

Under the first tab sheet “Main” you can enter general data for the calculation. Note the “Enable advanced options”, which gives access to more input options, which will be explained later.

Calculate:

- **AEP**; requires turbine object established on the map and wind data (can be in METEO object or a Site data object, which holds all needed information for a model calculation).
- **Time varying AEP**; requires you have a .WTI file or a meteo object with time series data
- **RIX**; requires elevation data in a line object set to be used for TIN calculation

For the two last mentioned, additional tabs for input specification will appear if checked.

Model parameters:

Wake decay constant – defines how much the wake expand behind the rotor. The default figure 0.075 means that, per meter behind the rotor, the wake expands 7.5 cm. In “non advanced mode” the choices are:

A lower expansion (offshore) gives a higher reduction of the wind speed behind the rotor and thereby larger wake losses. In high roughness or high complex orography (mountain area), the “Very closed farmland” can be used. In advanced mode there are more options.

Report features:

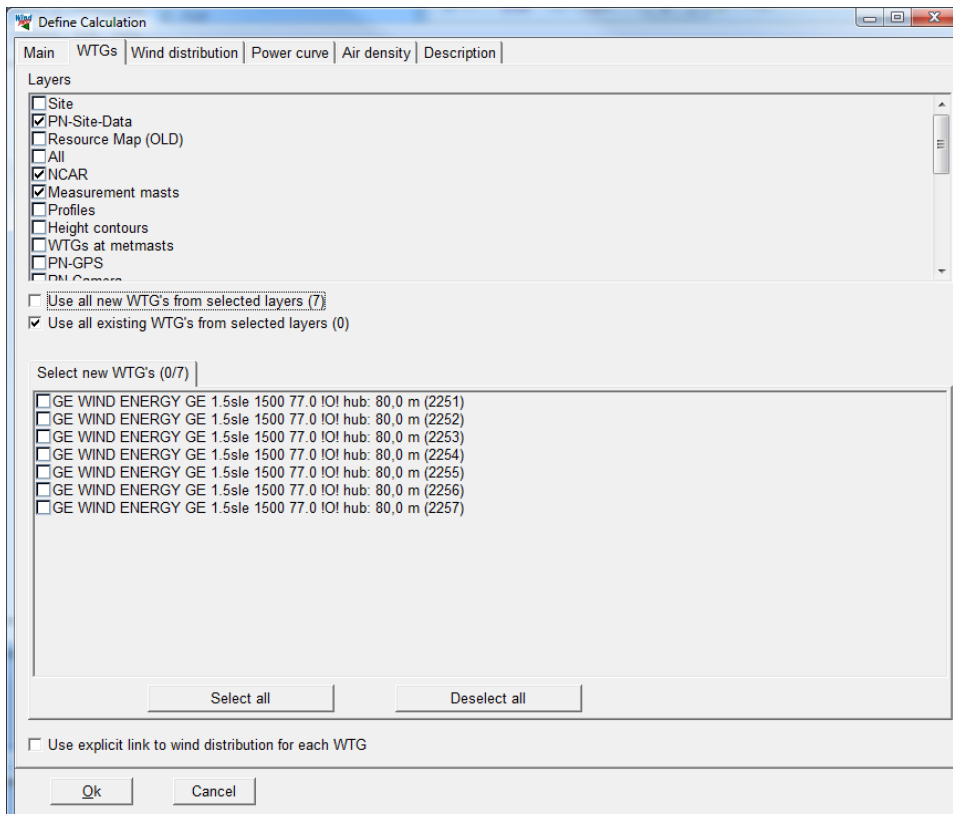
Hub height for key results gives calculated mean wind speed, energy and the equivalent roughness class for this height at the location where the Site Data Object is placed.

WTG area(s) on map give the option to include selected WTG Area's on the map as part of the report.

Handling of losses and uncertainties:

Here it is decided how the user wants to integrate these issues into the reporting. It is recommended to use the Loss & Uncertainty module to give this important part of the AEP calculation the right focus. For more "simple" or preliminary calculations, the other options can be used. The "Add simple reduction" to compensate for bias, loss and uncertainty reductions, add an extra column in the report with the reduced AEP result. You can define the text written at the print. The default is "Result – xx%"

WTGs

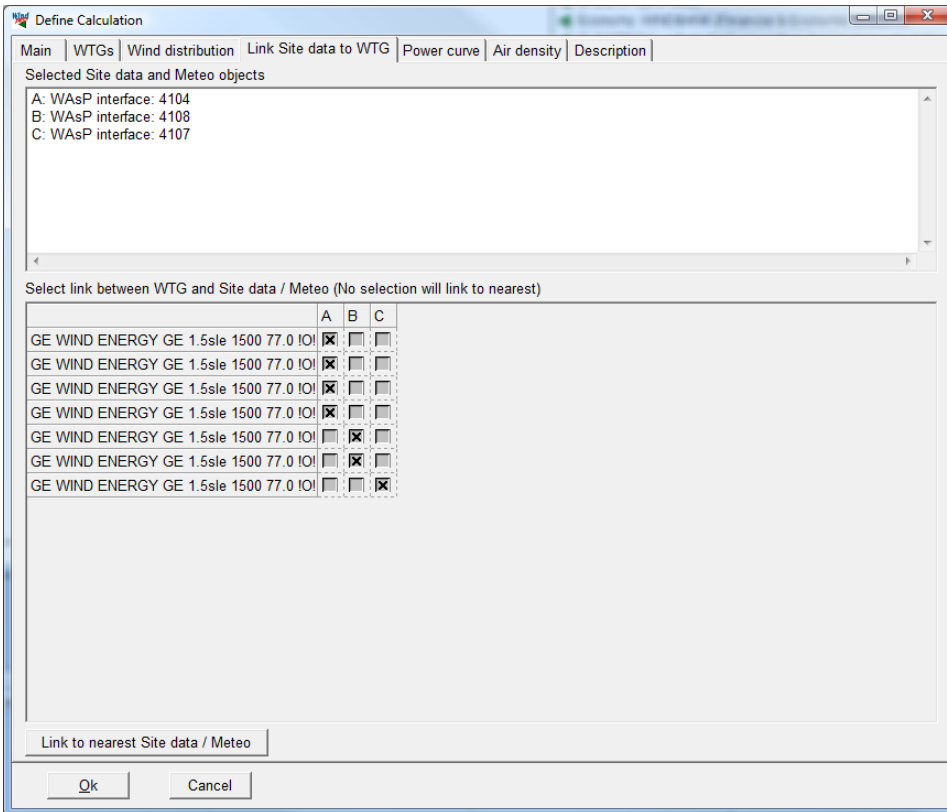


At the WTGs tab, the turbines to be calculated are selected. By default the turbines from visible layers appear, but other layers can be activated and, by unchecking "use all new from selected layers", turbines can be individually selected.

Checking the "Use explicit link to Wind distribution for each WTG" add another tab "Link site data to WTG":

Turbines with displacement height

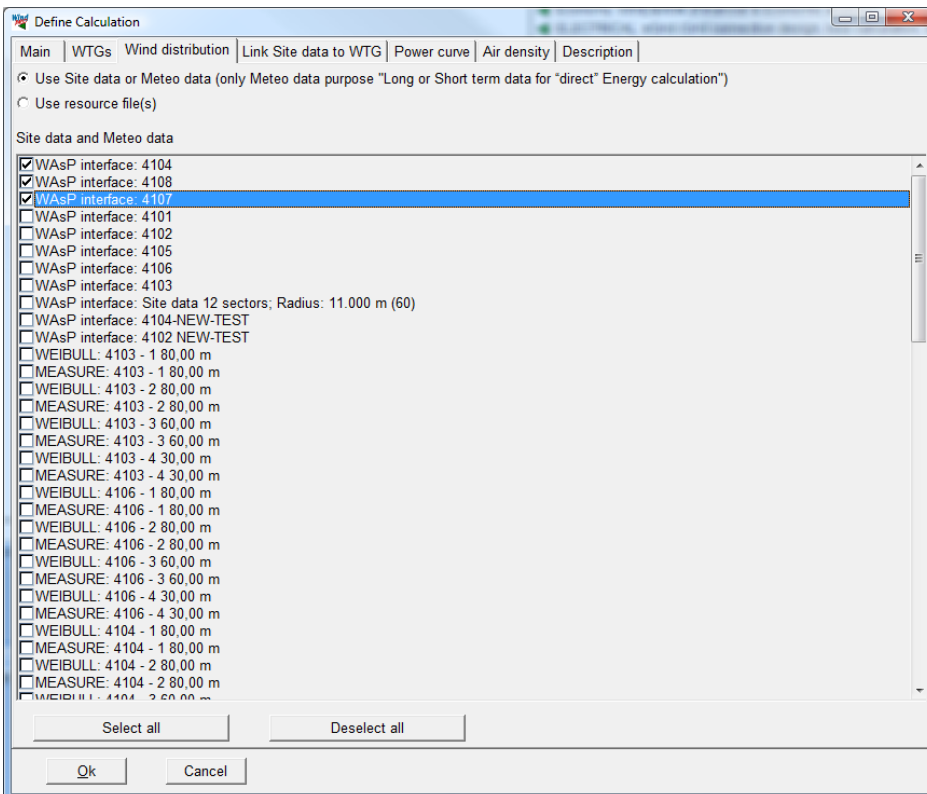
If the input field "displacement height" is given a value on the turbine object, the calculation hub height is automatically reduced with the displacement height. In the report as well the turbine hub height as the displacement height are shown. The displacement height is typically used if turbines are sited in forests where the wind profile is assumed lifted by the forest.



Before activating this, wind distributions must be chosen.

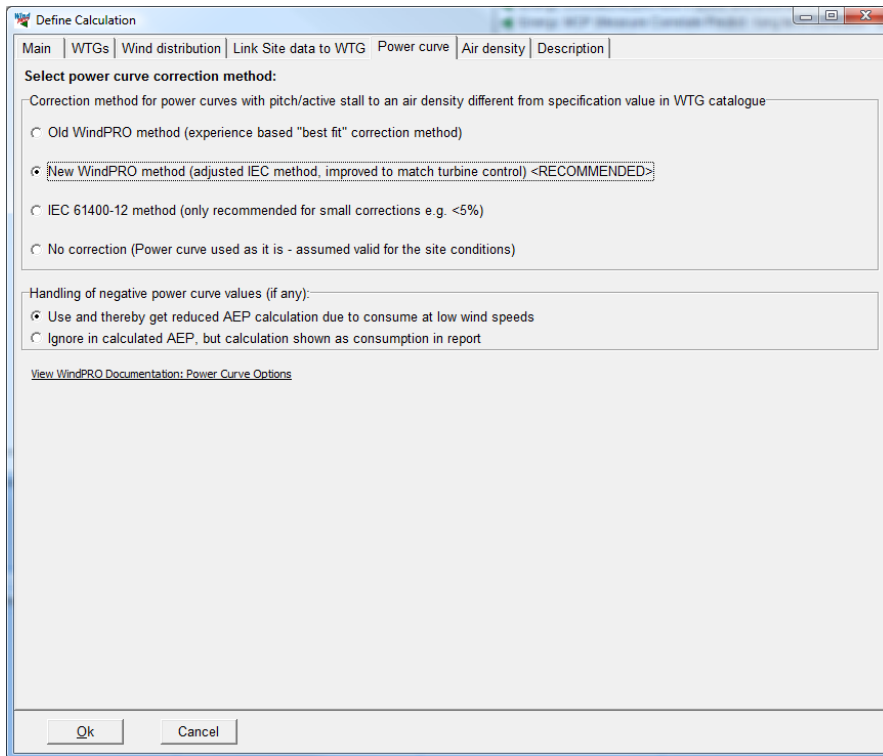
By default, each WTG “chooses” the nearest wind distribution object. In the matrix above, checkmarks can be moved so the user has full control as to which wind distribution object shall be used for which WTG.

Wind distributions



Wind distributions can also be allocated from site data objects as meteo objects – or based on wind resource maps.

Power curve



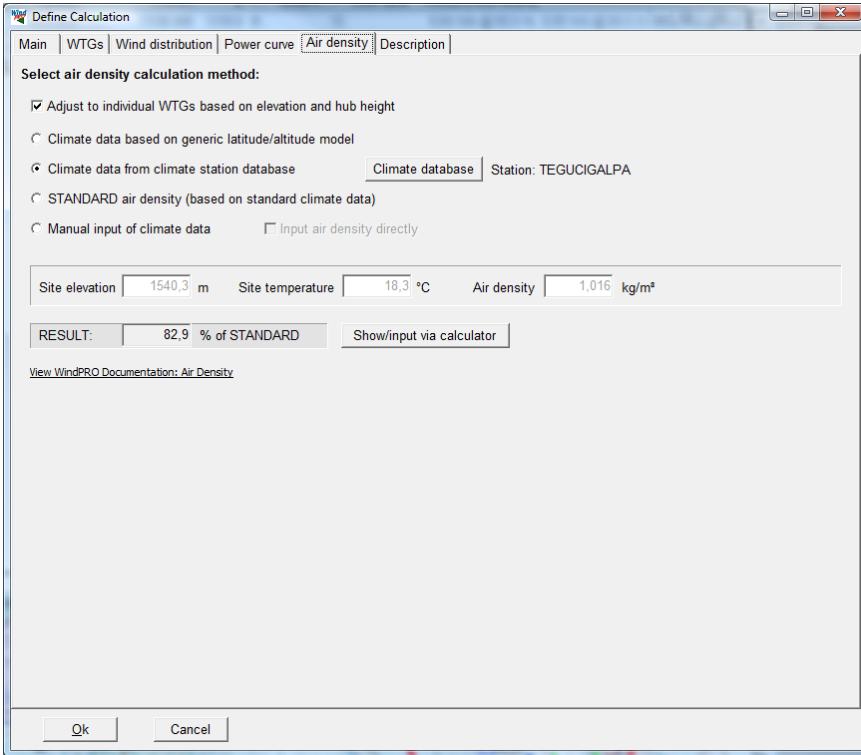
Power curves in WindPRO are normally only entered at standard air density (1.225 kg/m^3), and are then by WindPRO recalculated to the site air density. But the user can also enter the power curve in the turbine catalogue at local site air density and then choose “No correction” – or, basically, if the default correction is used and the site air density is used as input in the turbine catalogue as well as in the air density setup, no correction will be made.

There are more methods for air density correction, see the documentation by clicking the hyperlink text.

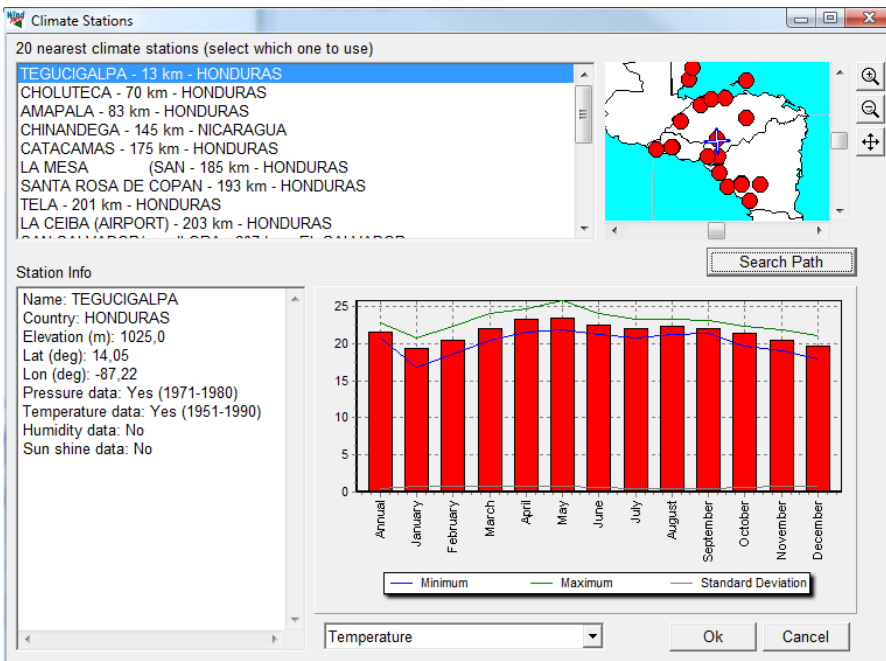
Some power curves have negative values, which can appear from 0 to around -4 m/s . But, most often the power values in this interval are set to 0. If the negative values are included, these can be handled two different ways:

1. Default: the power consumed at low wind speeds are included in the AEP calculation, and the AEP result thereby reduced.
2. Ignore the negative values in AEP calculation, but then report the calculated power consumed separately. This makes sense if a very accurate financial calculation is required, and the power purchase cost is higher than the price paid for delivered power.

Air density



Air density is, by default, calculated automatically based on site location, where the altitude is taken from each WTG object and the temperature is taken from the nearest climate database point. This is the recommended method, but please check if the climate database parameters seem reasonable by clicking the “Climate database” button:



Important is that the Elevation for the climate station and the temperature is correct. If not, choose another station.

Eventually, also check how the air density is “scaled” from the climate station to the site by clicking the “show/input” via calculator:

Edit air density

Calculation method and input for auto calculation of air density:
Note values for site is an example, if calculation at each WTG is selected.

Site elevation

Auto from site at hub height
 Manual input

Climate data

Auto from altitude/latitude
 From climate database
 Manual input, specify temperature data at base height
 Manual input, specify temperature data at site height

Advanced parameters / results (auto adjusted when loading from climate database)

Base data		Site data	Standard model options
Elevation	1025	1540 <input type="text" value="meter a.s.l."/>	<input type="checkbox"/> Elevation from standard model
Temperature	21,6	18,3 °C	<input type="checkbox"/> Temperature from standard model
Lapse rate		0,650 °C per 100 m	<input checked="" type="checkbox"/> Temperature lapse rate from standard model
Air pressure	902,20	849,58 hPa	<input checked="" type="checkbox"/> Pressure at base from standard model
Humidity	0,000	0,000 <input type="text" value="Relative humidity [%]"/>	<input checked="" type="checkbox"/> Humidity from standard model
Air density	1,066	1,016 kg/m³	

Evaluation

With current settings the air density relative to standard is:
 AEP is almost proportional to air density at same wind conditions.

How it works

The base height values give the fix point (temperature and pressure) – from climate database, user input or model calculations. The two parameters are scaled to site by altitudes based on standard models (where temperature lapse rate can be modified). While pressure from climate base can be quite uncertain, the use of pressure calculated from standard model is recommended, if no site pressure measurements verify result. Humidity is included, default by 0. This has very little influence, see graph.

Here it is seen how the climate station is located in 1025 m elevation and the site in 1540 m. The temperature is thereby converted from 21.6 to 18.3 °C and the pressure from 902 to 850 hPa. This reduces the air density for the site to 1.016 kg/m³ where it is 1.066 at the climate station. This is a 5% reduction which almost gives 5% reduction in calculated AEP relative to the use of the nearest climate data “as-is.”. It is also seen that the air density at this site only is 82.9% relative to standard, giving round 17% reduction compared to a site at standard air density conditions (15 °C at sea level).

3.4.1.2 Time varying PARK AEP calculation

Define Calculation

Main | WTGs | Wind distribution | RIX setup | Power curve | Air density | Time variation | Description

- Time varying data should represent exactly one year, 10 min to 1 hour resolution
- .WTI files automatically fulfilling these requirements are generated using the Meteo analyzer.
- When using data from Meteo Objects, compliance to the requirements is the user's responsibility. For special purposes, non complete years can be calculated, see in manual how these calculations are handled.

The optimal time varying calculation data will be 1 year from a meteo object from site fulfilling demands described in first line, including besides wind speed and direction also turbulence and temperature. If WAsP model is used, data will be transported with this model to each WTG position, and all detailed loss/bias calculations will be supported.

Use generic time variation data (*.WTI)
 Use time series from Meteo object

Use time varying air density if temperature and/or pressure in time series
 Use Reduction % from Main page on figures in reports
 Save time series result for each WTG for Result to file report. May cause Out of memory error.

Time varying calculation is a powerful option for different purposes, where the two most important are:

- 1) **Create a statistic**, like the 12-24 (12 months-24 hours) matrix, that can be used for negotiating PPAs or for evaluation of how like time tariffs invoke the expected income from the sold energy. Also, the duration curve produced as a part of the time varying calculation is a powerful tool for evaluation of e.g. how many hours a year a specific power demand can be operated from the wind parks production.
- 2) **Create a time step by time step AEP calculation** for each turbine for a performance check/model calculation check. Comparing this calculation with real production from the Scada system, our turbine computer makes it possible to sort data by direction, hour, month, wind speed etc. This allows you to see where eventual problems might be if actual production does not match calculated.

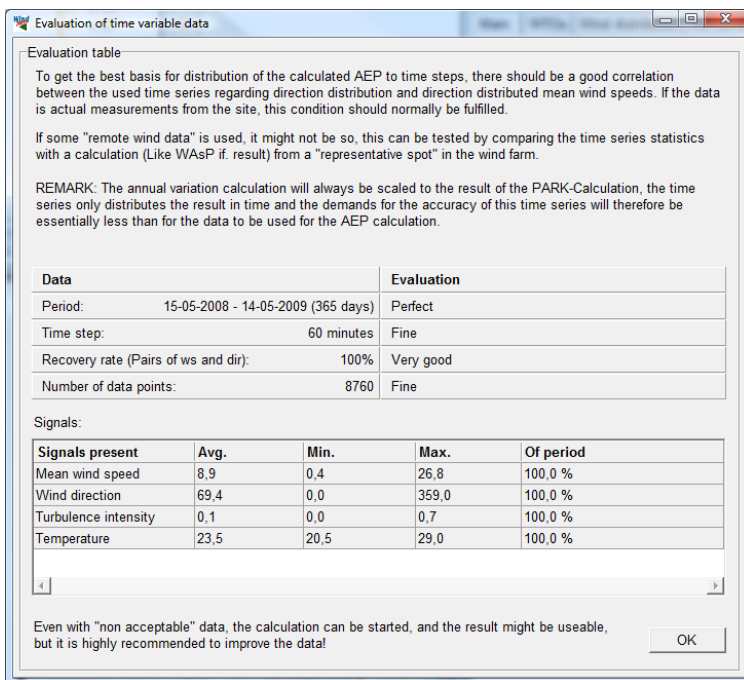
Output from the first issue is part of the standard reporting. For the second, the “Result to file” option must be used. A text file is saved and can be loaded from Excel or similar. Or data can be transferred directly via clipboard.

NOTE: For ALL Time varying calculations, the results are scaled to the non time varying calculation, so the reader of the reports does not get “confused” by varying results. An exemption from this is the calculated “Power” in the result to file, which represent the “raw” calculation result and is therefore best suited for checking how the model performs.

If a calculation is based on a WTI file, the result is a simple scaling of the calculated AEP based on a wind energy index time step by time step created from the WTI file, where the mean wind speed is scaled to calculated mean wind speed for each turbine.

If a calculation is based on a METEO object, the measured wind is transformed by the WAsP model from mast position to each WTG position. So this shall be used if a model performance check is wanted.

For issue 1) mentioned above, it is important to have a full representative year of wind data. No gaps in the data. This is best secured by generating a WTI file (see MeteoAnalyser). The “View” button can be used for checking the content of the file (or a meteo object data series):



For issue 2), the length of the period is less important. What is important is to have wind data concurrent to actual production data. A performance check can be performed on few months or more years of data. A problem can be the amount of data, if hundreds of turbines with several years of 10 min resolution data are calculated; there might be RAM overflow on the PC. Therefore, by default, only the sum for all turbines in the wind farm is reported in the result to file report. It must be checked on the input form if you want results turbine for turbine.

1	ORG data, new 120m free wind Park_cleaned data_NO_no.displ - 120,00 m Data are air density corrected																		
2	AEP scaled mean that the SUM total is equivalent to main calculation result for 1 year - the "raw" calculations can be found through the column "Power"																		
3	Measure height: 120,0 n 1775560 7247864																		
4	Time stamp	Wind spe	Direction	Tempera	Pressur	AEP scal	AEP scal	AEP scal	Power	Power	Power	Free wii	Free wii	Free wii	Wake w	Wake w	Wake w	Air dens	Air de
5	Date	[m/s]	[°]	°C	[hPa]	[MWh]	[MWh]	[MWh]	[kW]	[kW]	[kW]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[m/s]	[kg/m³]	[kg/m
6	01-01-2009	12,3	330	-7	#N/A	0,2476	0,2749	0,3034	1376	1540,4	1700,6	10,4	10,7	11	9	9,4	9,7	1,31	1,3
7	01-01-2009 00:10	12,7	326	-7,3	#N/A	0,2769	0,3048	0,3334	1538,7	1707,5	1868,4	10,8	11,1	11,3	9,4	9,7	10,1	1,312	1,3
8	01-01-2009 00:20	12,8	327	-7,7	#N/A	0,2847	0,3125	0,3415	1581,9	1751,1	1913,7	10,8	11,2	11,4	9,5	9,8	10,2	1,314	1,3
9	01-01-2009 00:30	12,1	328	-8	#N/A	0,2343	0,2613	0,2898	1301,9	1464,3	1624	10,3	10,6	10,8	8,8	9,2	9,5	1,315	1,3
10	01-01-2009 00:40	12,4	327	-8,3	#N/A	0,2565	0,2841	0,3126	1425,4	1591,9	1752,1	10,5	10,8	11,1	9,1	9,5	9,8	1,317	1,3
11	01-01-2009 00:50	12,2	327	-8,7	#N/A	0,2423	0,2696	0,2983	1346,6	1510,8	1671,8	10,3	10,7	10,9	8,9	9,3	9,6	1,319	1,3
12	01-01-2009 01:00	11,3	329	-9	#N/A	0,1835	0,2058	0,2299	1019,7	1153,1	1288,5	9,6	9,9	10,1	8,1	8,5	8,8	1,32	1,3
13	01-01-2009 01:10	11,5	331	-9	#N/A	0,1958	0,2186	0,245	1088,2	1224,9	1372,8	9,7	10	10,3	8,3	8,6	9	1,32	1,3
14	01-01-2009 01:20	11	330	-7	#N/A	0,1635	0,185	0,2075	908,4	1036,8	1163	9,3	9,6	9,8	7,9	8,2	8,5	1,31	1,3

Figure 37 The result to file into Excel. Here an example with 3 turbines. Notice the columns explained below.

Time stamp, Wind speed, Direction, Temperature and Pressure all come from the used meteo data series (or WTI file). If temperature and/or pressure are present an air density correction is performed for each time step. Pressure data is less important than temperature data while temperature variations typically influence air density much more than pressure.

AEP scaled – the calculated AEP scaled so the sum is the same as in the PARK main result. (so there are not different, confusing results). This can be used, e.g., if a utility want to know expected AEP hour by hour for analyzing the expected value of the wind production.

Power – the raw calculated power time step by time step. This is NOT scaled and should be used for comparing with actual power taken from turbine controller or Scada if model calculations shall be tested.

Free wind speed – wind speed transformed by WAsP to WTG location, before wake reduction.

Wake wind speed – wind speed transformed by WAsP to WTG location, after wake reduction.

Air density: The calculated air density for the specific time step and turbine.

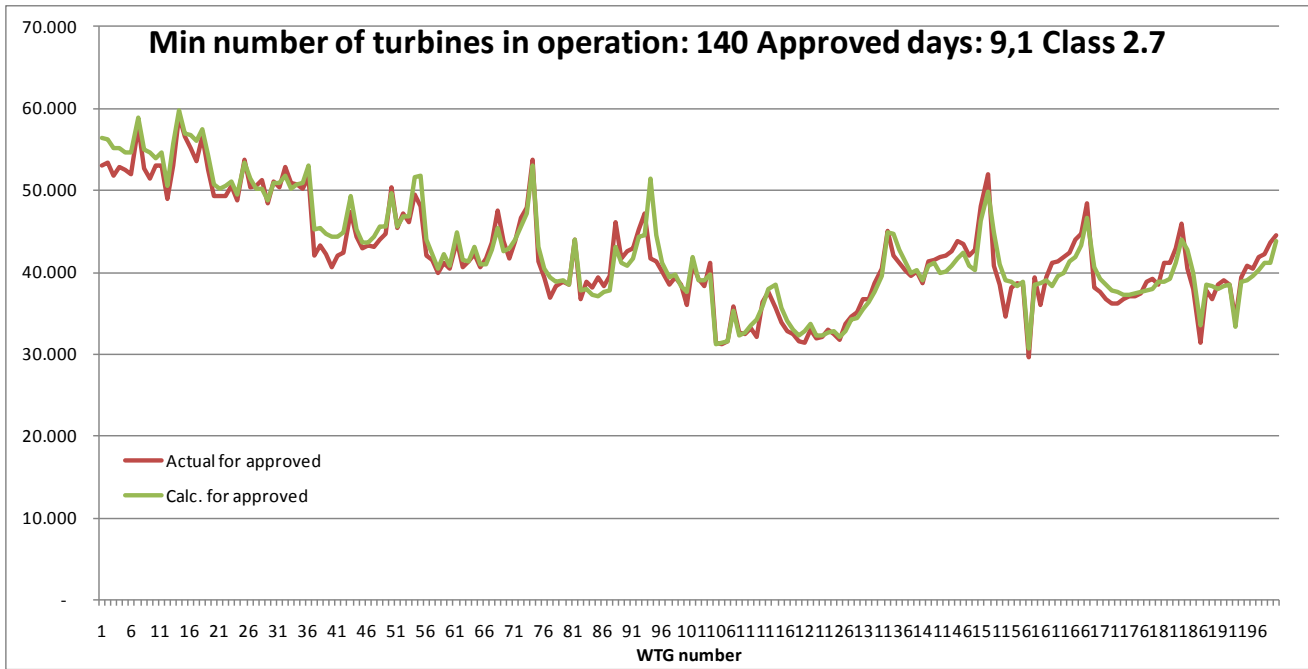
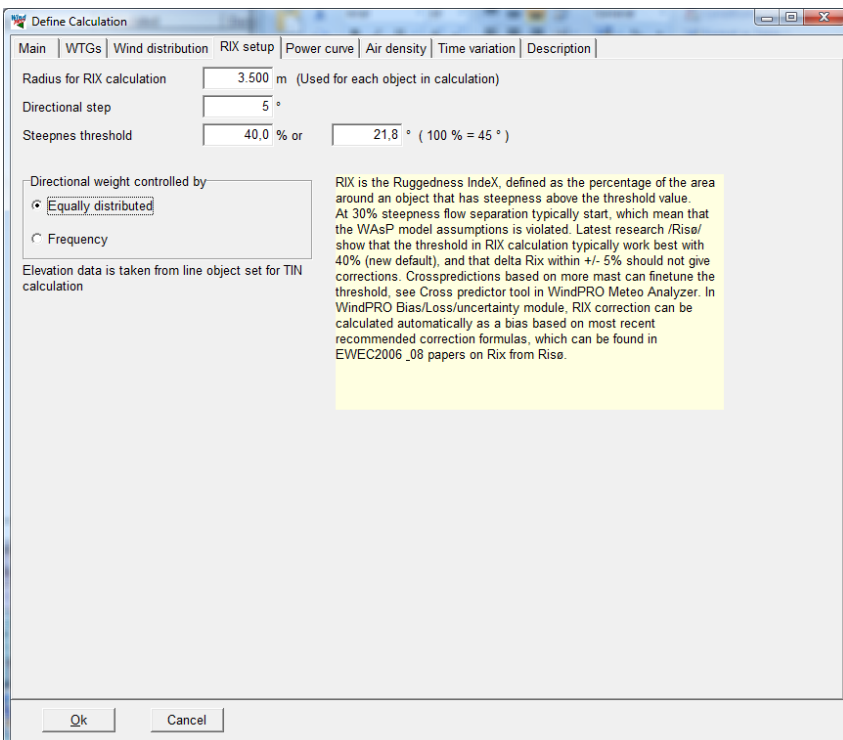


Figure 38 Example of a model performance check with 200 turbines calculated by 10 min. values. The data is sorted so only the time steps where most turbines are in operation (which are few days in this example) are included. The sample show there is a very fine correspondence between calculated and actual production, but in this case the model has been manipulated by increasing the roughness inside the wind farm from class 0.8 to class 2.7. This is so far the best repair option for very large wind farm arrays, which typically are over predicted by the wake model.

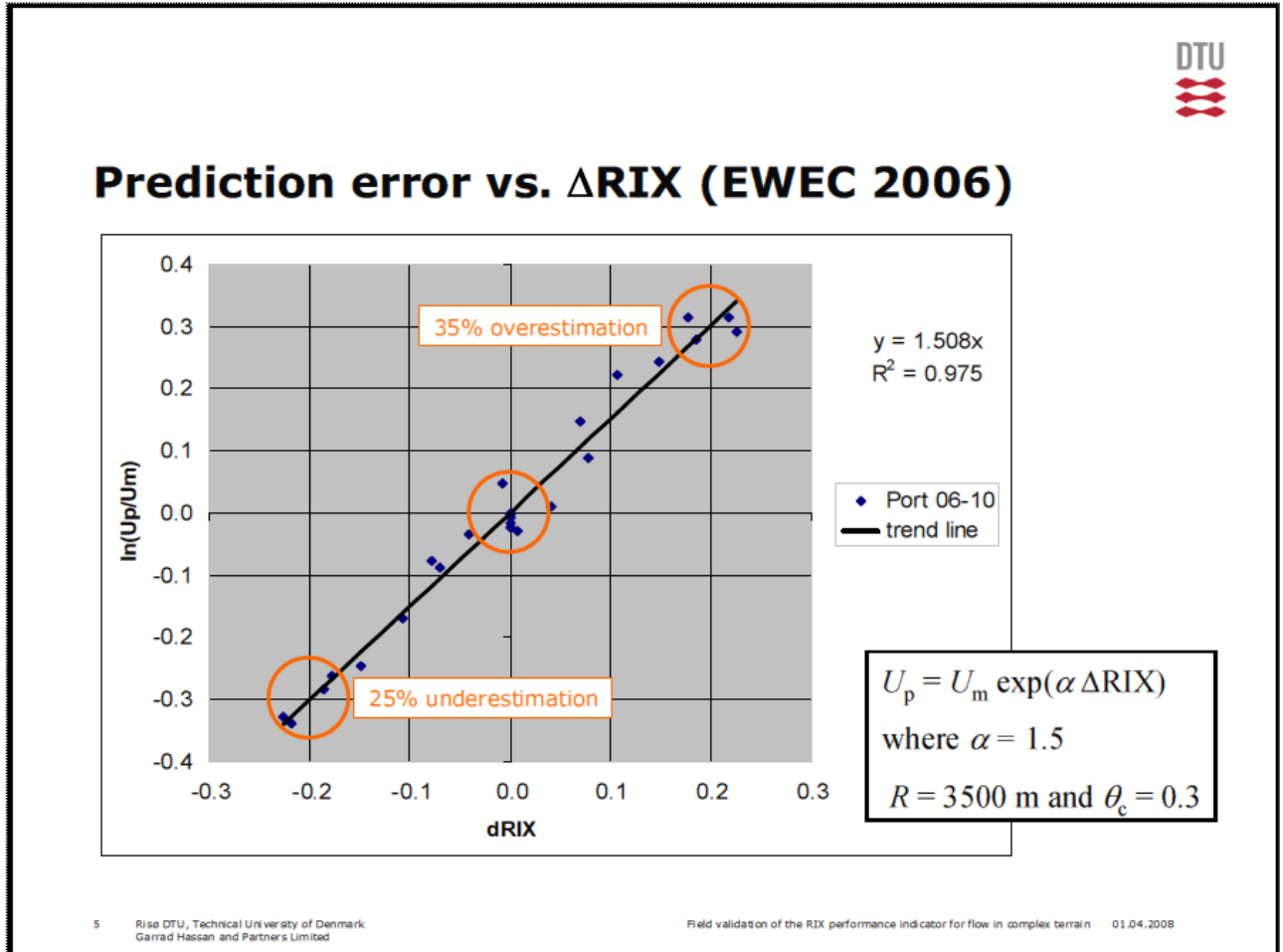
3.4.1.3 PARK RIX calculation



RIX is the Ruggedness Index, defined as the percentage of the area around an object that has a steepness above a given threshold value. At 30% steepness, flow separation typically starts, which means that the WAsP model assumptions are no longer valid. Experiments show that the RIX values can be used to fix WAsP model

calculation problems in steep terrain – or at least reduce the error introduced by flow separation. It is even seen in papers that RIX correction also improves CFD calculation results.

The Latest research by /Risø/ shows that the threshold in RIX calculation typically works best with 40% (new default), and that delta Rix within +/- 5% should not give corrections. Cross predictions based on more mast can fine tune the threshold, see Cross predictor tool in WindPRO MeteoAnalyser. In WindPRO Bias/Loss/uncertainty module, RIX correction can be calculated automatically as a bias based on most recent recommended correction formulas, which can be found in EWEC2006 & 08 papers on Rix from Risø, see extract below:

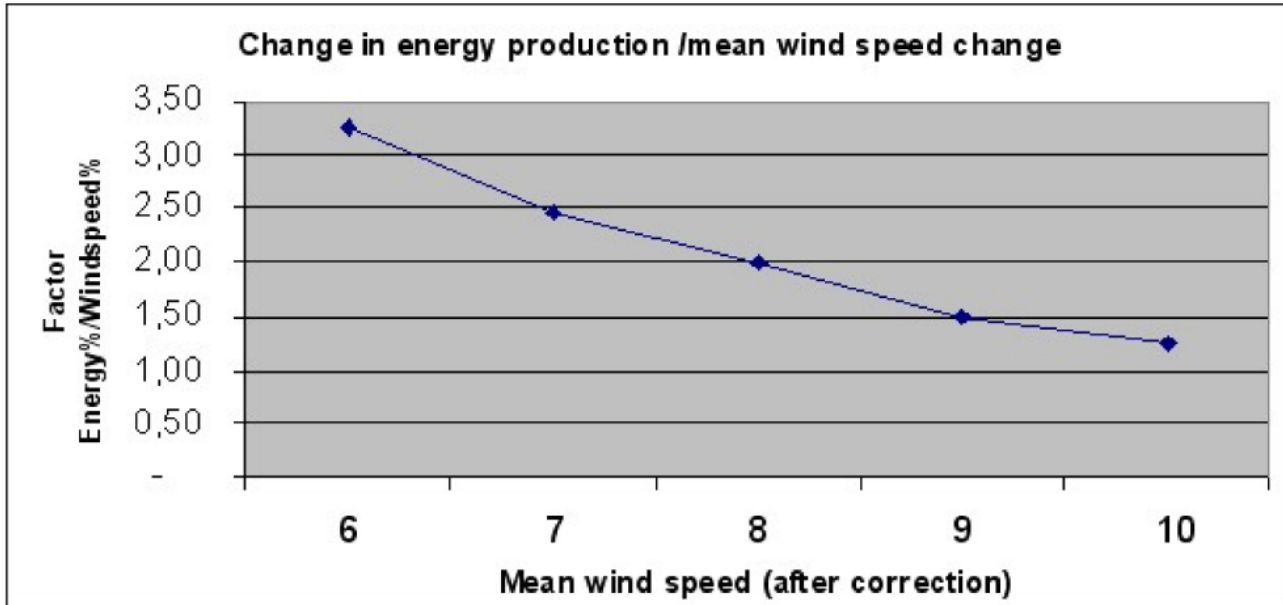


The main conclusion based on use of the RIX method is that if both reference site (measurement mast) and predicted site (WTG) are equally rugged (Delta RIX < 5%), very small calculation errors are expected.

If reference site (measurement mast) is very rugged, e.g. RIX = 0.2 and predicted site (WTG) are less rugged (e.g. RIX = 0), Delta RIX will be -0.2 and according to the graph, 30% too low wind speed prediction at WTG site could be expected. This could lead to around 60%¹ to low calculated energy production.

If the reference site is less rugged, e.g. RIX = 0, and the predicted site (WTG) is very rugged (e.g. RIX = 0.2), Delta RIX will be +0.2, and according to the graph, 30% too high wind speed prediction at WTG site could be expected. This could lead to around 60%¹ to high calculated energy production.

*1



**Source: EWEC06 paper:
IMPROVING WAsP PREDICTIONS IN (TOO) COMPLEX TERRAIN**

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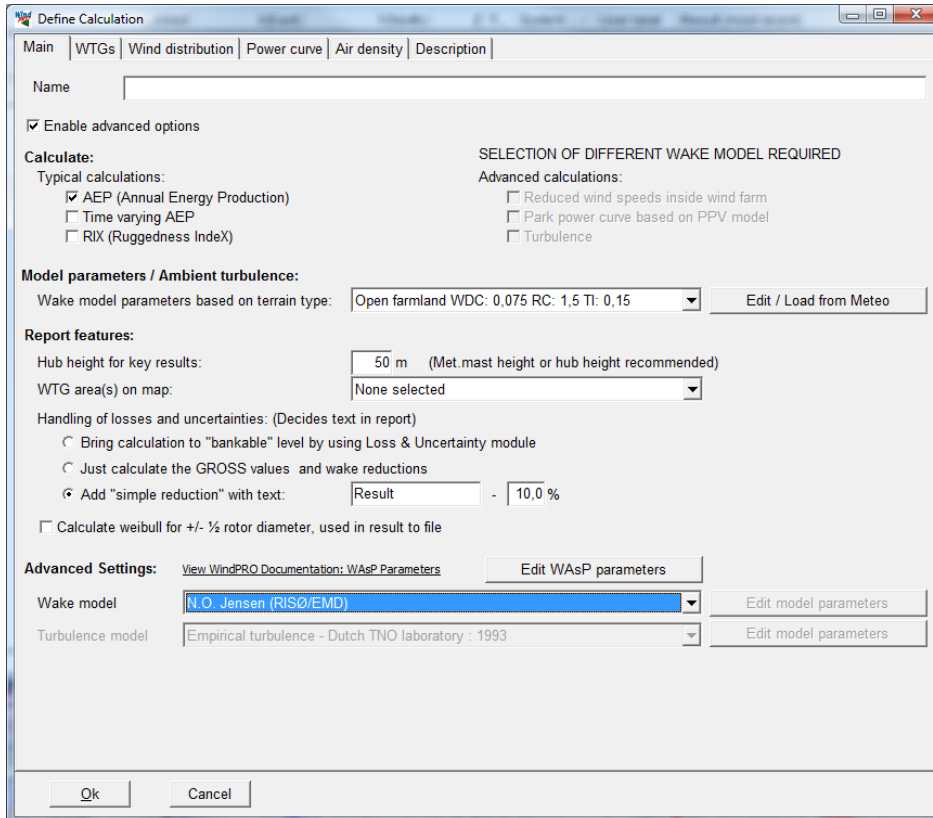
²Mechanical Engineering Department

University of Canterbury

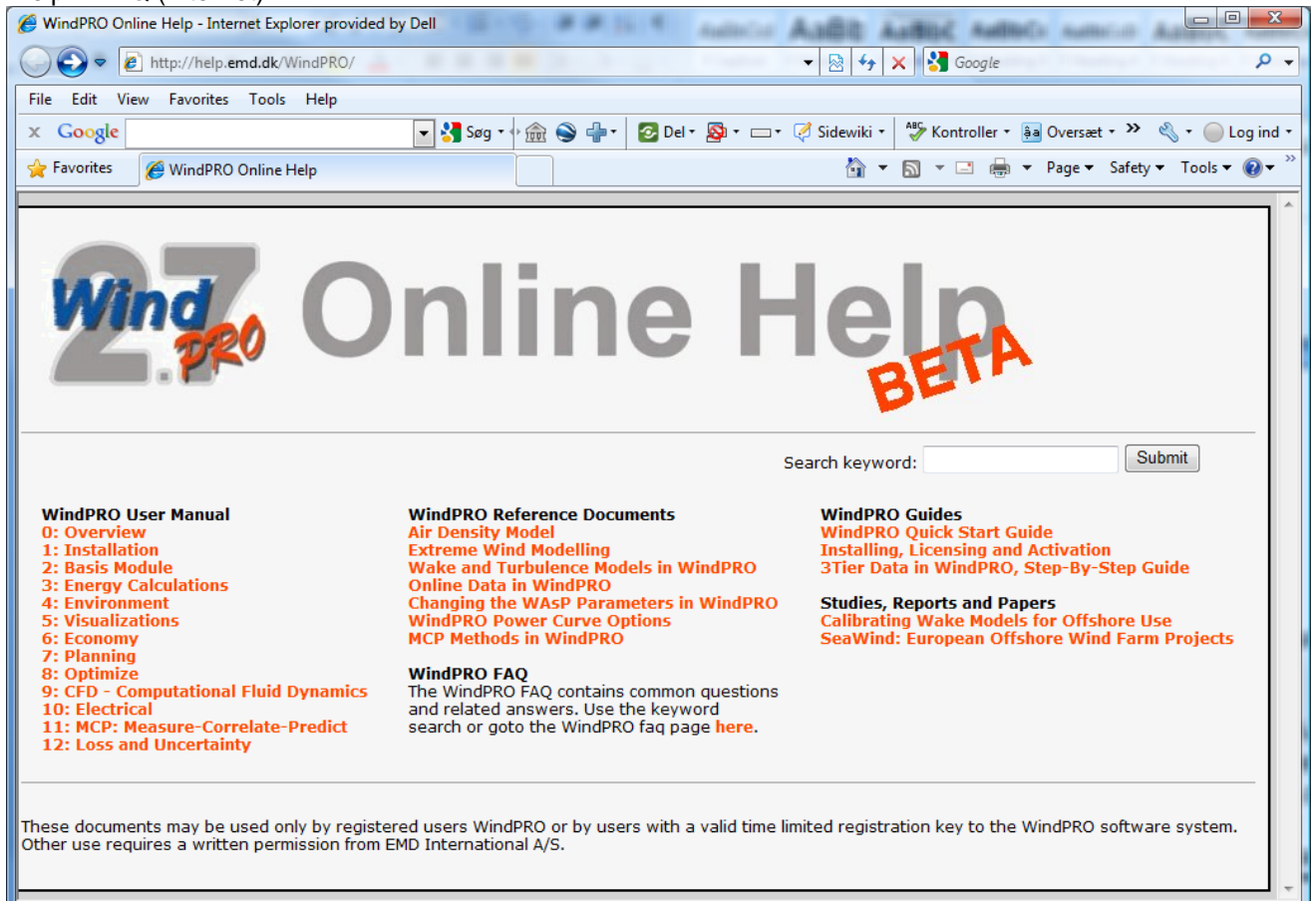
Christchurch, New Zealand

¹ Doubling of energy prediction error based on mean wind speed error is a rough conversion, which holds for wind speeds around 8 m/s. At 6-7 m/s tripling is more right, while only 1.5 factors should be used for 9 m/s, see graph below based on a typical WTG.

3.4.1.4 PARK calculation with “advanced options”



Checking the “Enable advanced options” gives access to several more features described in the following. Before this, we would like to introduce the WindPRO Online help page, where, typically, the more advanced features are frequently updated based on the latest research. The page can be opened from WindPRO menu “Help – FAQ (Internet)”:



Access to advanced calculations:

Advanced calculations:

Reduced wind speeds inside wind farm

Park power curve based on PPV model

Turbulence

These require you to choose another wake model than the default N.O.Jensen model.

The reduced wind speeds inside a wind farm creates a matrix that can be used to lookup the calculated reduction at a specific point, for any direction and any free wind speed. A way to use this is to place a very small turbine (0.1 m rotor diameter) at the position where a measurement mast are inside the wind farm, and thereby get the reduction in wind speed measurements due to surrounding turbines. Then the expected free wind speed can be established, which can be useful for performance check calculations.

Park Power curve based on PPV model gives the calculated Park power output related to a specific measurement mast position outside the park. This can be useful for like prognosis systems, where the wind prognoses are given at a specific point (measurement mast position). With the table the transfer function from wind speed and direction to Park output is given.

Turbulence calculations give the ambient + wake added turbulences for each turbine.

Calculate weibull for +/- ½ rotor diameter, used in result to file

By “report features” there are an additional checkbox. Here you can add calculation results for +/- ½ rotor diameter in the result to file. This makes it easy to evaluate the variation of the calculation results over large rotors. With the present AEP calculation tools, it is always assumed the hub height represents the average for entire rotor diameter. With a large increase in rotor diameters this might require changes in future calculation methods. With this report the user can start performing experiments for evaluation of the importance.

Wake decay constant/turbulence settings:

Open farmland WDC: 0,075 RC: 1,5 TI: 0,15

User defined

Offshore & Water areas WDC: 0,040 RC: 0,0 TI: 0,08

Mixed water and land WDC: 0,052 RC: 0,5 TI: 0,10

Very open farmland WDC: 0,063 RC: 1,0 TI: 0,13

Open farmland WDC: 0,075 RC: 1,5 TI: 0,15

Mixed farmland WDC: 0,083 RC: 2,0 TI: 0,16

Closed farmland WDC: 0,092 RC: 2,5 TI: 0,18

Very closed farmland WDC: 0,100 RC: 3,0 TI: 0,21

More choices are available in the list. For other Wake models than the N .O. Jensen, it is not the Wake decay constant, but the ambient turbulence that is used as input for the wake model. By the “Edit / Load from Meteo” you get access to refine the settings further:

Sector wise Wake decay constant/turbulence parameters

Grey columns are needed parameters for the selected wake model. Ambient turbulence is scaled in height according to description in the WindPRO manual.

Height for turbulence specification [m]

Number of wake sectors

From [deg]	To [deg]	Terrain type and class	Turbulence intensity	Roughness length [m]	Wake decay constant
-180	180	User defined	0,1468	0,055	0,075

Cancel

Sector wise WDC or turbulence can be entered or loaded from meteo data.

When loading ambient turbulence data as input into PARK, where this is required (depending on the array loss and turbulence model combination chosen), it is now possible to specify this data in more detail.

The selected time series + the number of standard deviations typed below, is used as the representative/characteristic turbulence.

Calculate mean turbulence from the following wind speed interval:

From m/s

To m/s

Number of standard deviations, n, to add: n=0: Mean turbulence; n=1.0: IEC 61400-1(ed.2); n=1.28: IEC 61400-1(ed.3):

n

Number of sectors:

The ambient turbulence is loaded from a time series data in a Meteo data object. It is possible to specify the setup, e.g. add one standard deviation to mean turbulence as required in the IEC edition 2 for turbulence calculation, or 1.28 standard deviations for IEC ed. 3 compatible calculations.

Wake model selection:

N.O. Jensen (RISØ/EMD)
No model
N.O. Jensen (RISØ/EMD)
N.O. Jensen (EMD) : 2005
Eddy Viscosity Model (J.F. Ainslie) : 1986
EWTS II (G.C.Larsen) : 1999
EWTS II (G.C.Larsen) : 2008

Regarding wake models, EMD recommends using the N.O. Jensen (RISØ/EMD) model. If you need turbulence calculations, the N.O. Jensen (EMD) 2005 is recommended. The three other models are intended for experimental use. Tests so far indicate that these models do not reduce calculation results enough when using the standard parameters. The parameters will be tuned based upon ongoing research in order to better correlate the predicted values to actual performance.

Turbulence model selection:

S. Frandsen: 1999 - Effective turbulence model
No model (ambient turbulence only)
B.Lange: 2002 - Eddy viscosity turbulence
Danish Recommendation: 1992
G.C.Larsen / EWTS II : 1999
S. Frandsen: 1999 - Effective turbulence model
Quarton/Ainslie: 1989 - Empirical turbulence model
Empirical turbulence - Dutch TNO laboratory : 1993
DIRT: 2004 - Added Turbulence Model

For turbulence calculations, the S. Frandsen 1999 or the TNO model are recommended as the most-accepted ones at this time.

The wake and turbulence models and other advanced functions of the PARK calculation are described in detail in the appendix on Wake and Turbulence Models.

3.4.1.5 Edit WAsP parameters

The WAsP parameters can be modified from this input form:

WAsP parameters
On this form it is possible to change the parameters used in WAsP calculations. When you click "Ok" the settings will be saved to an internal file, which will be used in all WAsP calculations in this project. Any non-default parameters will be highlighted in yellow.

Only for Windows versions of WAsP (DOS versions uses normal *.par file)
 Also for DOS versions. Only a subset, other parameters must be edited in wasp.par

Parameter	Minimum	Maximum	Default	Value
No. of standard heights for atlas file	2	5	5	5
Std. height #1	5	200	10	10
Std. height #2	5	200	25	25
Std. height #3	5	200	50	50
Std. height #4	5	200	100	100
Std. height #5	5	200	200	120
No. of standard roughnesses for atlas file	2	5	4	4
Std. roughness #1	0	2	0	0
Std. roughness #2	0	2	0,03	0,03
Std. roughness #3	0	2	0,1	0,1
Std. roughness #4	0	2	0,4	0,4
Std. roughness #5	0	2	1	2
Width of coastal zone	5000	50000	10000	10000
Depth of daily variation over land	50	100	100	100
Relative amplitude of daily variation near ground	0,01	0,25	0,12	0,12
Average offset over land from neutral at z=p2	0,01	0,25	0,11	0,11
Height of inversion in BZ model	100	5000	1000	1000
Softness of inversion in BZ model	0	1	1	1
Decay length for roughness area size	1000	1000000	10000	10000
True upwind direction in BZ model	0	1	0	F
Azimuth resolution in BZ model [°]	1	15	5	5
Depth of daily variation over water	25	300	50	50
Factor in Height of min. stab. induced var.	0	0,005	0,002	0,002
Rms heatflux over land	0	200	100	100
Rms heatflux over water	0	200	30	30
Offset heatflux over land	-200	200	-40	-40
Offset heatflux over water	-200	200	15	15
Sub-sectors in roughness map analysis	1	9	6	6
Max. number of roughness changes/sector	1	9	7	7
Max. interpolation radius in BZ model	5000	50000	20000	20000

Ok Cancel Set all values to default Import Export

Currently used WAsP parameters: Default WAsP parameter settings
WAsP version: WAsP 6-9 for Windows

For example, a few modifications are made to illustrate where it can be relevant:

Std. Height 5 is changed from 200 to 120m. If your hub height is 110 m, you might be better off using 100m and 120 m than 100m and 200m. The interpolation distance simply becomes smaller.

Std. Roughness #5 is changed from 1 m to 2 m. This could be relevant in a very high roughness region, where you expect above 1 m length (class 3.7), and thereby will avoid extrapolation, which is more uncertain than interpolation.

Finally, the heat flux parameters could be relevant to change in very hot areas (deserts), or if you want to force water stability conditions, you can simply set the water parameters for land.

Add "simple reduction" with text: Result - 10,0 %

Calculate weibull for +/- 1/2 rotor diameter, used in result to file

Advanced Settings: [View WindPRO Documentation: WAsP Parameters](#) **Edit WAsP parameters**

Wake model: N.O. Jensen (EMD) : 2005 Edit model parameters

Turbulence model: S. Frandsen: 1999 - Effective turbulence model Edit model parameters

Remark: if WAsP parameters are changed from defaults, the button becomes yellow. When you are in other parts of the software, like in meteo object, profile viewer, where you also have access to WAsP parameters, the button here will also be yellow. This reminds you that you are working with the modified WAsP parameters.

It is, of course, important that the modified WAsP parameters BOTH are used when generating the wind statistics AND in the AEP calculation. (Going up/down with WAsP with same parameters). It will typically be in the meteo object or the MeteoAnalyser experiments for “fixing” the WAsP parameters that will be performed.

3.4.2 Calculation Energy: METEO (Energy, one site)

In order to perform an energy calculation, you need a Meteo Object with purpose checked in under B or F, see description from METEO object below.

The Purpose setting helps you avoid seeing irrelevant data in other places within the model. This is done by selecting the appropriate boxes.

Height	A	B	C	D	E	F	G
80,0m - A	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
60,0m - B	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
30,0m - C	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
80,0m - D	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

Legend

- A) Long term data for STATGEN (creation of wind statistics)
- B) Long term data for "direct" Energy calculation (no MODEL involved for horizontal extrapolation)
- C) Long term / reference data for MCP ("reference" in long term correction)
- D) Short term data for MCP ("local data" in long term correction)
- E) Short term data for STATGEN ("special purpose" like follow up, temporary calculations etc.)
- F) Short term data for "direct" Energy calculation (no MODEL - "special purpose")
- G) Data for meteo analyzer (for substituting (patching) data in other METEO objects)

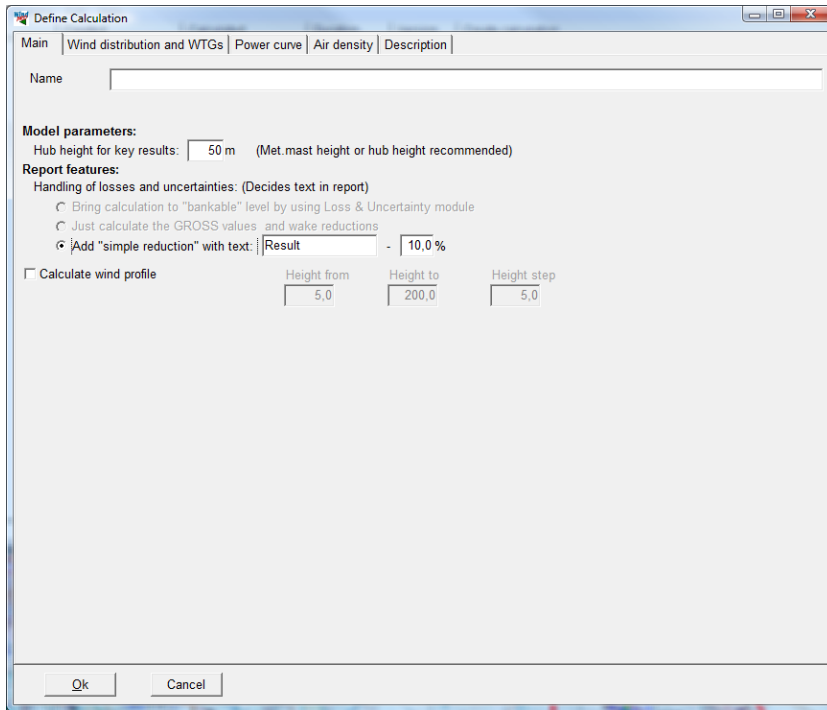
The METEO calculation is for calculation of AEP for one turbine, based on the data in a Meteo object. Data can be represented as a Time series, a TABLE (histogram) or a WEIBULL distribution. All can be manual entered in meteo object (or imported). When Time series are imported, Table and Weibull data are automatically created.

Thereby, the calculation can among other purposes be used for investigation of the difference using the time series, the “raw” table data or the “smoothed” Weibull data.

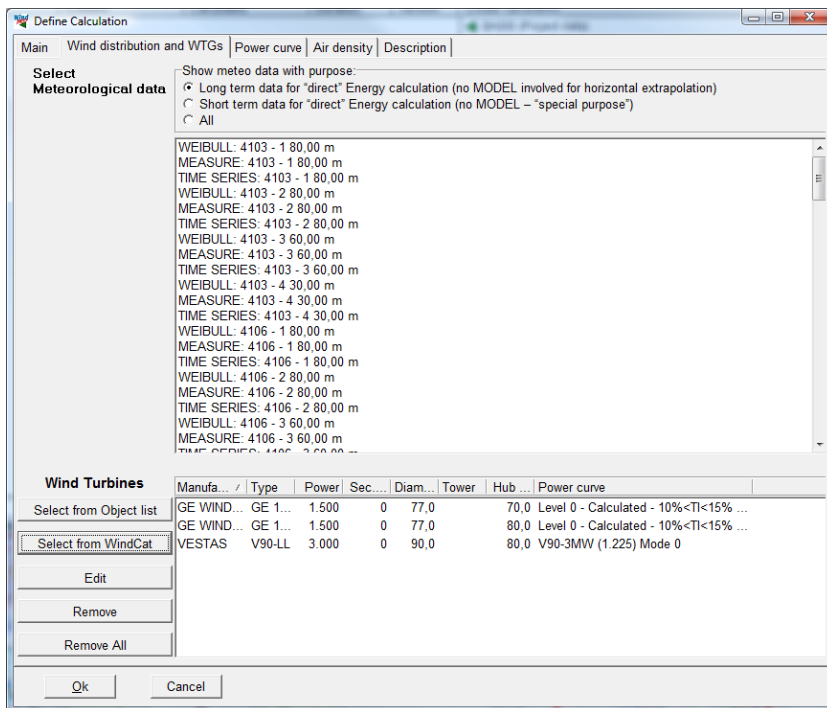
It can also be used for very simple calculations, e.g. just enter a mean wind speed into a meteo object (Weibull sheet) and a $k=2$, and you have the input for a simple calculation.

The METEO calculation can be used for comparing the expected AEP for a number of different turbines based on the same wind conditions.

Finally, a wind profile based on simple shear assumptions can be calculated.



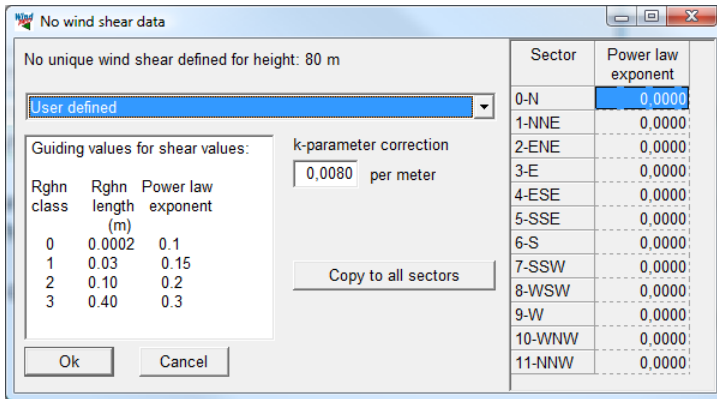
At the Main tab, the wind profile specification can be set up. Other inputs are explained in the previous chapter 3.4.1.



On the Wind distribution and WTGs tab, the wind data to be used is selected. By choosing the WEIBULL version, the data are smoothed by the best Weibull fit, while the MEASURE version takes the histogram (binned data) established from the raw data (or entered direct in the Meteo object). Choosing time series will use the very raw data.

The turbines can be selected from the turbine catalogue, and you can, in one operation, load all that are represented in the project by loading from the object list.

The tabs power curve and Air density are explained in previous chapter 3.4.1.



If no wind gradient exponent is specified in the Meteo Object, you are asked to specify when launching a calculation, if the calculation height differs from the wind speed height. Similarly, if there are more sets of wind shear defined in the meteo object, you can choose between those from the drop down menu.

After calculation:

Valid	Manufact.	Type-gen	Power, rated	Rotor diameter	Hub height	Total	Regional	Equivalent	Mean wind	HP-value	Air density	Displacement
			[kW]	[m]	[m] (Water)	[MWh]			[m/s]	[%]	[kg/m ³]	[m]
Yes	GE WIND	GE 1.5sle-	1.500	77	70	3.772,80	1		6,58	97	1,028	0
Yes	GE WIND	GE 1.5sle-	1.500	77	80	3.770,60	1		6,58	97	1,027	0
Yes	VESTAS	V90-LL-3.0	3.000	90	80	6.162,60	1		6,58	96	1,027	0

With the “result to file” option, results can be pasted to Excel for further processing.

3.4.3 Calculation Energy: MODEL

Calculations with WindPRO module MODEL involves a calculation model.

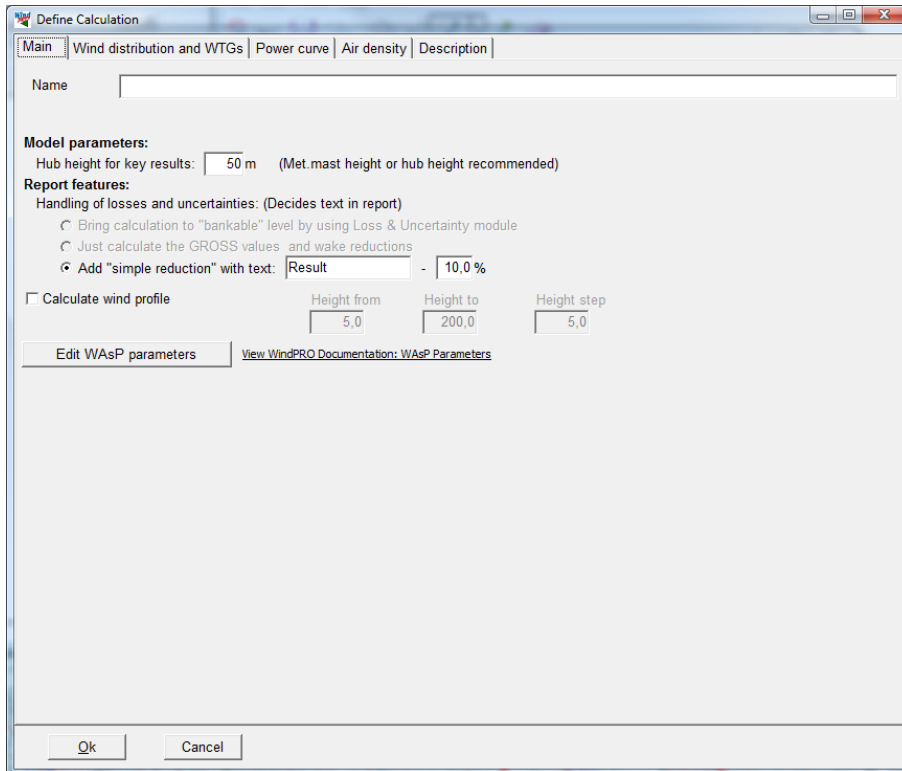
There are 4 different sub calculation modules, all included when purchasing MODEL that will be described roughly in this chapter - most of the features are similar to the ones explained under PARK, 3.4.1. For the first two described, WASP interface and ATLAS, the purpose setting in site data object decides which will be available.

3.4.3.1 WASP interface

The WASP interface calculation can be used for comparing the expected AEP for a number of different turbines based on the same wind conditions, i.e. it is assumed the turbine is located where the site data object selected in the calculation is positioned.

The WASP interface “operates” the WASP model – it is thereby the WASP model that calculates the wind distribution based on terrain and wind statistic. The wind distribution calculated by WASP model is then taken over by WindPRO that do the power curve and air density post processing work.

Finally a wind profile based on simple shear assumptions can be calculated.



At the Main tab, the wind profile specification can be set up. Other inputs and the Power curve and Air density tab are explained in chapter 3.4.1. The tab “Wind distributions and WTGs” are explained in previous chapter 3.4.2, just with the difference that, here, site data objects must be selected giving the wind distribution, not Meteo objects.

3.4.3.2 ATLAS

The ATLAS calculation is basically operated as the WAsP interface calculation (see previous chapter). It just does not require a WAsP license, but the model is far simpler and therefore not recommended for large scale projects.

3.4.3.3 RESOURCE

The RESOURCE calculation is documented in separate chapter 3.6.

3.4.3.4 CFD PRE/POST

The CFD PRE/POST is a “light” module for handling the most needed interfacing to CFD calculation models. Basically, it can export a data package the CFD model operator can use as input, and it can compare results as wind resource maps, e.g. compare to WAsP calculation. This part is described separately in in Chapter 9, but it must be noted that WindPRO CFD relations are under reconstruction and not all described in Chapter 9 is presently active.

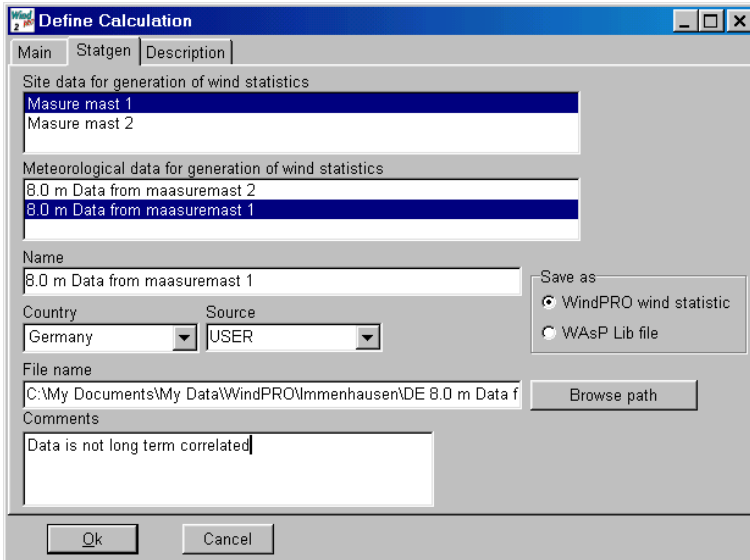
3.4.4 Calculation Energy: STATGEN (Wind Statistics / Wind Atlas)

Generation of a Wind Statistics requires the following:

- Measured wind data (inserted in a Meteo Object, where “For use in STATGEN” is selected)
- A terrain description (inserted in a Terrain Data Object where “For use in STATGEN” is selected)
- The program WAsP from RISØ, installed on the hard disk

The terrain description must be accurately performed, centered at the location of the measurement tower. It will be centered at the measurement tower automatically if the Line Object containing the roughness lines is set to “linked to Site data in energy calculations”. In this case, the position of the Meteo Object determines the position of the roughness rose.

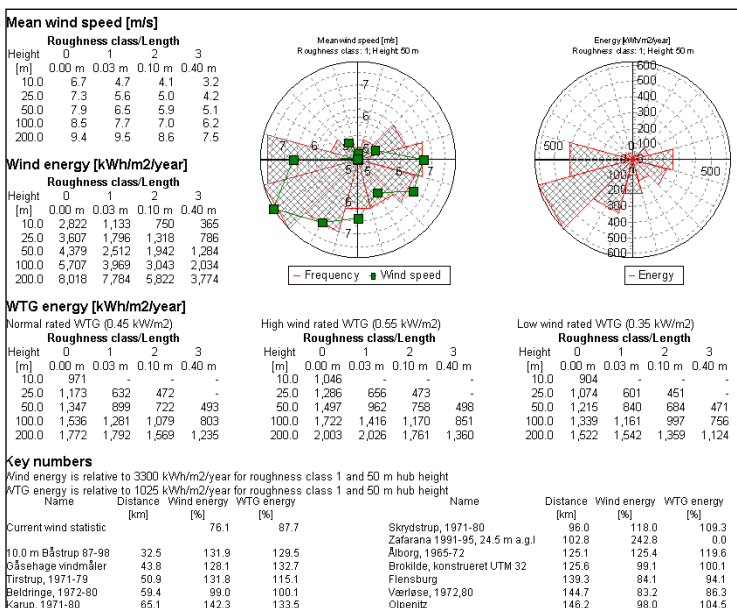
When the data for the two objects have been entered, you click on the calculation menu and select STATGEN.



When the appropriate combination of available objects has been selected, clicking on the “OK” button will start a WAsP-calculation. The Wind Statistics will be saved according to the specifications given in the window shown above.

NOTE: You can save the results as either a WindPRO Wind Statistic, which is an internal binary format, or in an ASCII WAsP format. In both cases, coordinates will be saved in the .lib file as a part of the header, which WindPRO can read for correct geographic presentation of the Wind Statistics. The internal WindPRO format has additional features. A comment text field can be saved together with the Wind Statistic. A regional correction factor can also be included.

Once the calculation has finished, you can generate a report, and the Wind Statistics can be evaluated (see below).



NOTE: Both the total wind energy content and the turbine energy level are calculated. The latter is “filtered” with a power curve. A list shows comparison with the nearest Wind Statistics in the current search profile for Wind Statistics.

The Wind Statistics are saved as specified in the calculation settings and can then be used for calculations in projects within the region. (See the WAsP manual for further details on generation of Wind Statistics).

Before using the Wind Statistic(s), it's necessary to set the Site Data Object to “for use in WAsP” (or ATLAS) and then select the generated Wind Statistic(s) when launching the calculation.

3.4.5 Wind index correction level conversion to wind speed

In WindPRO wind statistics, it is possible to include a correction factor that is applied to the calculated energy calculation (energy correction).

This works well as long as any adjustment of the wind statistic is only around the wind speed that was the basis for the creation of the correction factor. If it is, for example, created using data based on smaller reference turbines and then subsequently applied to much taller turbines (with a significantly higher average wind speed), the method can create an unintended bias, while the conversion “factor” from wind speed to AEP changes with adjusted mean wind speed.

We have, therefore, developed a modified conversion method, which changes the energy correction factor to a wind speed correction in the wind statistic. This has an additional advantage in that the calculated mean wind speed which is based on the wind statistic will be more accurately adjusted and the Weibull A-parameter in, for example, the “Result to file” export from the PARK module will now be correct.

In previous versions of WindPRO, the use of a wind statistic with an energy correction factor applied has resulted in a simplified conversion of the mean wind speed in the reports, but the Weibull A parameter was not corrected.

The existing method using an energy correction factor will still be available in v2.6 but the plan is to remove this from v2.7.

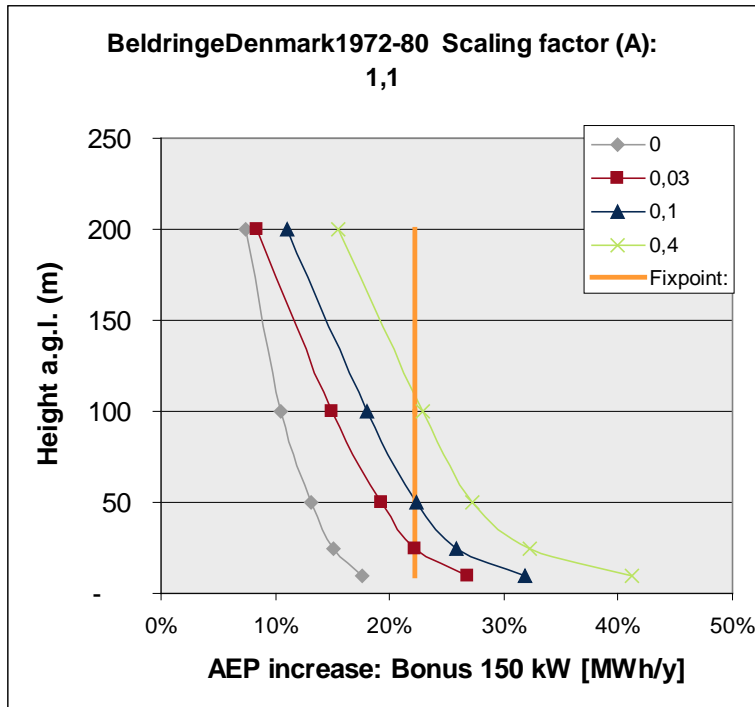


Figure 39 An illustration of the energy scaling compared to wind speed scaling. With energy scaling, the correction on AEP in any calculation will be as shown with the “fixpoint” line, here approximately 22%. With wind speed scaling, the AEP correction will be the same for the fixpoint, that was basis for the creation, here 25m hub, roughness length 0.03m (Rcl. 1) and a Bonus 150 kW turbine – but used for a 100 m hub height, for example, roughness length 0.03m (Rcl. 1) and the same power curve, the AEP correction will now be approximately 15%.

For v2.6, there will be three possible conversion situations as described in the following:

3.4.5.1 From MCP calculations

This is the simplest conversionsince the software will have information on power curve as well as mean wind speed used for creation of the correction factor.

The Index correction method in the MCP module produces a correction factor, which is supposed to be valid for the specific type of turbine and mean wind speed selected in the calculation setup. That information is used when the index correction factor is converted to a wind speed correction factor. In this way we ensure the correct wind speed correction factor in the wind statistic.

Compared to v2.5 this means that a correction factor is no longer applied to the final production. Instead a correction factor is applied to a wind statistic based on the original local time series.

Tests have ensured that the results are very close to the original v2.5 method. If, however, one wants to calculate exactly as the v2.5 method, one performs the Index correction as normal and in the calculation report or when saving the wind statistic notes down the correction factor. Then a regular Statgen is performed on the original local data and in the Site data object for WAsP calculation the wind statistic is edited with the correction factor (see below). Note that this possibility is supposed to disappear in v2.7.

3.4.5.2 Older or manual adjusted

In this situation we do not know the basis for the creation, and offer the user a tool for manually entering the adjustment.

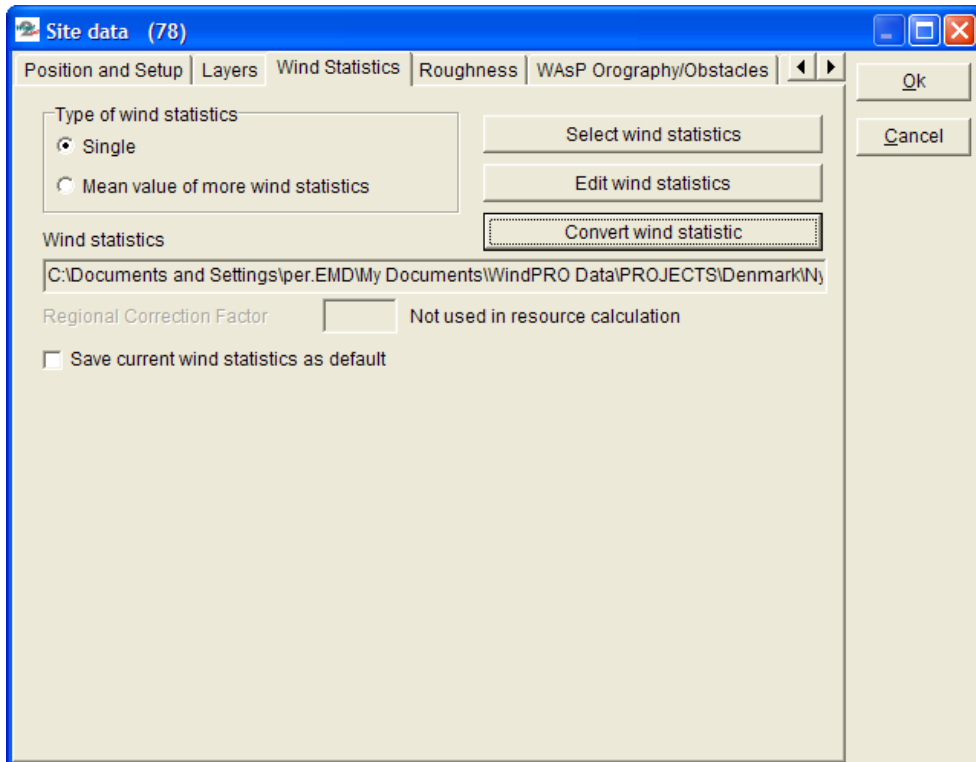


Figure 40 Choosing “Convert wind statistic” from a site data object gives the dialogue shown in Figure below.

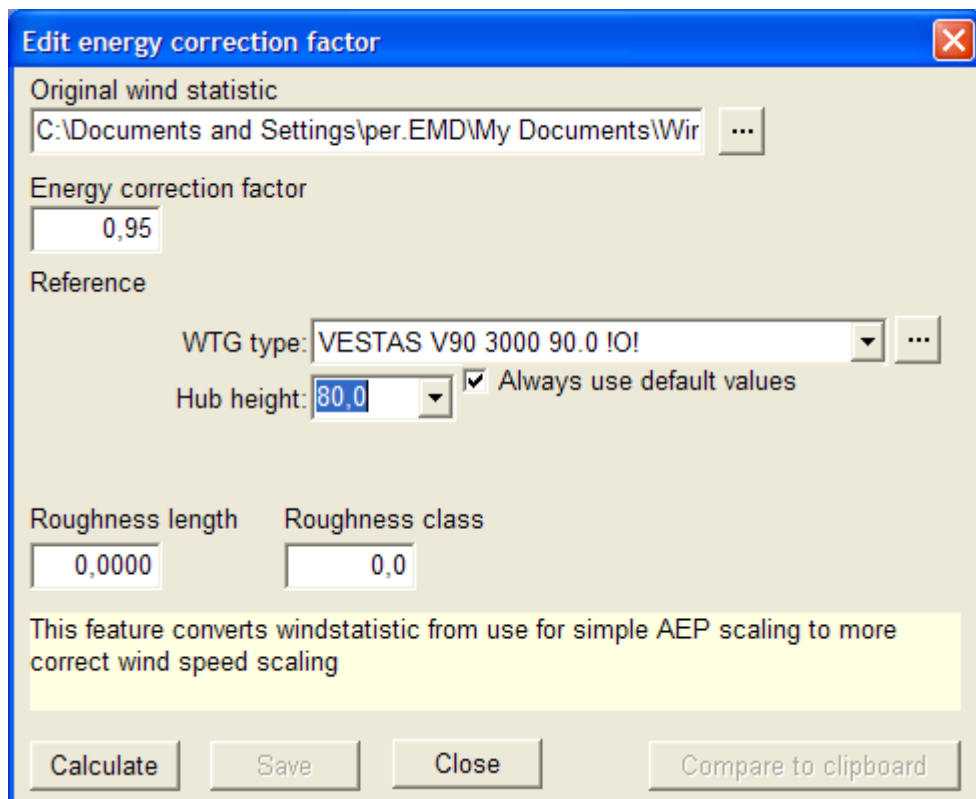


Figure 41 A wind statistics with energy correction factor can be loaded and converted to wind speed correction based on a specific power curve, hub height and roughness.

With “Compare to clipboard” the original and converted data can be pasted to excel so the changes can be evaluated.

3.4.5.3 Danish “regional corrections” DK’92

For calculations in Denmark, WindPRO has used a regional correction factor applied to the Wind statistic DK’92 automatically based on individual WTG positions.

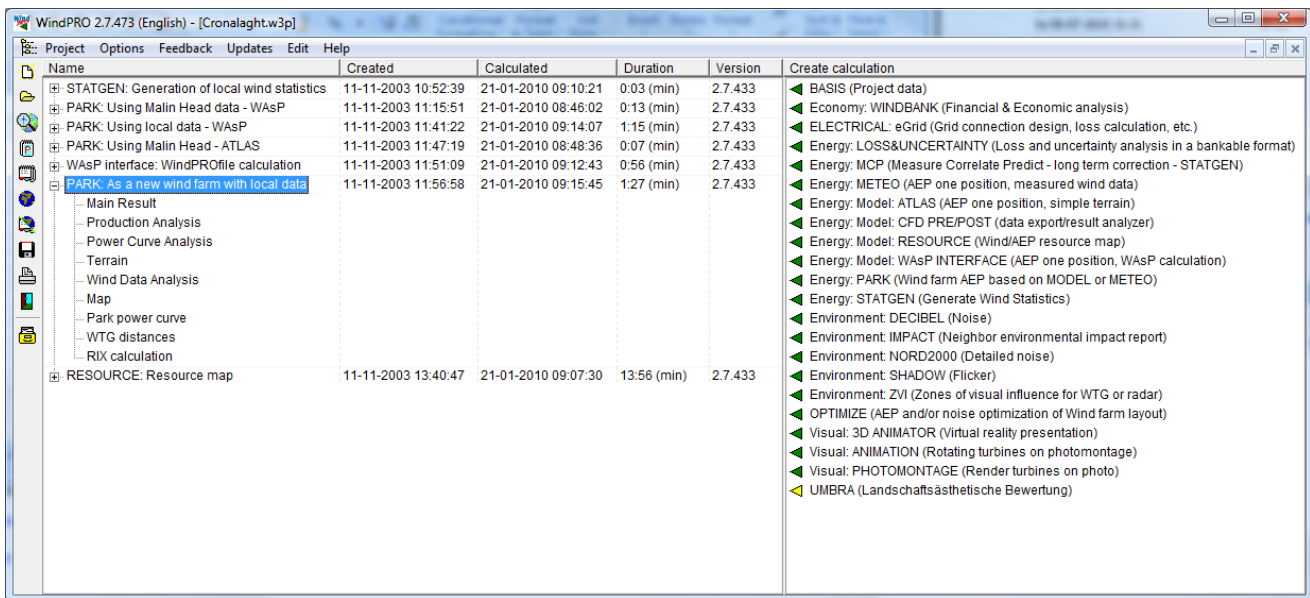
This wind statistic has two problems:

1. It assumes a standard air density, whereas WindPRO now calculates a default site specific air density, giving 2-3% higher results;
2. It does not take into account the adjusted long time wind energy level (7-8% in 2006). Therefore, with an automatically calculated air density, the result of a calculation will be approximately 10% too high. It can be even more optimistic if the new turbines are tall or placed in high wind areas due to the previously described built-in bias in the energy correction factor.

We, therefore, are working on a new wind statistic compensating for all bias. This work will not be finalized for the v2.6 release, but should be available in v2.7.

3.4.6 Printing and reading reports

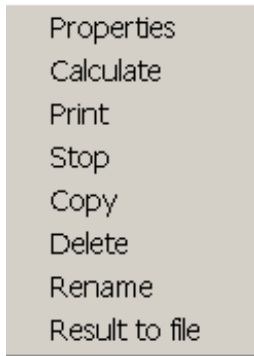
3.4.6.1 Printing



When the calculation has finished, the window shown above will appear, listing the available reports that can be printed.

There will be info columns telling when a calculation was created, last calculated, the duration and with which version.

A sub-level report will automatically pop up on the screen if you double-click on a sub-level report name. The sub-level report has its own right-click options. When you right-click on the calculation header or on one of the calculation reports, you gain access to the following features:



Properties - Edit calculation setup for recalculating (or view calculation setup).

Calculate - Recalculate (e.g. if positions of WTG have changed, but the calculation setup is unaltered).

Print - Show the print options with the possibility of making changes (e.g. map scaling).

Stop - To stop a running calculation.

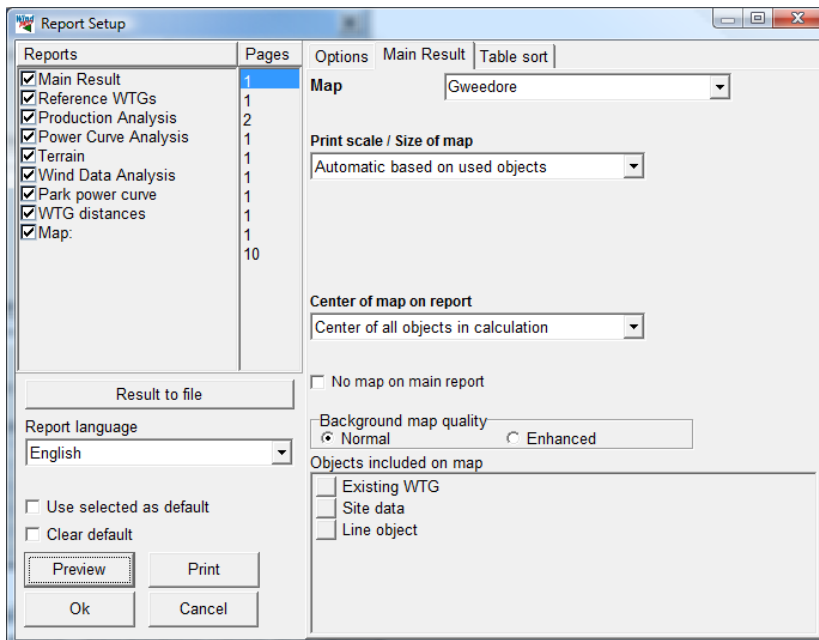
Copy - Make a copy of the calculation. This is useful if a calculation, based on changed object information, is required with the present calculation setup without overwriting the former calculation.

Delete: Removes the actual calculation report.

Rename: For changing the calculation name, description, and uncertainty reduction percentage without recalculating

Result to file: Makes it possible to save results to a file or copy to clipboard.

From the “Print” option, the following screen will appear:



There are a number of options available for changing printouts. When you select a report, the right half of the screen offers you different setup options, depending upon the report.

NOTE: The object settings (label size etc.) can only be changed when the “Map” report is selected.

For more details on printing reports, see Chapter 2, BASIS.

3.4.6.2 Reading reports from Energy calculations

Examples of reports are given in Chapter 1. Below, a few samples from reports will be shown and some of the key figures will be explained. New in version 2.5, you can print calculated wind profiles for each wind direction sector (only from WAsP Interface calculation).

Wake Model		N.O. Jensen (RISØ/EMD)	
Calculation Settings			
Air density calculation mode	Fixed for all WTGs (Based on Std. Atmosphere Model)		
Result for site center elevation+key height	1,225 kg/m ³		
Air density relative to standard	100,0 %		
Hub altitude above sea level (asl)	0,0 m		
Annual mean temperature at hub alt.	15,0 °C		
Wake Model Parameters			
From angle	To angle	Terrain type	Wake Decay Constant
[°]	[°]		
-180,0	180,0	Open farmland	0,075
Wake calculation settings			
Angle [°]		Wind speed [m/s]	
start	end	step	start
end	step	start	end
0,5	360,0	1,0	0,5
			30,5
			1,0
Wind statistics		IE Malin Head, 1970-79.wws	
WAsP version		WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13	
WAsP parameters		Non-default WAsP parameters - detailed information at the end of "Main results"	

The assumptions for the energy calculation concerning the Wind Statistic(s) chosen, air density, wake decay constant and WAsP version, are shown above.

Key results for height 50,0 m above ground level								
Terrain	IG	East	North	Name of wind distribution	Type	Wind energy [kWh/m ²]	Mean wind speed [m/s]	Equivalent roughness
A	186.373	424.102	Malin Head	WAsP (WAsP 6-9 for Windows RVEA0011 1, 0, 0, 13)		9.152	9,9	0,2

Key results are based on the position where the Site Data Object is placed and the hub height specified in the calculation setup.

Equivalent roughness is the roughness class in flat terrain with no obstacles that would give the same calculated energy production. This can vary with the chosen hub height for key results if there are obstacles or orography, while the reduction/speed up from obstacles/orography varies with height.

Calculated Annual Energy for Wind Farm												
WTG combination	Result PARK [MWh/y]	Result-10,0% [MWh]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results ^{a)}			Full load hours [Hours/year]	Mean wind speed @hub height [m/s]			
					Capacity factor [%]	Mean WTG result [MWh/y]	Mean wind speed					
Wind farm	20.405,2	18.364,7	21.049,2	96,9	42,1	2.295,6	3.688	9,6				
^{a)} Based on Result-10,0%												
Calculated Annual Energy for each of 8 new WTGs with total 5,0 MW rated power												
Terrain	WTG type			Power, rated	Rotor diameter	Hub height	Power curve		Annual Energy		Park Efficiency	Mean wind speed
	Valid	Manufact.	Type-generator				Creator	Name	Result	Result-10,0%		
				[kW]	[m]	[m]			[MWh]	[MWh]	[%]	[m/s]
1 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufacturer 05-03-2000 1.225 30.00 0.00	2.369,2	2.132	97,1	9,69
2 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufacturer 05-03-2000 1.225 30.00 0.00	2.407,5	2.167	95,8	9,89
3 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufacturer 05-03-2000 1.225 30.00 0.00	2.479,9	2.232	95,8	10,10
4 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufacturer 05-03-2000 1.225 30.00 0.00	2.275,2	2.048	97,7	9,36
5 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufacturer 05-03-2000 1.225 30.00 0.00	2.230,3	2.007	98,0	9,22
6 A	Yes	VESTAS	V47-660	660	47,0	40,0	EMD	Level 0 - calculated - - 07-2001	2.867,2	2.580	97,3	9,39
7 A	Yes	VESTAS	V47-660	660	47,0	40,0	EMD	Level 0 - calculated - - 07-2001	2.848,4	2.564	97,1	9,32
8 A	Yes	VESTAS	V47-660	660	47,0	40,0	EMD	Level 0 - calculated - - 07-2001	2.927,4	2.635	96,8	9,56

In the report sample shown above, it must be noticed that the specific results all are deducted, here with 10% covering expected losses and uncertainty. The wind speeds shown are free wind speeds (no wake reduction). The column with the deduction of xx% is controlled by the user when setting up the calculation. Wind farm efficiency is a measure of how much each single turbine produces, taking the wake losses into account relative to the gross production.

Capacity factor is the percentage of hours in a year that the WTGs would need to operate at rated capacity, to obtain the same production as calculated.

For example: A 600 kW WTG is estimated to produce 2,643 MWh/year. Dividing the annual production by WTG's rated capacity of 600 kW: 2,643,000 kWh / 600kW = 4,405 hours. Since there are 8,760 hours in a year, 4,405 / 8,760 yields a capacity factor of 50.3%.

Calculated Annual Energy for each of 5 reference WTGs with total 3,0 MW rated power												
Terrain	WTG type			Power, rated	Rotor diameter	Hub height	Power curve		Calculated prod. without new WTGs [MWh]	Actual wind corrected energy [MWh]	Goodness Factor	
	Valid	Manufact.	Type-generator				Creator	Name				Efficiency
1 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufacturer 05-03-2000 1.225 30.00 0.00	2.384,5	2.383,0	100	
2 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufacturer 05-03-2000 1.225 30.00 0.00	2.455,5	2.501,0	102	
3 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufacturer 05-03-2000 1.225 30.00 0.00	2.546,0	2.632,0	103	
4 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufacturer 05-03-2000 1.225 30.00 0.00	2.300,4	2.346,0	102	
5 A	No	VESTAS	V39-600	600	39,0	40,5	User	Manufacturer 05-03-2000 1.225 30.00 0.00	2.242,9	2.321,0	103	

When using existing WTGs in a calculation, WindPRO provides a report called "Control WTGs", where the calculated yield is compared to the actual yield that is entered in the "Statistics tab sheet" in the Existing WTG Object. The "Goodness Factor" in the right-most column is described below.

Goodness factor = Actual yield (long term corrected) / calculated yield

Where the actual yield is assumed to be corrected to long-term conditions by the wind index method, and the calculated yield is based on wind data that is parallel to WTG operation. In both cases, a Goodness Factor of 100% indicates that there is an exact match between the predicted and actual production. If the Goodness Factor is less than 100%, e.g. 90%, then the actual WTG production is 10% less than predicted. This may be due not only to an inaccurate calculation. It could also be due to grid losses and availability. For this reason, the actual yield entered in existing WTG Data Object should be corrected for losses and availability.

PARK - Production Analysis

Calculation: PN-test - WAsPWTG: All existing WTGs, Air density: 1,225 kg/m³

Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	379,1	158,6	171,0	500,9	1.050,8	1.164,1	1.062,3	769,0	1.025,2	1.351,7	956,8	496,7	9.086,3
+Increase due to hills	[MWh]	122,9	44,9	66,6	191,1	304,2	414,0	329,6	206,5	256,0	434,4	422,8	267,4	3.060,3
-Decrease due to array losses	[MWh]	8,3	7,1	3,2	1,0	30,2	40,1	21,5	28,4	12,2	2,0	38,1	25,5	217,5
Resulting energy	[MWh]	493,7	196,4	234,4	691,1	1.324,8	1.538,0	1.370,5	947,1	1.269,0	1.784,1	1.341,4	738,7	11.929,2
Specific energy	[kWh/m²]													1.997
Specific energy	[kWh/kW]													3.976
Increase due to hills	[%]	32,4	28,3	38,9	38,2	29,0	35,6	31,0	26,9	25,0	32,1	44,2	53,8	33,68
Decrease due to array losses	[%]	1,7	3,5	1,4	0,1	2,2	2,5	1,5	2,9	1,0	0,1	2,8	3,3	1,79
Utilization	[%]	25,5	29,2	27,5	21,9	16,3	19,2	24,0	28,1	25,8	21,4	19,8	23,3	21,7
Operational	[Hours/year]	348	226	307	527	658	840	826	696	739	885	767	526	7.346
Full Load Equivalent	[Hours/year]	165	65	78	230	442	513	457	316	423	595	447	246	3.976

In the "Production Analysis" report, the results of the energy calculations for any or all WTGs (new, existing, or individual WTG) can be printed for further analyses. In the figure above, the directional calculation data is shown. The changes due to orography, obstacles, and array losses are provided in absolute figures as well as percentages. This can help to give you a sense for the importance of the different modeling elements and lead you to ideas for optimizing the layout.

The last three lines from the printout shown above are explained below:

Utilization – The percentage of the total wind energy in the available swept-rotor area that is utilized. For high-wind sites, this figure will be much lower than for low-wind sites. The figure does not directly indicate the quality of the site, but may be more useful for comparing different WTG types on a specific site.

Operational – The number of hours per year that the WTG will operate with the given power curve and wind data. The maximum will be 8,760 hours (total number of hours in a year). For example, The information can be used in flicker calculations.

Full Load Equivalent – The number of hours required to produce the calculated energy if the WTG(s) are operating at rated capacity.

NOTE: If the report is printed for a specific WTG, in addition, the Weibull A, k and frequency parameters will be shown for each direction.

PARK - Power Curve Analysis

Calculation: Using Local Wind data - WAsP WTG: 6 - VESTAS V47 660 47.0 IOI Manufacturer 24/8-2000 1.225 25.00 0.00, H

Name: Manufacturer 24/8-2000 1.225 25.00 0.00	
Source: Manufacturer 24/8-2000	
Created by Stop wind speed Power control CT curve type	
EMD	Pitch User defined
25.0	
HP curve comparison	
Vmean	[m/s] 5 6 7 8 9 10 10.2 (Current site)
HP value	[MWh] 855 1,368 1,876 2,350 2,781 0 0
VESTAS V47 660 47.0 IOI hub: 40.0 m	[MWh] 848 1,362 1,885 2,371 2,795 3,143 3,214
Check value	[%] 1 0 0 -1 -1
Power curve	
Original data from Windcat, Air density: 1.225 kg/m3	
Wind speed	Power Ce Wind speed Ct curve
[m/s]	[kW] [m/s]
3.0	0.0 0.00 3.0 0.00
4.0	3.0 0.04 4.0 0.92
5.0	44.0 0.33 5.0 0.89
6.0	97.0 0.42 6.0 0.88
7.0	166.0 0.46 7.0 0.88
8.0	252.0 0.46 8.0 0.83
9.0	350.0 0.45 9.0 0.81
10.0	450.0 0.42 10.0 0.75
11.0	538.0 0.38 11.0 0.66
12.0	600.0 0.33 12.0 0.57
13.0	635.0 0.27 13.0 0.40
14.0	651.0 0.23 14.0 0.31
15.0	657.0 0.19 15.0 0.24
16.0	659.0 0.15 16.0 0.20
17.0	660.0 0.13 17.0 0.17
18.0	660.0 0.11 18.0 0.14
Power, Efficiency and energy vs. wind speed	
Data used in calculation, Air density: 1.203 kg/m3	
Wind speed	Power Ce Interval Energy Acc. Energy Relative
[m/s]	[kW] [m/s] [MWh] [MWh] [%]
1.0	0.0 0.00 0.50-1.50 0.0 0.0 0.0
2.0	0.0 0.00 1.50-2.50 0.0 0.0 0.0
3.0	0.0 0.00 2.50-3.50 0.3 0.3 0.0
4.0	2.9 0.04 3.50-4.50 5.6 5.9 0.2
5.0	43.2 0.33 4.50-5.50 24.8 30.7 1.0
6.0	95.3 0.42 5.50-6.50 60.5 91.2 2.9
7.0	163.0 0.46 6.50-7.50 111.1 202.3 6.4
8.0	247.5 0.46 7.50-8.50 173.7 376.0 11.9
9.0	343.7 0.45 8.50-9.50 239.3 615.3 19.4
10.0	442.1 0.42 9.50-10.50 295.2 910.6 28.8
11.0	529.9 0.38 10.50-11.50 328.7 1,239.3 39.2
12.0	592.5 0.33 11.50-12.50 333.0 1,572.3 49.7
13.0	628.6 0.27 12.50-13.50 311.8 1,884.1 59.5
14.0	646.1 0.23 13.50-14.50 274.9 2,159.0 68.2
15.0	653.7 0.19 14.50-15.50 232.3 2,391.3 75.6
16.0	657.3 0.15 15.50-16.50 190.3 2,581.6 81.6

The Power Curve Analysis can be printed for each WTG in the calculation. The columns on the left side show the original power curve, including the Ct curve (for array loss calculation). The columns on the right side

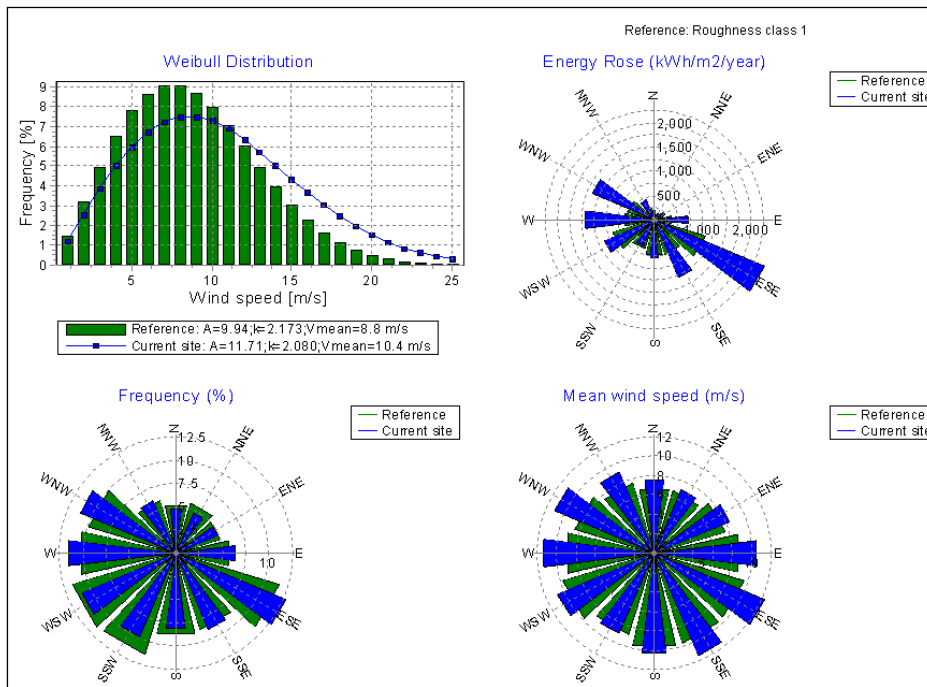
show the power curve converted to actual air density conditions (the one used in calculations). The calculated energy (for a specific site) divided into wind speed bins, and accumulated energy are also shown. This indicates what percent of the total calculated energy production is produced at wind speeds below 5.5 m/s (in this case, 1%).

The HP curve comparison in the printout indicates what the WTG would produce at different mean wind speeds, calculated based on a normalized power curve. This can often be a better estimate than a measured power curve, since a power curve measurement involves considerable uncertainty. When no HP values are shown, as in the example above (Current site), the HP lookup table does not have information for this extreme wind speed region (or for some WTGs with extreme specific power (kW/m² rotor area), no information is available). The HP values are based on a study of several power curves grouped into specific power. The sub-groups are:

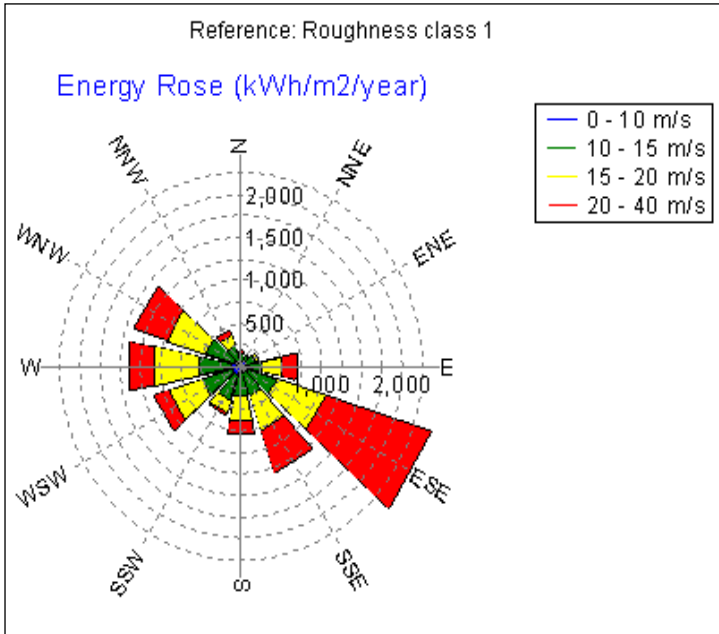
- Stall regulation with 1 generator and 1 speed
- Stall regulation with 2 generators or variable speed
- Pitch regulation (2 generators or variable speed assumed)

(See also Section 3.5.2).

NOTE: If a noise-reduced version of a power curve is used, the HP check should be performed on a non-reduced power curve, since the noise-reduced curve will always produce higher positive check values.



In the printouts, wind data can be compared with a reference, which is associated with flat terrain and a roughness class of 1. This reference is chosen because it is the best onshore condition, and, thereby, the effects of a coastline near the site, or a hilly site, etc. can be clearly seen. In the example above, the site benefits greatly from the local orography in most sectors, and they all result in much more energy than a flat roughness class 1 site.



As an alternative to a comparison with a flat reference, a more detailed color setup can be made where the roses for energy and frequency are divided into wind speed intervals.

PARK - WTG distances
Calculation: Using Local Wind data - WAsP

WTG distances

Z	Nearest WTG	Z	Horizontal distance	Distance in rotor diameters
[m]	[m]	[m]	[m]	
1 326	5 287		238	6.1
2 333	3 344		218	5.6
3 344	2 333		218	5.6
4 289	5 287		242	6.2
5 287	1 326		238	6.1
6 296	7 292		219	4.7
7 292	8 306		209	4.4
8 306	7 292		209	4.4

Lastly, this is an example of the WTG distance report. The nearest WTG to each WTG is determined and the distance calculated, and then reported in meters as well as in rotor diameters. In the case of unequal rotor diameters between the two nearest WTGs, the larger rotor diameter is used (which yields the lowest rotor diameter distance).

Report pages on turbulence are described in the wake and turbulence model appendix.

3.4.6.3 Printing data to a file (Results to file)

This option is very useful, especially if the PARK calculation results will be further analyzed. When you click on "Results to file" the following window appears:

The screenshot shows a dialog box titled "Results to file" with a close button in the top right corner. The dialog is organized into six distinct sections, each with a "File name" input field and a set of action buttons:

- Park result:** Includes "Save", "Save as...", and "Copy to clipboard" buttons.
- To XML file:** Includes "Save" and "Save as..." buttons.
- Park result, sector wise:** Includes "Save", "Save as...", and "Copy to clipboard" buttons.
- WTG distances:** Includes "Save", "Save as...", and "Copy to clipboard" buttons.
- Park power curve:** Includes "Save", "Save as...", and "Copy to clipboard" buttons.
- Wake wind speeds from single turbine:** Includes "Save" and "Save as..." buttons.

A "Close" button is positioned at the bottom left of the dialog box.

Results from the Park calculation (all park calculation results) as well as WTG distances and wind speeds inside the wind farm can be printed in a structured format to a file for import in e.g. Excel. The information can also be copied to the clipboard and then be pasted into an Excel or other spreadsheet application.

Park results

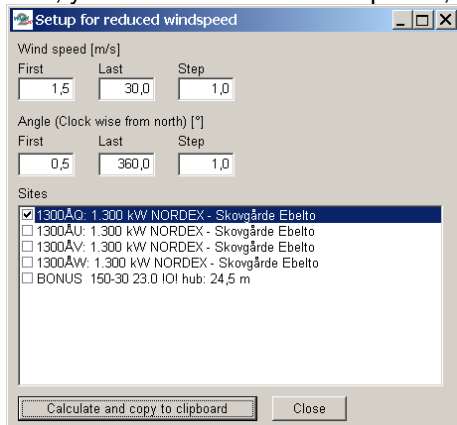
A table with all relevant information from the PARK calculation is very efficient for post processing in spreadsheet. An overview of all information in the file is shown below.

NOTE: The table shown below is a transposed version of the output.

Label	Example	Explanation
WTG num		1 WTG numbered from 1 with lowest system label first
WTG type	New	New or existing
LIB file	ES Munesia-40m1.lib	Windstatistic
East	318.391	Coordinate
North	4.540.176	Coordinate
Z	581	h.a.s.l
Valid	Yes	Refer to power curve
Manufact.	DUMMY	Refer to power curve
Type		Refer to power curve
Power	3.500	Refer to power curve
Diam.	100	Refer to power curve
Height	95	hub height
Row data/Description	126.6°, 200.0 m	If row of WTGs the angle and distance else description field
Creator	USER	Refer to power curve
Name	Constructed based on 3MW experience	Refer to power curve
User label	WTG#1	User label
Result	7.027,10	Calc. result incl park efficiency, no uncertainty withdrawn
Efficiency	97,1	Park efficiency
Regional Correction Factor	1	Refer to wind statistic
Equivalent roughness	2,1	is the roughness class in flat terrain with no obstacles that would give the same calculated energy production
Mean wind speed	6,3	Calculated at hub height
HP result (std. air density)	7.023,00	Calculation result based on HP table lookup instead of "real" power curve
Calculated prod. without new WTGs	0	Calculation of existing WTG without new
Actual wind corrected energy	0	Actual production from "statistics" of existing WTG
Goodness Factor		Actual/calc. for existing WTG
A (Sum)	7	Weibull A-parameter, all sectors
k (Sum)	1,72	Weibull k-parameter, all sectors
A (0)	9,1	Weibull A-parameter, sector 0 (North)
k (0)	1,93	Weibull k-parameter, sector 0 (North)
f (0)	9,3	Frequency, sector 0 (North)
A (1)	5	As above, sector 1
k (1)	1,92	As above, sector 1
f (1)	5,8	As above, sector 1
<i>For all following sectors the same as above</i>		

Wind speeds inside wind farm

First, you can define the wind speeds, angles, and for which sites the data is to be extracted.



You also specify where and in what resolution the data is needed.

Explanation:	Wind speeds - first row the "unreduced" (center value for interval), below in table the reduced										
	UTM ED50 Zone: 32 East: 603066 North: 6225290 1300AQ: 1.300 kW NORDEX - Skovgårde Ebelto										
Directions:	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	
(center of	0,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
direction	30,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
interval)	60,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	90,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	120,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	150,5	1,49	2,49	3,42	4,24	5,17	6,1	7,07	8,04	9,03	10,04
	180,5	1,46	2,44	3,26	3,77	4,33	5,08	5,81	6,64	7,54	8,48
	210,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	240,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	270,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	300,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5
	330,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5

The table shown above contains the extracted data, which can be used for cleaning measurements in a wind farm. This requires some "reverse engineering" in order to do this. The Lookup function in Excel is used for this purpose.

Park power curve, Turbulence inside wind farm, and Wake wind speeds from a single turbine.

These results are discussed in detail in the appendix on wake and turbulence models.

3.5 ENERGY – Losses, Uncertainty, and Checking

3.5.0 Introduction to Losses, Uncertainty, and Checking

To carry out a production calculation by using a modern computer program is a worthwhile exercise. However, since large-scaled investments are usually involved in wind energy projects, it's important that the user of the program be able to check to see whether the results are realistic or not. The many detailed printouts from WindPRO are useful for this purpose.

A detailed loss and uncertainty evaluation has become more and more important the recent years, while the margins for financial feasibility have become smaller. Therefore there is now a separate module in WindPRO for performing this evaluation. We, therefore, highlight some of the more important issues in this chapter and refer to chapter 12 Loss and Uncertainty.

3.5.1 Losses and Uncertainties

3.5.1.1 Losses

Losses must be estimated and deducted from the calculated results. It is highly recommended to use the WindPRO Loss and Uncertainty module (Chapter 12) for this purpose. If this is NOT used, a rough guideline would be to subtract 5-15% from the wake loss calculated AEP, much dependent on site location., Some of the more important losses are reviewed below:

Wake losses – Included in PARK calculation.

Grid – (Can be calculated by the eGRID module in WindPRO). It's important to remember the losses in the built-in transformer in the WTG (for large WTG's), since the power curve is typically measured before the transformer losses. Grid losses will typically be round 2% including the transformer.

Availability – Typically, modern WTGs have availability losses of approximately 3-5%. It is very dependent upon manufacturer guarantees and service/maintenance agreements. In some countries, grid down-time is quite common and losses can be high, but in most industrialized countries, grid availability is normally considered to be 100%.

Blade degradation, icing, and extreme temperatures – This can be a problem in some regions, requiring a more specific analysis.

High-wind hysteresis – If the wind speed is above the shut down speed for WTG (at least once per year), there will be some time before the WTG resumes operation. This is not included in the production calculations and must be deducted manually. From our experience in Denmark, approximately 0.3% of annual production will be lost each time this happens (this is only a rough estimate).

Operation mode losses – Turbines may operate at reduced levels for different reasons such as turbulence (closely-spaced WTGs stopped in certain wind directions), flicker (during hours when the nearest neighbors experience significant flicker) or noise reduced mode (e.g. during night time). At present, the user must account for deductions manually.

Lastly, there may be some bias due to RIX (see chapter [3.4.3.1 RIX calculation](#)) or power curve experience that should be corrected for before the net production figure is obtained

Note: See the detailed loss list in Chapter 12.

3.5.1.2 Uncertainties

As for losses, it must be mentioned that in Chapter 12 a far more comprehensive description is given. But for the users without this module, we maintain the rough guidelines for a simpler calculation here.

The following uncertainties are usually present in a production calculation (figures in brackets indicate estimated uncertainties under good conditions):

- The wind data/ Wind Statistics (5%)
- The long term correction of the wind data (MCP) (5%)
- The model extrapolation (vertical and horizontal) based on Terrain Description, i.e. roughness, hills and obstacles (5%)
- The Power Curve (5% if verified, see Section 5.2)

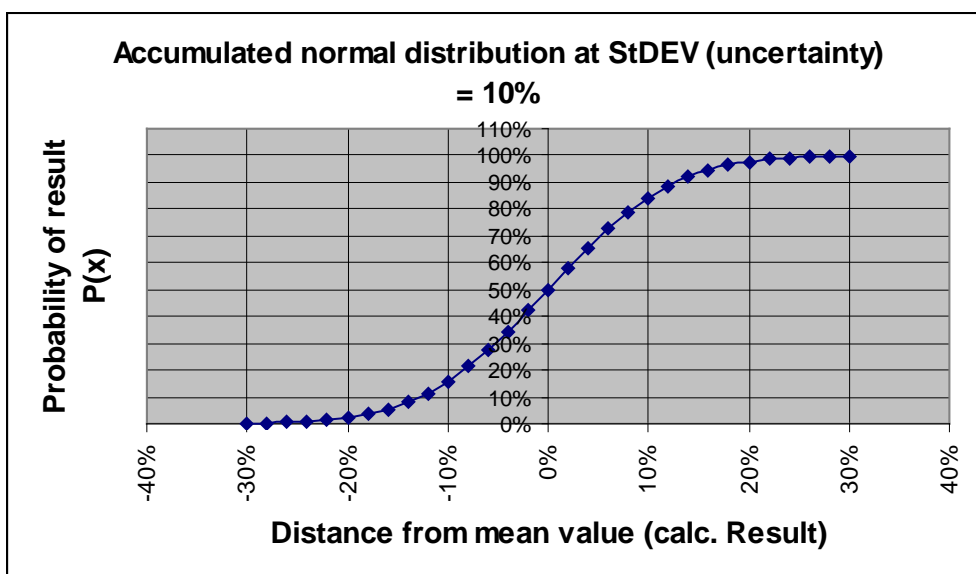
For very large wind farms, an essential extra contribution can come from the wake loss model

A commonly used method of estimating the joint uncertainty of independent, uncorrelated uncertainties is to calculate the RMS value, i.e.:

$$\text{Joint uncertainty} = \text{SQRT}(5^2+5^2+5^2+5^2) = \text{SQRT}(100) = 10\%$$

A more recently discovered uncertainty is the long-term variability of the wind. Previous (before 2005) it was quite common to accept 10 years as sufficient long-term data. In northern Europe, practical experience has shown that this is much too short a period, possibly due to special climate conditions in this region.. Different analyses pinpoint that up to approximately 30 years seems to be needed to characterize a long-term wind climate. But even with this, the next 20 years, when the wind farm is expected to be in operation, might be 5% below the long-term average. Therefore, the latest recommendation is to add an extra 5% uncertainty on the long-term variability of the wind.

NOTE: If the predicted uncertainties are treated as standard deviations, and the uncertainty is assumed to be 10% (= 1 st.dev), this means that there is a probability of 84% that the calculation results (minus losses) of less than 10% will be achieved. This is also called the P(84) case (or 84% probability of exceedance). If a P(90) probability of exceedance is desired based on the same uncertainty assumptions, 12.8% must be deducted. This is based on the characteristics of the normal distribution (see figure below).



When the calculated production is verified with the actual production, it's important to be aware that there is an uncertainty in establishing the production corrected to a "normal year", e.g. the long-term scaling of actual production figures. The following uncertainties are based on experience from WTGs in Denmark:

- With one year of production data +/- 10%
- With two years of production data +/- 5%

It's generally assumed that a good production estimate can be made with an uncertainty of +/-8% (Danish or similar conditions, with many reference turbines).

This seems to be the case for about 95% of all calculations carried out in Denmark over the previous years.

Two things are especially important in order to achieve a small uncertainty:

- Experience with turbine installations in the area which have been running for some years
- Experience in using the calculation method and regular checks on how your calculations perform compared to real experience.

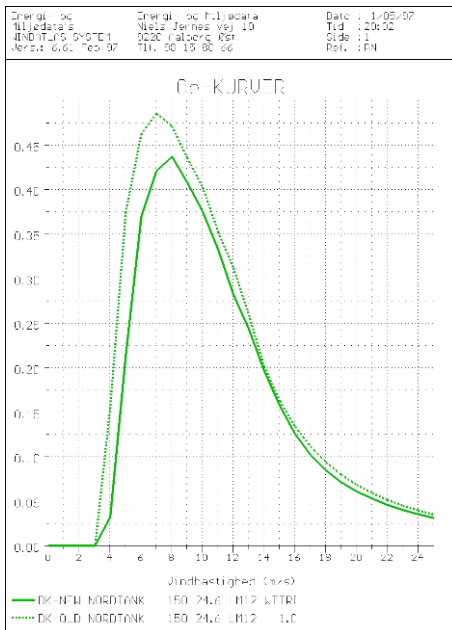
One would therefore expect that 95% of the production estimates that have been made by an experienced user/consultant in Denmark and Germany lie within +/-10%.

For new regions where there is no experience, a significant increase in the uncertainty should be expected, especially in complex terrain. It's not possible to set any guidelines for these uncertainties.

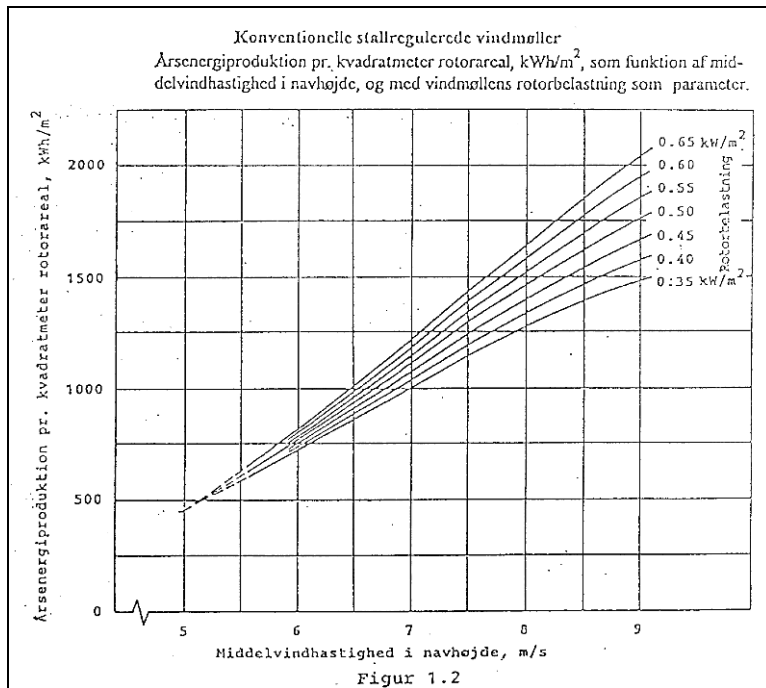
NOTE: Uncertainty is one thing, but errors are quite another. If data is erroneous, there is no upper limit for how incorrect the estimated production can be compared to the actual production.

3.5.2 Checking the Power Curve

A key parameter when checking the power curve is the non-dimensional C_e curve, which can be used for direct comparison of different power curves. If the maximum C_e value exceeds 0.45, either the power curve is incorrect or the manufacturer has developed an extremely efficient WTG.



Comparison of C_e curves from WTGs of similar construction and size is also a good way to look for errors. The figure above shows a power curve measurement that should have been rejected in the first place due to an unrealistically high C_e value.



Another possible method of verification is to compare the estimated production by using the “Helge Petersen” (HP) curves with the production based on the power curve. The HP curves are shown in the above figure. These curves show key figures based on a large number of rather new turbines ranging from 150 kW to 2 MW. These curves have been updated in 2001, and a printout from the WTG Catalog will give the values from these curves for the specific WTG. Comparisons with actual power curve calculations are performed. A portion of the printout from the WTG catalogue is shown below.

HP curve comparison							
V _{mean}	[m/s]	5	6	7	8	9	10
HP value	[MWh]	206	331	464	578	665	754
WT/TRIPOD	1.225 25.00 -0.80 [MWh]	206	331	457	572	671	749
Check value	[%]	0	0	2	1	-1	1

From version 2.4, the HP values have been improved with the following:

WTGs smaller than 150 kW are given reduced HP values based on experience, so that:

- 50-149 kW is reduced to 90% for 50 kW, and linearly reduced up to 100% at 150 kW.
- WTGs below 50 kW are reduced to 90%.
- 1 generator, pitch-regulated WTGs are reduced by 4% for mean wind speeds below 7 m/s.

With these corrections, the HP values will be more accurate for all WTG sizes.

3.5.3 Verification by using existing WTGs

The best check is to use production information from other WTGs in the area for which reliable information is available. Information on the energy production and the power curve is essential. Regarding the production, it's important to adjust data from short measuring periods (less than 3 years) to long-term wind conditions (normal year). For Denmark, Holland, and Germany, there are good wind energy indices available. Please note the comments at the end of this section regarding possible errors when making production verifications. In other countries where no energy indices are available but where several WTGs have been installed, you can establish your own index based on the WTGs with more than 3 years of operational data. But note that the 3 years is only valid if there is sufficient long-term data to correct the production. Latest experience shows that in e.g. Northern Europe, even 25 years is not enough to establish reliable long-term wind expectations. Up to 50 years may be required.

Performing the production check involves performing a production calculation for the existing WTGs while using the same assumptions and data as used for the new WTGs (adjusted to the existing terrain conditions if the terrain of the existing sites vary from the terrain conditions of new site). If the calculated production differs by more than approximately 5%, you should be able to find the explanation.

Possible reasons for errors in the production check for shorter production periods (less than 3 years):

1. The wind direction

The production of a WTG sited in terrain with very different roughness in the different direction sectors will be very sensitive to the prevailing wind directions during the reference period.

2. Seasonal variations

A WTG sited in an area with many crossing hedges and/or high roughness will produce much less of its annual production during the summer with relatively weak wind than a coastal or offshore WTG, which, on a relative basis, does not benefit as much from the strong winter storms as the low-wind sited WTG, even when both WTGs would be running at their maximum output.

3. Geographic differences

Even over distances of a few hundred kilometers in simple terrain, there can easily be significant differences in the geostrophic winds.

4. The Power Curve

The ratio between the swept rotor area and the nominal generator rating will have significant influence on the production check, as will the power regulation system (stall or pitch regulation). During a period with high winds, some WTGs with pronounced stall characteristics will only produce approximately 2/3 of their rated power, while other WTGs may produce even 1/3 above their rated power. Lastly, some WTGs will have lower cut-out wind speeds than others.

3.5.4 Verification by using additional wind data

If no reference turbines are available in the area, then verification calculations on the basis of other wind data will give a good indication of the level of uncertainty by a simple comparison of results. One should generally never base production estimation on only one set of wind measurements unless these have been verified through other measurements. The risk of not noticing errors is simply too high. EMD has made a more comprehensive study regarding the checking of existing wind farms energy production against calculations, where many different investigations have been performed. The complete study can be downloaded from EMD's home page: www.emd.dk.

Below main result graphic is shown.

3.5.4.1 Overview of the case studies and main specifications

Case Id	Country	Place	Terrain	Wind farm	Start	Metecrological mast on site	Metecrological mast near site	Measurement height	Wind speed at 40 m on site *)	Goodness, "standard" calculation	Highest goodness	Lowest goodness	NCAR based Goodness	
01	DK	Klim Fjordhoime	Flat, open, inland, close to fjord	35 x 600 kW Vestas	1996	No	Parallel	10	7.0	1.00	1.02	0.98	-	
02	DK	Torrild	Hilly, inland	15 x 150 kW Bonus	1989	Parallel		0	6.2	1.05	1.10	1.05	-	
03	DK	Torrild, Vindslim	Hilly, inland	15 x 150 kW Bonus	1989	Parallel		0	6.2	1.15	-	-	-	
03	DK	Avedøre (København)	Harbour, close to large city	12 x 300kW Bonus	1993	No	Parallel	0	6.9	1.02	1.02	0.80	0.90	
03	DK	Lynetten (København)	Harbour, close to large city	7 x 600kW Bonus	1996	No	Parallel	0	6.4	1.00	1.05	0.70	0.90	
03	DK	Dräger (København)	Flat, close to large city and sound	8 x 95 kW Tellus	1989	No	Parallel	0	6.3	0.98	1.00	0.74	0.90	
03	DK	Middelgrunden	Offshore, close to large city	20 x 2 MW Bonus	2001	No	Non parallel	50	6.9	0.96	-	-	-	
04	DK	Tune knob	Offshore	10 x Vestas 600 kW	1995	No	No	0	7.8	1.03	1.04	1.00	-	
05	DK	Knebel	Hilltop, coastnear, local obstacle	4 x 95 kW Nordtank + 150 kW NTK	1982	No	No	0	7.5	0.98	1.10	0.97	-	
06	DK	Brokvide	Coastal open flat land	12 x 600 kW Vestas	1996	No	Parallel	10	7.2	1.05	1.05	0.91	1.15	
07	DK	Silstrup	Hilly, inland, close to fjord	3x 225kW Vestas	1990	Parallel	Jan-00	10	7.2	0.98	1.02	0.83	-	
08	SE	Göteborg	Fjord with skerries, close to open sea	3 x 225 kW Vestas + 6 x 600 kW Vestas	1996	No	No	0	7.0	0.83	1.02	0.83	0.85	
09	FIN	Pori	At open sea, flat, skerries	7 x 1 MW Bonus + 300 kW NTK	1999	Parallel		0	38, 62, 87	6.2	1.01	1.20	0.90	0.81
10	DE	Fehmern	At open sea, flat, dikes	Mixed: Bonus, Enercon, HSW, Vestas	1987	Parallel		0	10, 30	7.8	0.93	1.07	0.89	-
11	DE	Knull	Complex obstacles, medium mountainous	Tacke, Enercon E18 + E40	1993	Parallel		0	10	6.0	0.85	1.24	0.78	-
12	DE	Hartmansheim	Complex obstacles, medium mountainous	Mixed: Bonus, Tacke, Enercon, HSW, Enron	1993	Parallel		0	10, 30	6.0	0.73	0.85	0.70	-
13	NL	Rotterdam	At large fjord, flat, dikes	Mixed	1999	No	No	0	6.5	1.00	1.05	0.89	-	
14	FR	Port La Nouvelle	Coast near, hilltop	4 x Vestas V39 (+1 x V25)	1993	No	No	0	7.5	0.90	1.20	0.85	1.99	
15	EIRE	Cronalacht	Coast near, hilltop	5 x Vestas V39 600 kW+ 3 x Vestas V47	1997	Non parallel		0	10, 30	9.6	1.00	1.00	0.94	1.04
16	POR	Sines	Coastal, gentle hill, close to city	12 x 500 kW WindWorld	1995	No	No	0	6.0	1.54	1.80	0.59	1.47	
17	GR	Sitia, Modi	Flat plateau in complex mountainous region	17 x 600 kW Bonus	1998	Parallel		0	40	9.0	0.97	1.04	0.92	2.60
18	TR	Cesme	Coast near, mountain region	12 x Vestas V44 + 3 x Enercon	1999	No	Parallel	10, 20, 30	7.2	0.92	0.94	0.86	-	
19	AUS	Esperance	Coast near, hilly	9 x Vestas V27, 225 kW	1994	Non parallel		0	10, 30	7.5	0.93	1.05	-	1.26
20	USA	Fargo, Minnesota	Flat inland	2 x NEG-Micon 750 kW	1999	Parallel		0	30, 40	6.1	1.08	1.10	0.94	1.00

*) The expected "real" mean wind speed of site based on all gained experience

The table shown above provides an overview of the various case studies.

The goodness is defined as: actual wind farm production divided by the calculated production, corrected for differences in the wind energy index for the production period and the wind data period, if they are non-parallel.

The column "Standard calculation" corresponds to what we would consider as the calculation based on the best-available data for the site but not necessarily the calculation that yields the most accurate results.

Many different calculations and parameter variations have been tested in each case. The highest and lowest goodness values give an indication of the uncertainty in each case, and are due to the very different setups in each case; they are not directly comparable. In some cases, the lowest and highest goodness values are based on individual differences from WTG to WTG, but in most cases, the lowest and highest goodness values are based on using different wind data for the calculations. The "NCAR based goodness" is based on calculations using the nearest NCAR upper-air data taken down to the specific site by the WAsP model.

3.5.4.2 Examples of wind data uncertainties

The two following examples illustrate how uncertain the basis for the production calculation can be when working in new areas where WTGs with some years of operation are not yet available and where the quality of measured data is poor.

Portugal

A wind energy project was established based upon on-site wind measurements.

The actual production turned out to be only half of the estimated production. The following errors and uncertainties were found:

- The wind measurements were based on instant readings, which were taken at irregular intervals and written down by hand. There were no guarantees that the data was representative. For example, the

readings were carried out primarily during the day, which may cause large error margins since wind often blows less during the night.

- The measurement equipment was not calibrated and the measurement height was only 8 m agl.
- The measurements were made on a hilltop where the conversion of wind data from measuring height to hub height can be quite uncertain.
- The use of the Wind Statistics from the nearest meteorological station would have given much more precise results. However, this station was rejected in the first place due to its complex location close to the ocean and the city.

Ireland

In connection with a project, on-site measured data was received from the client. Data from the European Wind Atlas was available from 3 stations, all within about 70 km from the site.

The calculations based on the data from the European Wind Atlas and the on-site measurements respectively gave the following results:

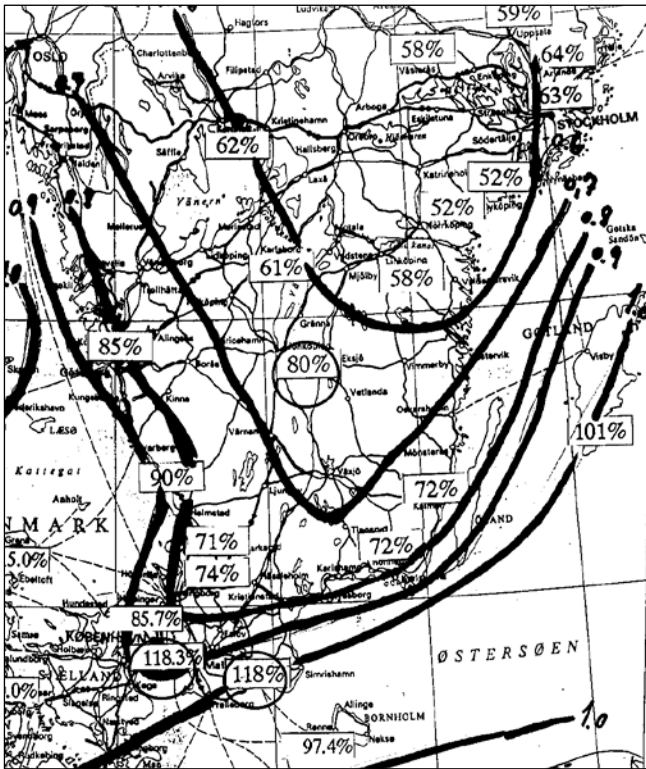
Data origin	Relative calculated production
Station 1	100%
Station 2	92%
Station 3	56%
On-site measurements	163%

It can be seen that the deviations are large (a factor of 3 from lowest to highest production). This clearly indicates that one should never rely on only one set of data unless it is very well documented.

3.5.4.3 Verification by using additional Wind Atlases for a large area

If a large number of Wind Atlases (Wind Statistics) are available for a large area (e.g. a country or a province), you can verify these by calculating the energy production on the basis of the same WTG and the same assumptions (e.g. Roughness Class 1 in all directions), and calculate the associated production indices (using the average of all the production figures). The resulting indices (e.g. in percent) are marked at the corresponding geographic positions on a map. You can then try to fit smooth curves through points of equal or close to equal indices. In general, the geotropic wind (which the Wind Atlases should represent) will only change a little over a certain area. It should therefore be possible to fit smooth curves without sharp bends. This exercise will often reveal an incorrect Wind Atlas.

The next figure shows a check of some Swedish Wind Atlases. As supporting data for the curve fitting around Denmark, the actual production from a number of turbines was also used.



3.6 ENERGY - Wind Resource Maps

3.6.0 Introduction to Wind Resource Map

A wind resource map is a useful tool, which has many purposes, for example:

- Planning of wind energy projects, where the search for good sites is a part of the process.
- Evaluation of the wind energy potential in a region or a country.
- Support for wind farm layout, where the best sites within a certain area are desired. This can be automated from the OPTIMIZE module, see chapter 8.

A wind resource map where you just want to find the best spots can be established for very large areas as well as small areas.

With WindPRO, you can handle very large areas in one process. The software can handle an unlimited number of .map files (roughness and orography), and it can automatically work with several Wind Statistics that will be changed and weighted according to the distance to the sites in question. WASP is used as the calculation engine.

3.6.1 Background Data for the Wind Resource Map

The following data is needed to generate a Wind Resource Map:

- One or more digitized roughness maps covering the calculation area plus the additional area extending approximately 10-20 km beyond the Wind Resource Map area.
- One or more digitized height contour line maps covering the calculation area plus the additional area extending approximately 5-10 km beyond the Wind Resource Map area, depending on the terrain complexity at the site.
- One or more Wind Statistics valid for the calculation area. Weighting can be automatically based on distance to wind statistics.
- Optional: Obstacles in the area. These are often not taken into account when calculating wind resource maps, but it's possible via WindPRO.

3.6.1.1 Digitized Roughness Map

You can create a digital roughness map in the following ways:

Manual digitizing

This involves a combination of field studies and map studies, followed by digitizing in WindPRO. In WindPRO you can digitize directly by using the Line Object, or indirectly by using an Area Object followed by exporting to roughness lines. The Area Object is strongly recommended for larger areas or complicated areas since this avoids problems such as crossing lines or discontinuous lines, which can cause dramatic errors in the WASP calculation.

Automatic generation

You can generate roughness maps based on information from databases which contain information on land use, or GIS systems. In this case also, the Area object should be used. EMD did use a more refined processing method when we made a detailed roughness map of the entire country of Denmark for calculating a detailed wind resource map. Please check On-line data in Area object or contact us for further information on the subject.

(see also Basis, Section 2.8, Line object for further information).

3.6.1.2 Digitized Height Contour Lines

This data will often be available from public sources, check the On-line data from the line object. As an alternative, you can digitize from maps (see Basis, Section 2.8, Line object for further information).

3.6.1.3. Wind Statistics

For more information on Wind Statistics, see Section 3.2.1.2 and 3.2.4. A unique feature in the RESOURCE module is that it can change Wind Statistics automatically and weight them during the calculation.

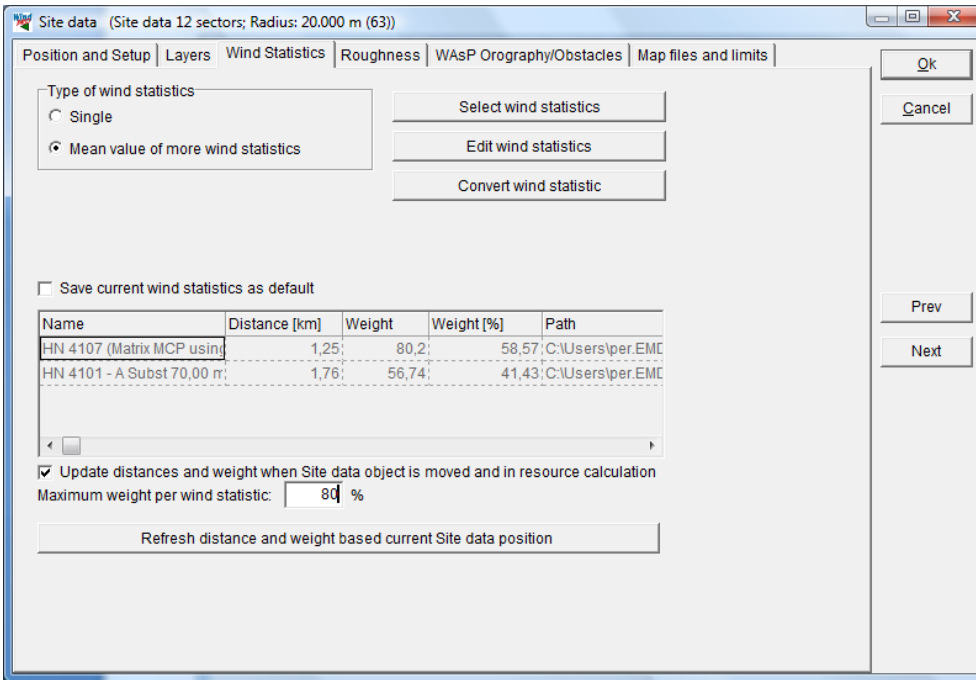
3.6.1.4. Local Obstacles

Local obstacles can be added to the calculation as described in Section 3.1.5. It should be noted that the calculation speed will be reduced significantly by adding just one local obstacle. The reason for this is that WindPRO calls a “normal” WAsP calculation for each calculation point in order for it to be able to treat the obstacle correctly. If no obstacles are included, the WAsP resource option is called, which operates much faster.

3.6.2 Entering data for the calculation

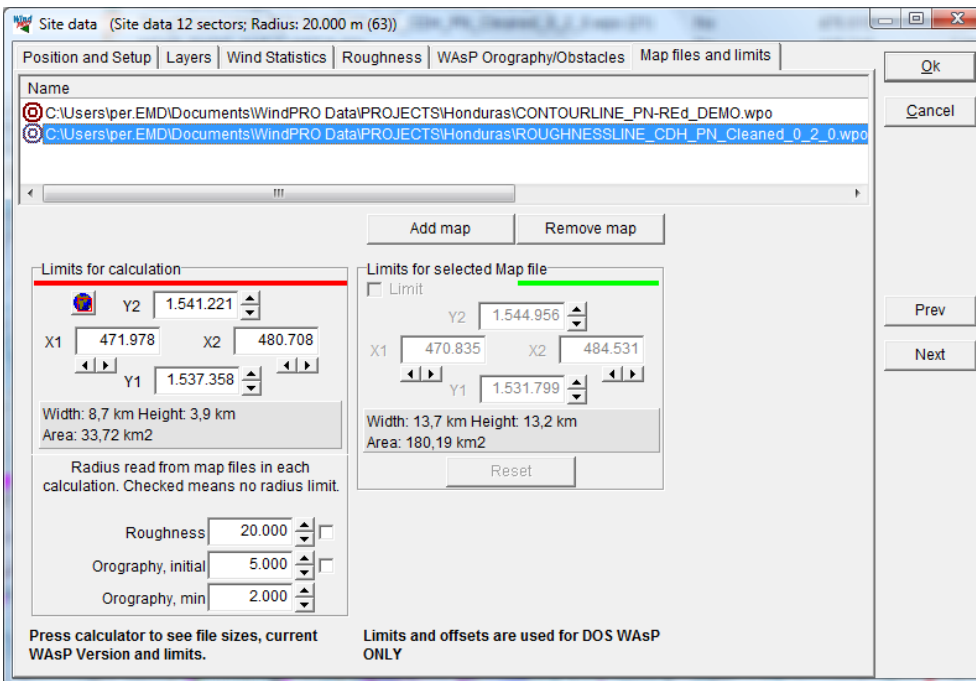
When the data has been established it must be attached to a Site Data Object.

First select the Site Data Object that is to be used in RESGEN. It's of minor importance where the object is positioned.



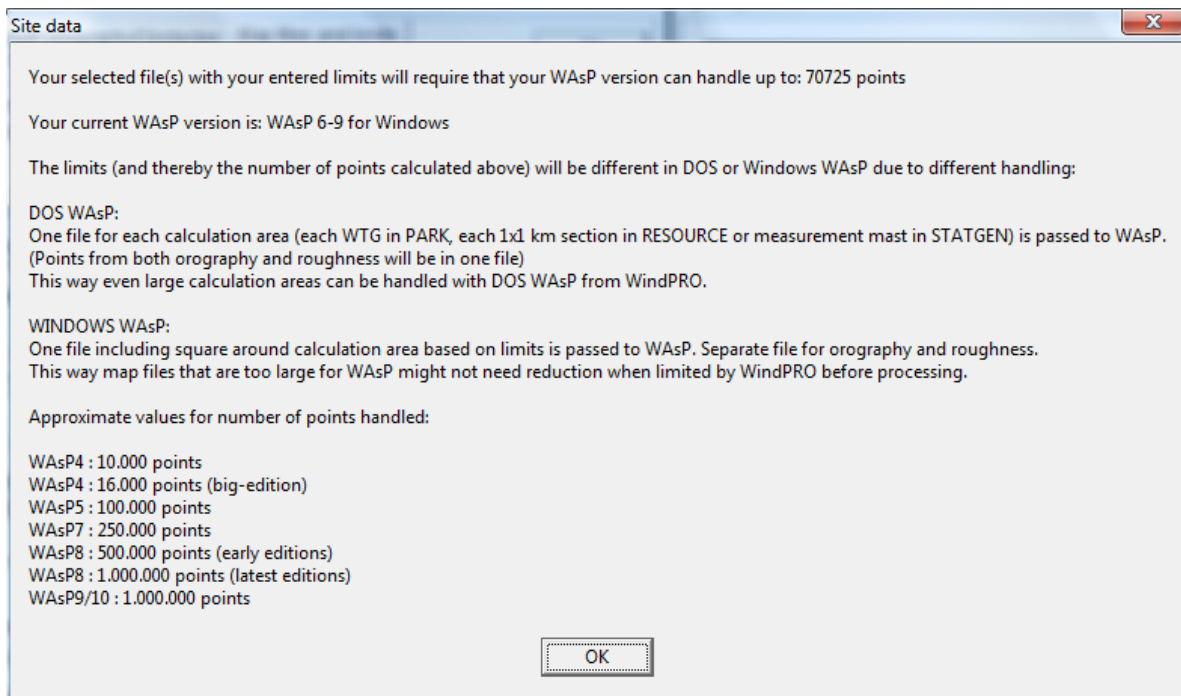
The wind statistic selection – in the example, “mean value of more wind statistics” is chosen, and it is set to update distance weight when moving from one calculation point to the next. A maximum weight per wind statistic of 80% been set. Thereby you can avoid small local minima or maxima just around the wind statistic points.

After having selected the Wind Statistic(s) (see the previous comments) and added information regarding obstacles, you add the maps and define map limits for the calculation area.



The important setting in the form above is the “Radius read from map files in each calculation”. By limiting the radius, combined with “tiled calculation” (WindPRO divides the resource map calculation in tiles like 1 x 1 km squares), unlimited large resource maps can be calculated. The radius limit is to avoid sending too large map files to WAsP calculation for each tile. So, if the map file contains a lot of points (high point density), it might be necessary to limit the radius for reducing the map area sent to a WAsP calculation. In the present version, This can only be done experimentally. From WindPRO 2.8 the calculation tool that can help in finding these limits will reappear. Below is shown the capability of the different WAsP versions. The form below will, at present, only be available when site data object purpose is set to WAsP calculation (or STATGEN). To get some help

for analyzing if the WAsP capabilities seem to be violated by your file sizes, change the purpose to WAsP calculation temporarily and press the calculator button.

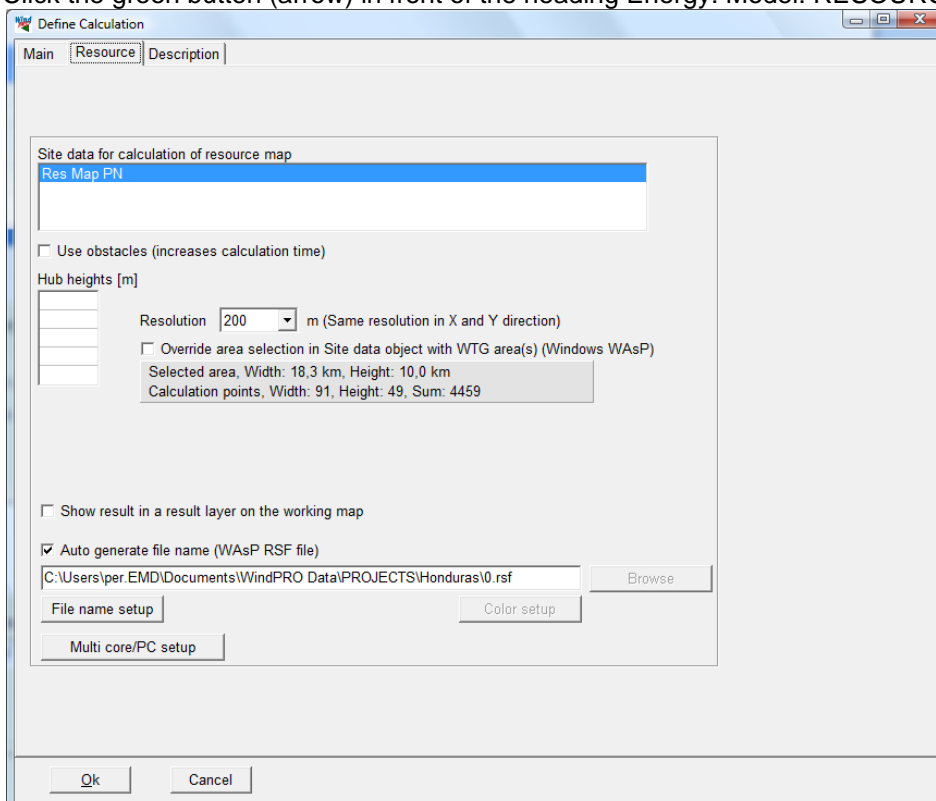


With the “pick tool” you can set the calculation region directly on the background map.

NOTE: At calculation time you can decide to let a WTG-area decide the area to be calculated and the selection in the site data object is thereby overruled.

3.6.3 Calculating a Wind Resource Map

Click the green button (arrow) in front of the heading Energy: Model: RESOURCE.



In the Resource tab sheet, you can choose to use a previously-calculated resource file, or perform a new calculation. If you choose to start a new calculation, you can specify up to five different hub heights (heights above terrain level) to be calculated, the resolution, and the name of the result file.

You can “Override area selection in Site Data Object with WTG Area”. This can only be used in conjunction with the Windows version of WAsP. Instead of using the rectangle defined in the Site Data Object, a freely definable area digitized in a WTG Area Object can be used. This has two advantages:

1. You do not need to calculate a lot of unnecessary points which saves calculation time.
2. You can get a nicer presentation. For example, if a map is calculated for a municipality, only the municipality is covered by the resource map.

3.6.3.1 Multi core / PC setup

WindPRO performance on this computer: Number of cores: 2

Max performance (All processors/cores is used for WindPRO calculation)
 Balanced (if more processors/cores, all except one is used for WindPRO calculation)
 Don't use this computer for WindPRO calculation (requires use of other computers)

Use other computers in local network:
 Select network folder for data exchange:

IMPORTANT:
 To utilize this option, you need to start the tool "WAsPResCalc" from "Program Files\EMD\WindPRO2.7" on each computer that shall help with the calculation.

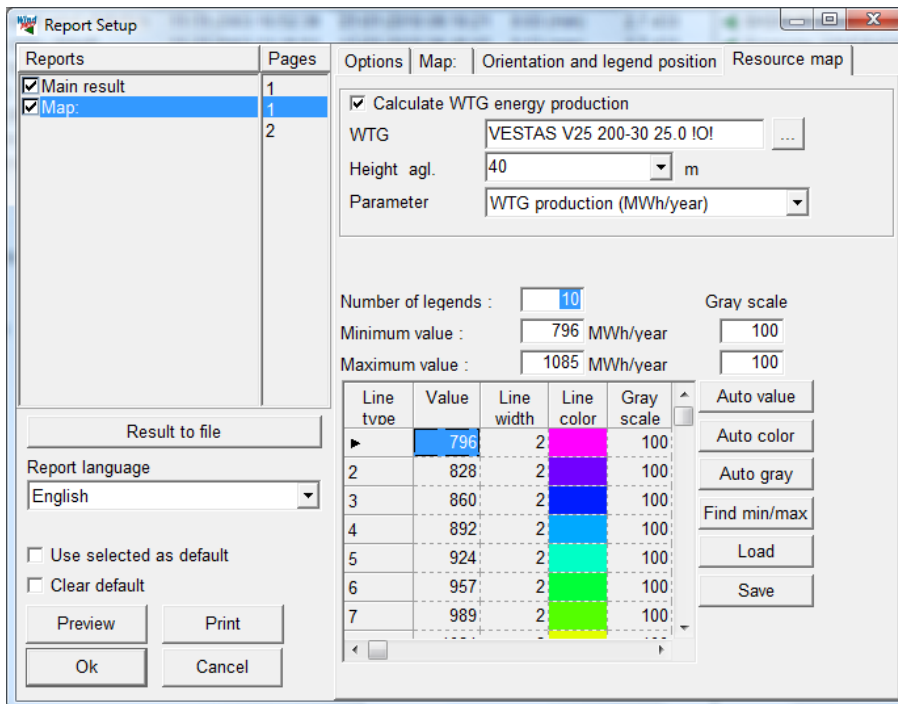
Specific setup for wind resource calculation:

Tile size m The calculation will be split in 190 tiles. (Calculated from settings in site data object - if "override with WTG-area" the tile calculation is incorrect)

The tile size setup make the calculation work like this:
 The wind resource map calculation is divided in tiles of tile size x tile size. Using more processors each processor will look for "next tile in calculation queue".
 For each tile the same wind statistic is used meaning that using weighted wind statistic, will result in using the same weight within the tile.
 This can result in slightly different results from the WindPRO 2.6 calculation where wind statistics were weighted for each calculation point
 To get exact same calculation results as in ver. 2.6, set tile size = resolution and in site data object check "use the entire map file" - this is in general not recommended due to calculation time
 For each tile the map files loaded is defined by settings in site data object. This mean that large areas can be calculated even if the entire map file is too large for a WAsP calculation
 If a small area (like 1000 x 1000 m) is calculated with high resolution and/or weighted wind statistics, the tile size should be reduced to like 100 x 100 m to get a more continuous weighting
 Also for small areas with high resolution tile size should be reduced to utilize more processors - if there is only one tile, only one processor will handle the calculation
 If the number of tiles is smaller than the number of processors available for the calculation, not all available processors will be used.

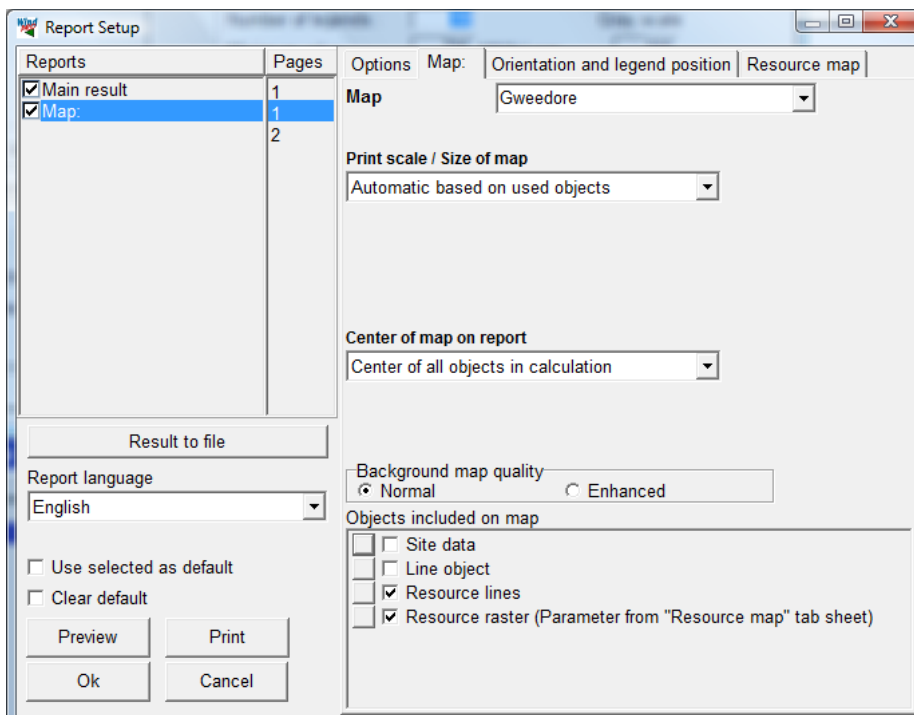
With the multi core/PC setup, more cores in the local processor as well as other processors in the network can be used in helping to calculate the wind resource map. This will make calculations much faster. All functionality should be explained by the above shown screen. NOTE: There must be a WAsP license on each PC that takes part in the calculation. There are no requirements for a WindPRO installation, just the WaspResCalc program mentioned on the screen above.


3.6.4 Printout of Wind Resource Map



After the calculation has been performed, the new resource map is ready for presentation. At this point, you can select parameters for presentation (resolution, colors, etc). If WTG production is chosen for presentation, they will not be air density corrected – production figures as “wind resource maps” will only be seen as relative figures.

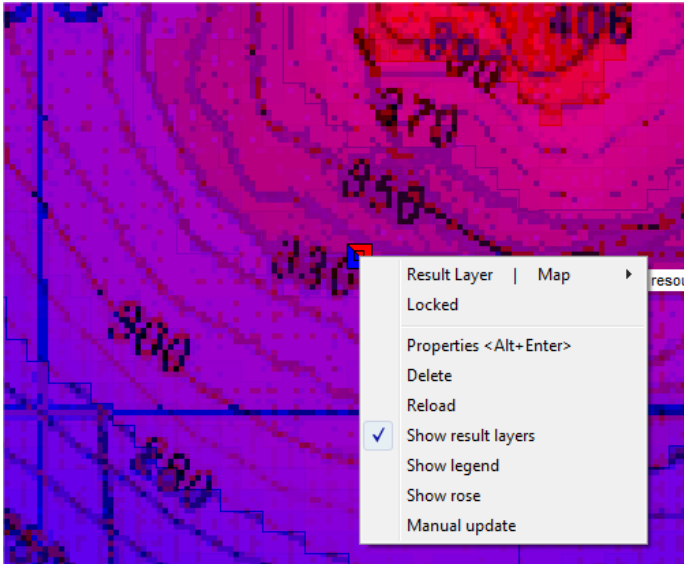
NOTE: Instead of resource lines, on the “Map” tab sheet you can select the “Resource raster” data option (see below)



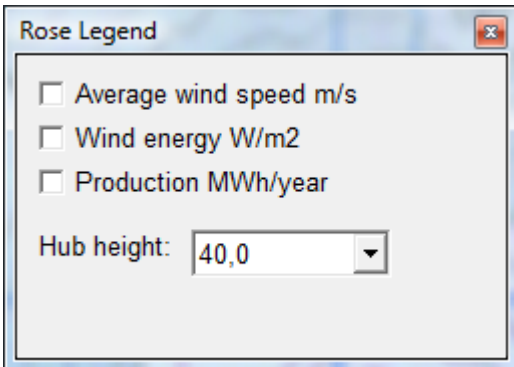
When “Resource raster” is selected, the parameter you wish to show will be set on the Resource map tab sheet, but the color setting will be defined by clicking on the  button next to “Resource raster”. To define the color setup, see “Result layer” in Section 2.10, Basis.

The Result Layer Object is a powerful tool and can be used as overlay on the calculated wind resource map directly on top of your background maps.

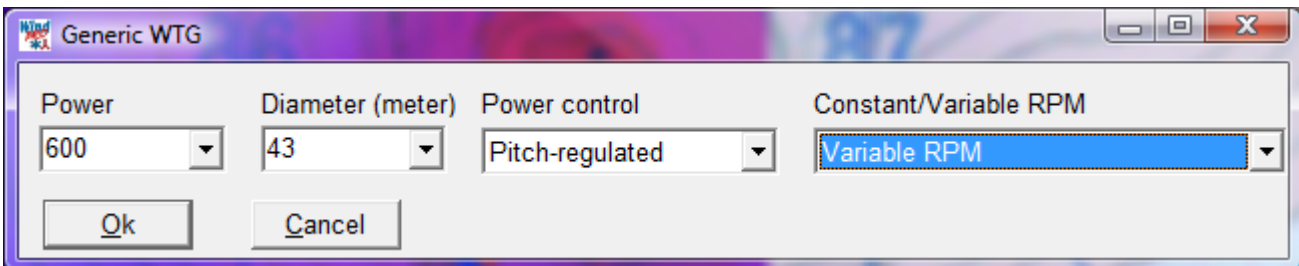
3.6.5 Analyze site with roses on Wind Resource Map



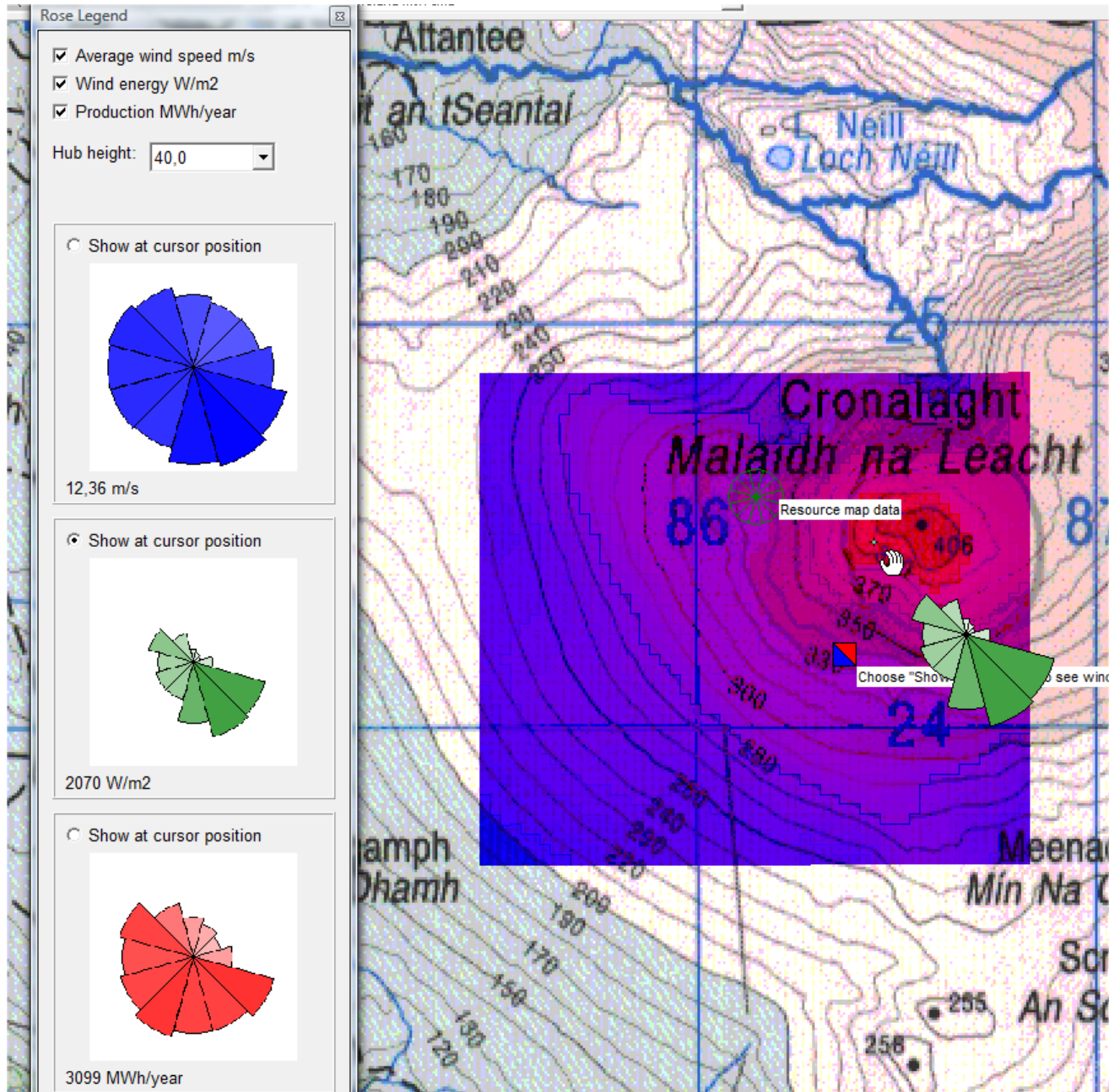
Right click on the result layer object and click on the “show rose”.



In the rose legend, wind speed as an average, as energy, or as production can be chosen



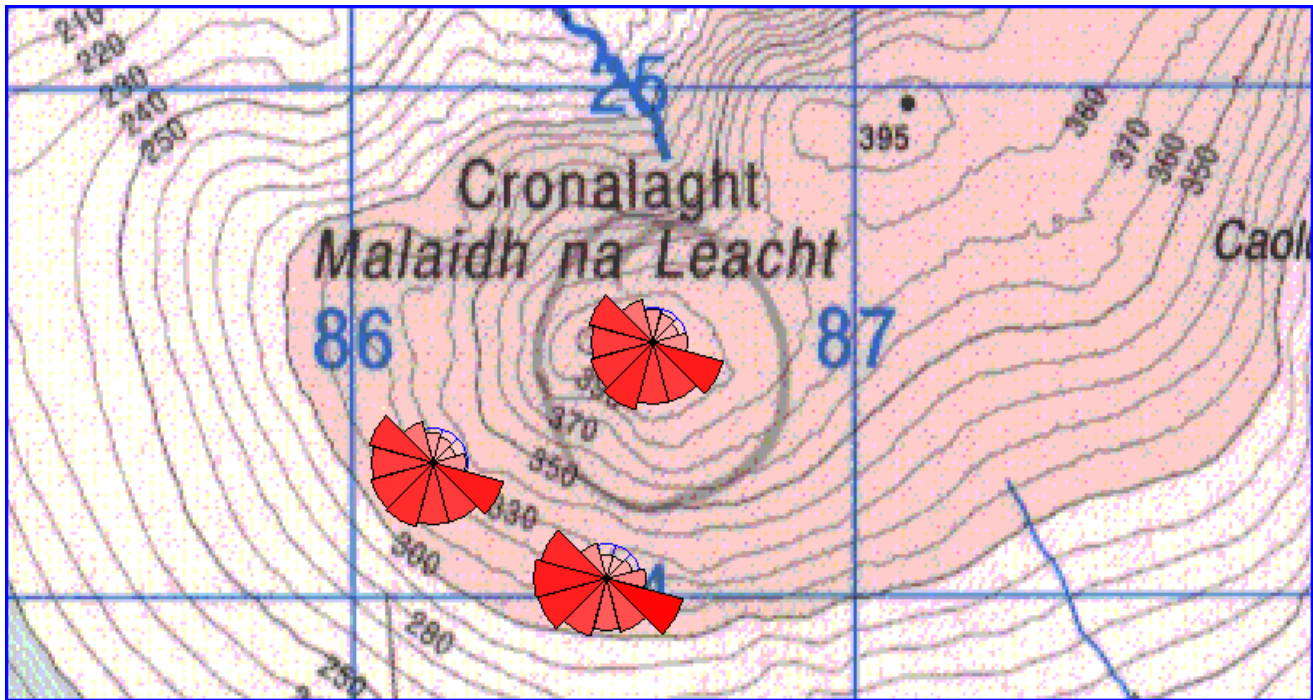
When production is chosen, a generic turbine can be selected. The HP-standard power curve values will be used. Note: they will not be air density corrected – production figures as “wind resource maps” shall only be seen as relative figures.



The legend shown here contains all three options. The energy (green) here is selected for “show at cursor position”. When the cursor is moved around on the resource map, the three legends are updated and the roses are shown for the cursor position. And, on the map itself, the selected one is shown for the cursor position. This is an efficient tool to analyze a resource map and see how wind conditions changes on the site. Note: The example shown pertains to the position where the little crosshair is located NW of the hand symbol.

3.6.5.1 Roses at site data objects

A special variation of the above example is explained here to show roses at site data objects. When more site data objects are shown on map and the option (right click at site data object) “show energy rose” is chosen, the wind energy rose is calculated based on the specifications in the site data object. This can e.g. be used if there are more measurement masts on the site, to establish an energy rose for each of them based on concurrent data for each of the masts. Then it can be visually inspected if the masts seem to agree, and eventually errors in data for specific masts can be identified – or changes in the wind flow over the site can be seen. See example below.



Energy roses at 3 site data objects. For an update (if e.g. more are added), you must deselect the “show energy rose” and select it again.

[ⁱ] Ross, Sheldon M.: *Introduction to Probability And Statistics For Engineers and Scientists*, John Wiley & Sons, 1987.

[ⁱⁱ] Efron, Bradley & Robert J. Tibshirani: *An Introduction to the Bootstrap*, Chapman & Hall, 1998.

[ⁱⁱⁱ] Cramér, Harald: *Mathematical Methods of Statistics*, Princeton University Press, 1946.

[^{iv}] Troen, I & E.L. Petersen, *European Wind Atlas*, Risø National Laboratory, 1989, ISBN 87-550-1482-8.

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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 values 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% exceedance 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.

Pure tones penalty are added to the demand: 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

The screenshot shows a dialog box titled "Noise calculation model" with the following settings:

- Noise calculation model:** ISO 9613-2 Germany
- Wind speed:** Loudest up to 95% rated power
- Octave data required:**
- Spectral distribution:**
- Ground attenuation (Agr):** Alternative
- Meteorological coefficient C0:** 0,0 dB. Recommended maximum: 2 dB
- 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 and Impulse tone penalty are added to WTG source noise
- Height of immission 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

Buttons: Ok, Cancel

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 (BImSchG)". 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 include 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.

Noise calculation model
ISO 9613-2 United Kingdom

Wind speed
Wind speed range From 4,0 m/s To 12,0 m/s Step 1,0 m/s

Octave data required
 Spectral distribution

Ground attenuation (Agr) Ground factor
General 1,0 [0-1] 0: Hard ground, 1: Porous ground

Meteorological coefficient C₀
0,0 dB. Recommended maximum: 2 dB

Type of demand in calculation
3: WTG noise is compared to ambient noise plus margin (UK, AT etc.)

Noise values in calculation
All noise values are 90% exceedance values (L₉₀)
WTG catalogue source noise values are auto reduced with 2 dB

Pure tones (Note: ONLY used if at least one WTG is informed to have pure tones)
Pure and impulse tone penalty are added to WTG source noise

Height of immission point above ground level, used when no value in NSA object
4,0 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 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 C₀

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 L₉₀ 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 L₉₀ 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.

The screenshot shows a dialog box titled "Noise calculation model" with the following settings:

- Noise calculation model:** ISO 9613-2 France
- Wind speed:** Fixed wind speed, 8,0 m/s
- Octave data required
- Spectral distribution
- Ground attenuation (Agr):** None
- Meteorological coefficient C0:** 0,0 dB. Recommended maximum: 2 dB
- Type of demand in calculation:** 2: WTG plus ambient noise is compared to ambient noise plus margin (FR 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 are added to demand
- Pure tone penalty:** 0,0 dB(A)
- Height of immersion 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
-

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, published by Statens Forurensningstilsyn (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.

Noise calculation model
ISO 9613-2 Norway

Wind speed
Fixed wind speed 8,0 m/s

Octave data required

Spectral distribution

Ground attenuation (Agr)
Alternative

Meteorological coefficient C0
0,0 dB. Recommended maximum: 2 dB

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 immission point above ground level, used when no value in NSA object
4,0 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

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, C₀

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".

Noise calculation model
German Codes VDI 2714 (outdated)

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)

Pure tones (Note: ONLY used if at least one WTG is informed to have pure tones)
Pure and Impulse tone penalty are added to WTG source noise

Height of immersion 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

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.

Noise calculation model

Danish Codes

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)

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 immission point above ground level, used when no value in NSA object

0,0 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

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 Naturvårdsverk, 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 in 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 immersion 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

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

Wind speed range From To Step

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 immission 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

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.

The screenshot shows the 'WTG(s)' tab of a configuration dialog. The 'WTG type' is 'ENERCON E-70 E4 2000 71.0 !O!'. The 'Hub height [m]' is '85,0'. There are checkboxes for 'Always use default values' (unchecked) and 'Show only valid detail data' (checked). The 'Power curve' is 'Level 3 - guaranteed* - 1400kW/Rev. 1.0 - 04/2005'. The 'Noise data' is 'Level 3 - guaranteed - 1400kW/Rev 2.1 - 12/2009'. Other fields include 'Visual data: Default', 'eGrid data: Default', 'Displacement height: 0 m', 'Number in row: 1', and 'Symbol color: Red'. Navigation buttons 'Ok', 'Cancel', 'Prev', and 'Next' are on the right.

Advanced noise curve selection

Checking the “Adv.” Box opens up advanced settings.

This screenshot shows the same dialog box but with the 'Adv.' checkbox checked. The 'Power curve' is now 'Level 0 - guaranteed* - Rev. 1.1 - 04/2005' and the 'Noise data' is 'Level 0 - guaranteed - OM I/Rev 5.1 - 02/2006'. A 'Purpose' section on the right has radio buttons for 'Optimize' (selected) and 'Lden'. Below these are four buttons: '+', '-', '^', and 'v'. A 'Setting 0 (1 defined)' section shows 'Setting 0' with a 'Use' radio button selected. The rest of the dialog remains the same as in the previous screenshot.

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).

Position | Layers | Demands | Area | Description

Insert NSA properties in

Country specific form Denmark Danish 2007

Freely definable form

Open land

Residential areas

User defined

Noise demand

Check for more wind speeds

Wind speed	Noise demand [dB(A)]
6,0 m/s	42,0
8,0 m/s	44,0

Wind speed: From, to, step

6,0 8,0 2,0

Distance demand

Distance demand [] m

Immission height above ground level

Use standard value from calculation model

Immission height (a.g.l.) [] m

Buttons: Ok, Cancel, Prev, Next

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”.

Position | Layers | Demands | Area | Description

Insert NSA properties in

Country specific form

Freely definable form

Noise demand

Only WTG noise is considered (DK, DE, SE, NL etc.)

Ambient noise is considered (UK, FR etc.)

Distance demand

Distance demand [] m

Immission height above ground level

Use standard value from calculation model

Immission height (a.g.l.) [] m

Buttons: Ok, Cancel, Prev, Next

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 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.

The screenshot shows a software dialog box with the following sections and controls:

- Position | Layers | Demands | Area | Description** (tabbed header)
- Insert NSA properties in**
 - Country specific form
 - Freely definable form
- Noise demand**
 - Only WTG noise is considered (DK, DE, SE, NL etc.)
 - Ambient noise is considered (UK, FR etc.)
- Noise demand**
 - Input field: 45.0 dB(A)
 - Check for more wind speeds
 - Check for spectral distribution
- Distance demand**
 - Input field: [] m
- Immission height above ground level**
 - Use standard value from calculation model
 - Input field: [] m
- Buttons:** Ok, Cancel, Prev, Next

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).

Position | Layers | Demands | Area | Description

Insert NSA properties in

Country specific form

Freely definable form

Noise demand

Only WTG noise is considered (DK, DE, SE, NL etc.)

Ambient noise is considered (UK, FR etc.)

Noise demand

Check for more wind speeds

Check for spectral distribution

Wind speed: From, to, step

Wind speed	Noise demand [dB(A)]
4,0 m/s	40
5,0 m/s	42
6,0 m/s	42
7,0 m/s	44
8,0 m/s	44
9,0 m/s	46

Distance demand

Distance demand m

Immision height above ground level

Use standard value from calculation model

Immision height (a.g.l.) m

Ok

Cancel

Prev

Next

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.

Position | Layers | Demands | Area | Description

Insert NSA properties in

Country specific form

Freely definable form

Noise demand

Only WTG noise is considered (DK, DE, SE, NL etc.)

Ambient noise is considered (UK, FR etc.)

Ambient noise

Check for more wind speeds

Check for spectral distribution

Wind speed: From, to, step

Wind speed	Ambient noise [dB(A)]
4,0 m/s	29
5,0 m/s	30
6,0 m/s	31
7,0 m/s	31,5
8,0 m/s	32
9,0 m/s	32

Margin or Allowed additional exposure

dB(A)

Check for more wind speeds

Check for spectral distribution

Sound level always accepted

dB(A)

Distance demand

Distance demand m

Immision height above ground level

Use standard value from calculation model

Immision height (a.g.l.) m

Ok

Cancel

Prev

Next

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

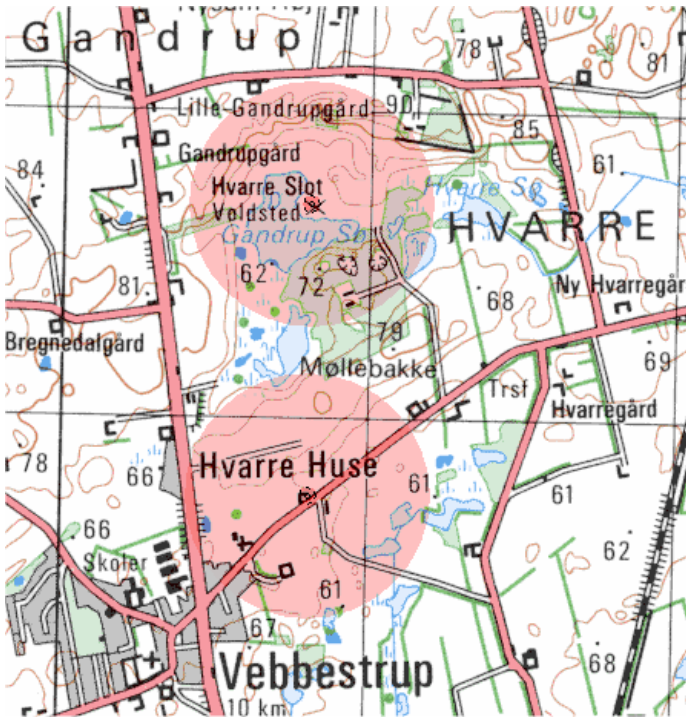
If the NSA has been entered as an area rather than a point, it is possible to edit the node points of the area in the Area tab sheet. Node points can be added, edited, or deleted. If the node points need to be copied to Excel, or from Excel to WindPRO, then the entire object needs to be copied to or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

#	X	Y
1	551849	6287909
2	552048	6287995
3	551961	6288225
4	551646	6288221
5	551701	6287980
6	551798	6287751

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.

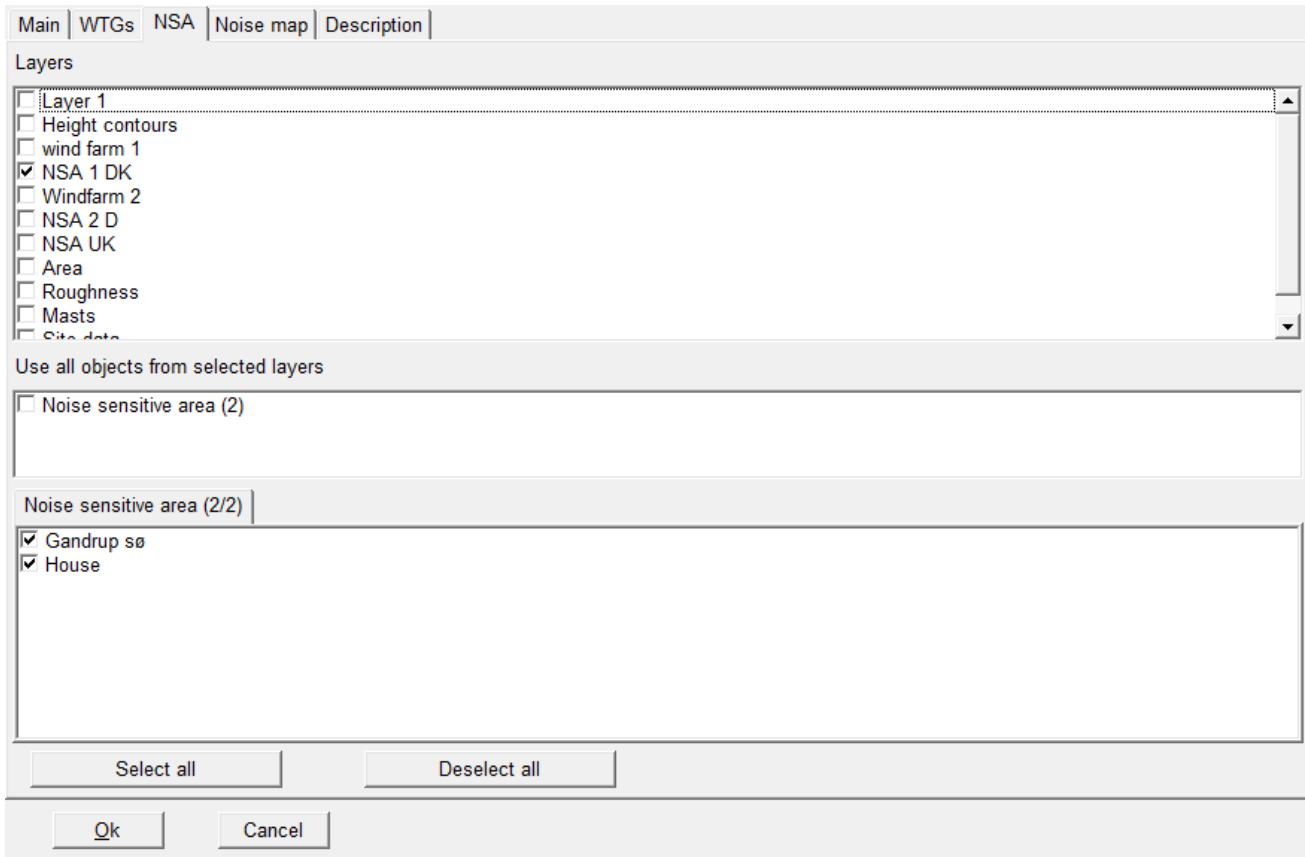
Finally a noise calculation model must be selected. Depending on the codes selected, the calculation options for the particular code can be inspected or changed using the “Edit model parameters” button. For a description of these options please refer to the description of the appropriate model in Section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

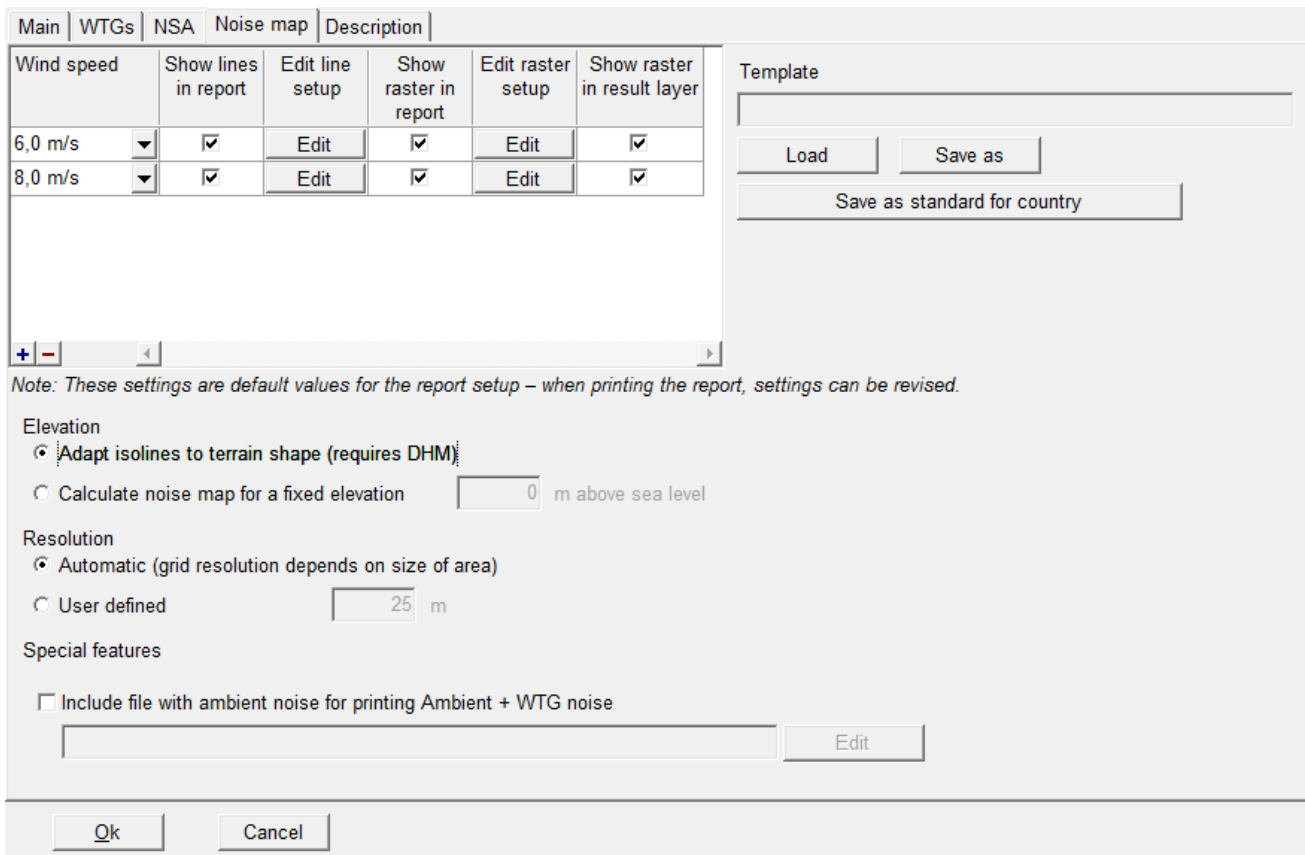
NSA (Noise-sensitive areas)

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.

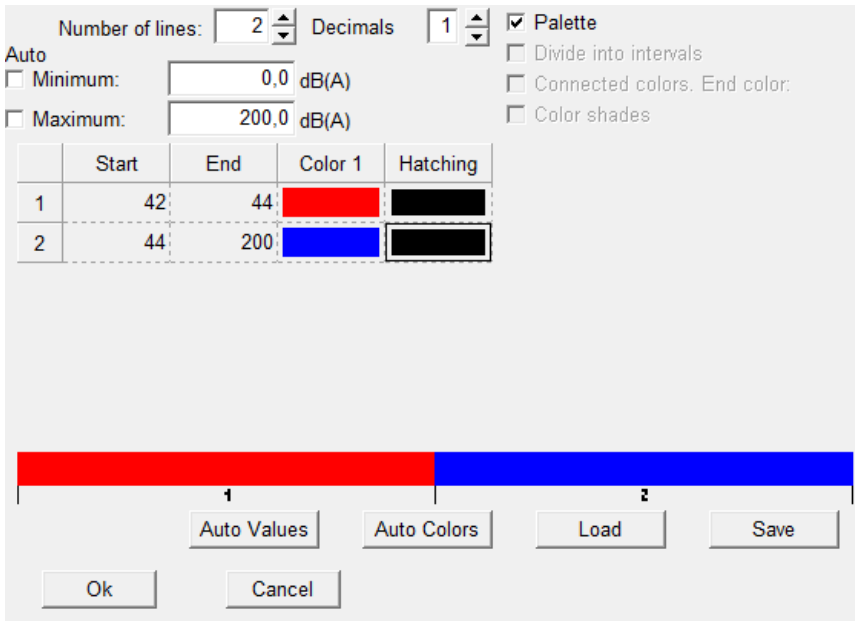
The line setup looks like below, which is similar to the setup options in the print report setup.

Number of legends :	<input type="text" value="2"/>	Gray scale	<input type="text" value="100"/>
Minimum value :	<input type="text" value="42 dB(A)"/>		<input type="text" value="100"/>
Maximum value :	<input type="text" value="42 dB(A)"/>		<input type="text" value="100"/>

Line type	Value	Line width	Line color	Gray scale
1	37,0	2	 	100
▶	42,0	2	 	100

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.

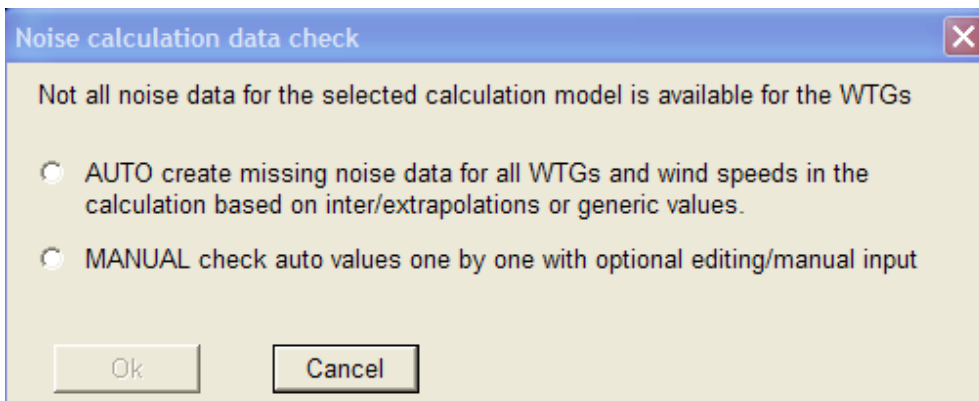
The resolution is automatically selected based on the area size keeping the calculation time down by increasing the grid size when the area calculated is increased. Alternatively a fixed grid size can be selected.

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.

WTG:

Noise data:

Available data, partly generic: (select a data set to EDIT or press Start calculation)

Lwa,ref	Wind sp... /	Hub height	Data type	Pure tones	Penalty	Octave data	Wind...
100,5	6,0	60,0	ExtraPolated	Yes	3	Generic	1,0
103,5	8,0		From Windcat	Yes	3	Generic	1,0

Lwa,ref (Based on entered octave data) dB(A) Pure tones

Wind speed dependency dB(A)/m/s

Octave data

Calculate generic values Octave data already A-weighted

62.5 Hz 125 Hz 250 Hz 500 Hz 1000 Hz 2000 Hz 4000 Hz 8000 Hz

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.

WTG: NORDEX N62 1300-250 62.0 IO!

Noise data: Level 0 - official - - 07-2002

Available data, partly generic: (select a data set to EDIT or press Start calculation)

Lwa_ref	Wind sp... /	Hub height	Data type	Pure tones	Penalty	Octave dat
100,5	6,0	60,0	ExtraPolated	Yes	3	Generic
103,5	8,0		From Windcat	Yes	3	Generic

Data generated by WindPRO based on simple inter/extrapolations

Lwa_ref (Based on entered octave data) Wind speed dependency

Pure tones

Octave data

Calculate generic values Octave data already A-weighted

62.5 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
<input type="text" value="82,1"/>	<input type="text" value="89,1"/>	<input type="text" value="92,5"/>	<input type="text" value="95,1"/>	<input type="text" value="94,9"/>	<input type="text" value="92,0"/>	<input type="text" value="87,2"/>	<input type="text" value="77,7"/>

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

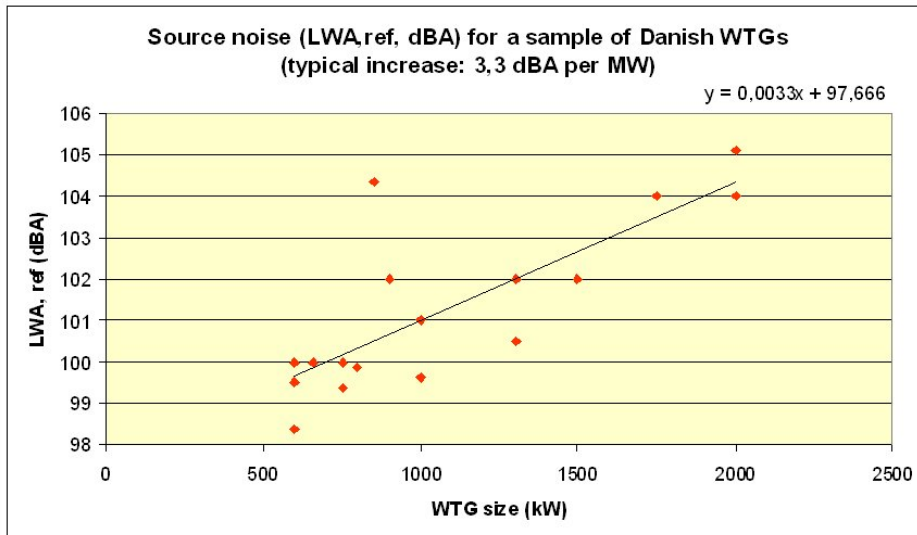
While it is best to have complete and correct data for the noise impact calculation it is often the case that data are missing. In those cases EMD strongly recommend to obtain the missing data from the wind turbine manufacturer and enter those value into the wind turbine catalogue. However analyses are 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.



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.

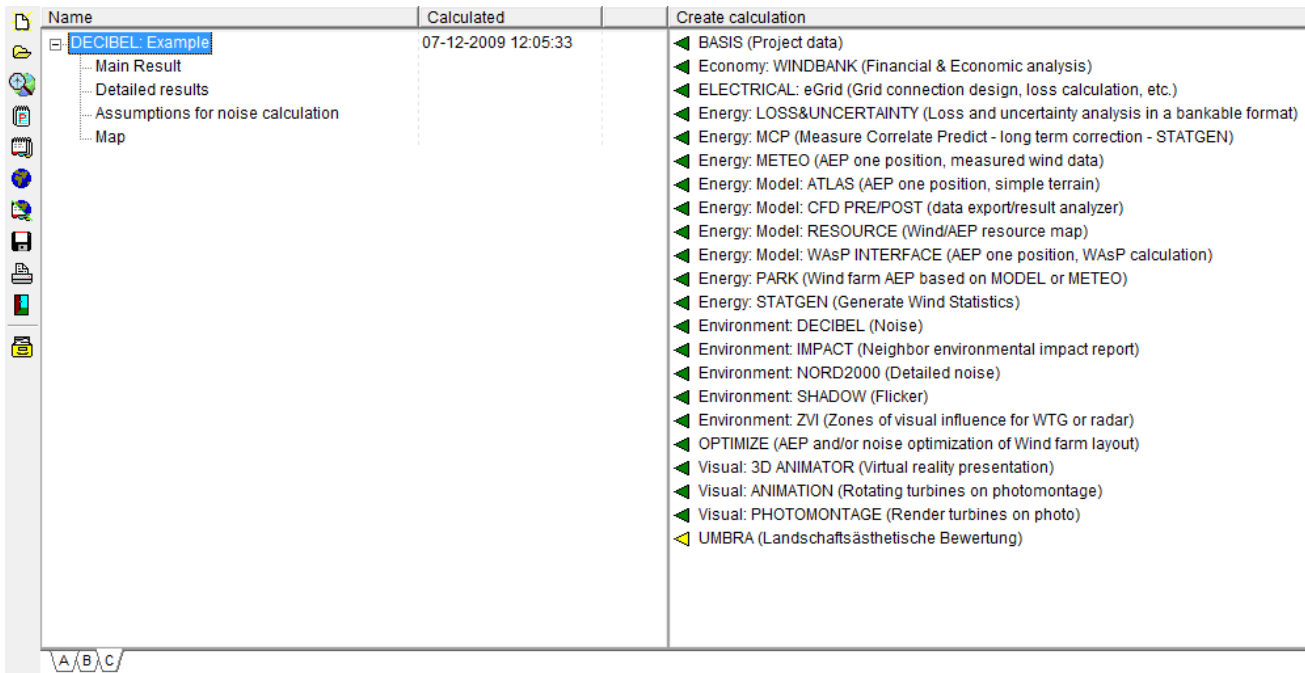
If no octave band distribution is available for the particular hub height WindPRO will look to other heights to find the closest wind speed for a base distribution.

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

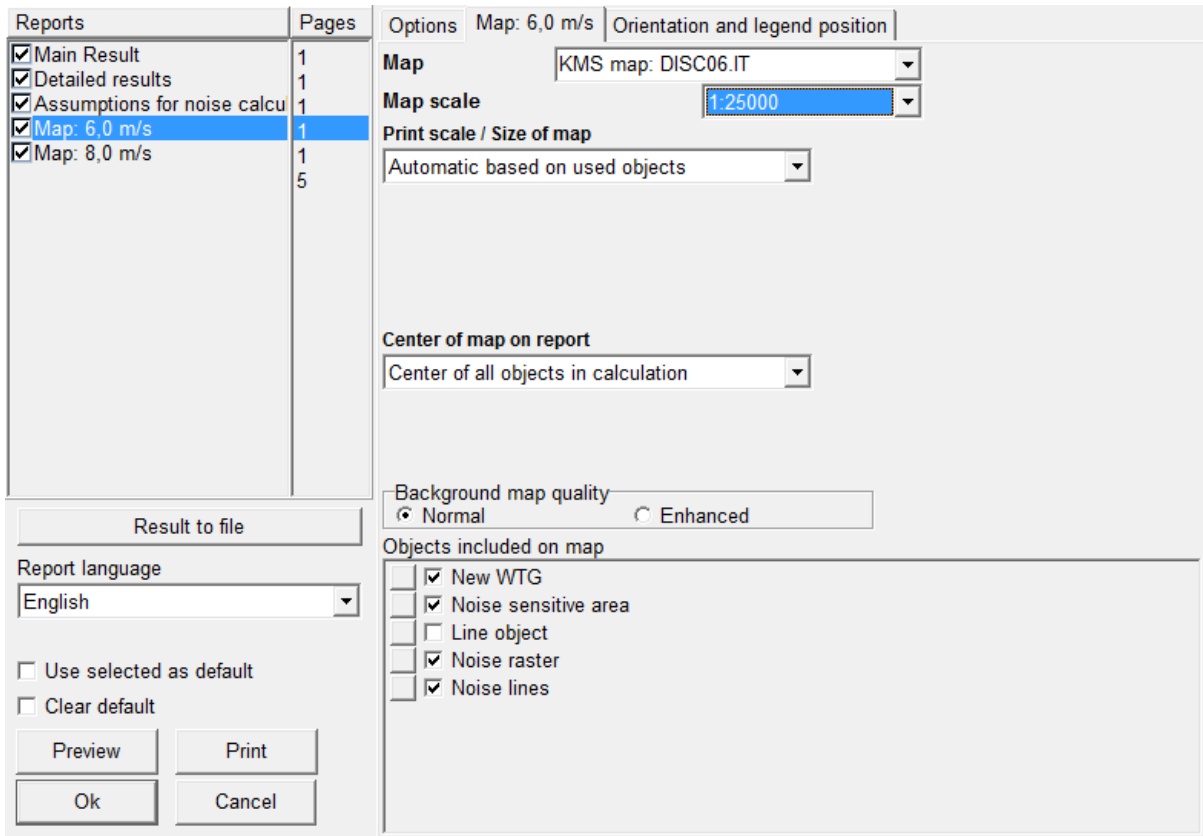
After the calculation has been completed, a window like the one shown below will appear which lists the available reports that can be printed.



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).



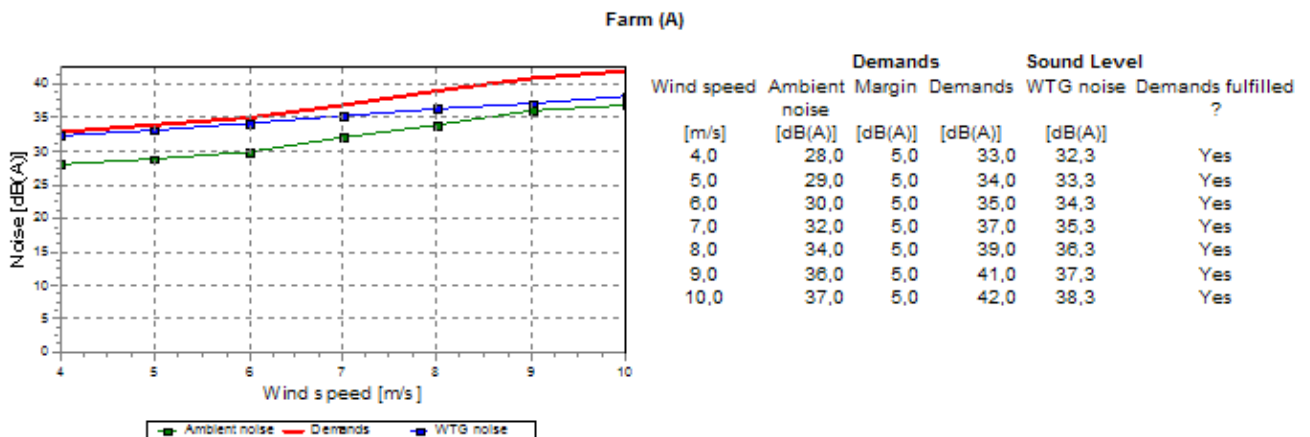
In the checkbox to the left, the individual report elements can be selected or deselected for printout. By clicking on the report name you gain access to the setup mode for the selected report in the right half of the window. Here, details regarding the individual reports can be set (e.g. the map scale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



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”

The screenshot shows a dialog box with five sections, each for saving a different type of data. Each section contains a text input field for the file name and three buttons: 'Save', 'Save as...', and 'Copy to clipboard'. The sections are:

- WTG data**: File name input field, Save, Save as..., Copy to clipboard.
- WTG distances**: File name input field, Save, Save as..., Copy to clipboard.
- NSA data**: File name input field, Save, Save as..., Copy to clipboard.
- Noise lines in shape format**: File name input field, Save, Save as...
- Detailed results**: File name input field, Save, Save as..., Copy to clipboard.

A 'Close' button is located at the bottom left of the dialog box.

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).

Main | WTGs | Noise map | Description

Name

Calculate

Standard calculation:

- Noise at Noise sensitive areas (NSA's)
- Noise map (in report/result layer)

Interactive noise lines on map for layout optimization. ...

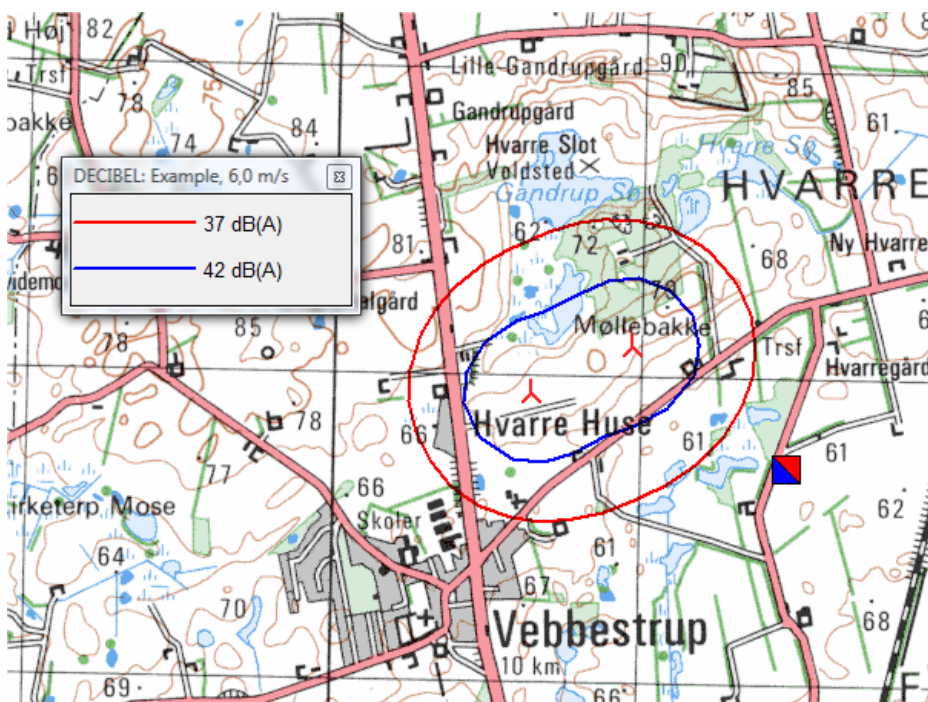
Noise allowance map

Noise calculation model

Note: If another model is selected, model parameter changes are reset.

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.



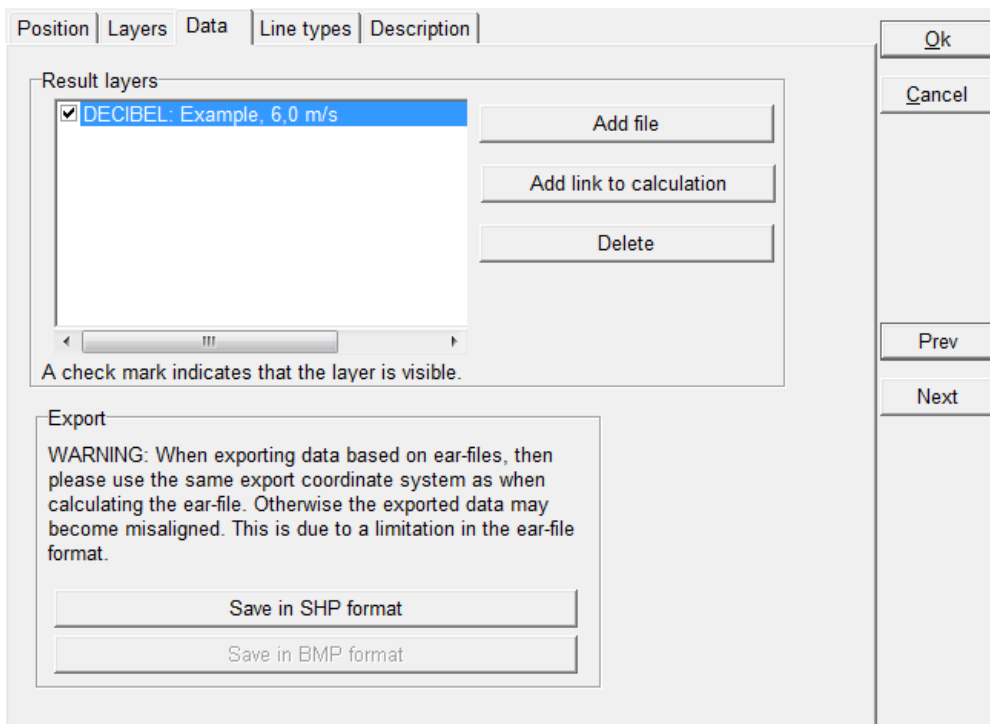
You can move the turbines, change noise settings or turbine types, remove turbines or add turbines (in the layers used for the calculation). When the turbines are deactivated (no turbines selected anymore) the update

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 by 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.

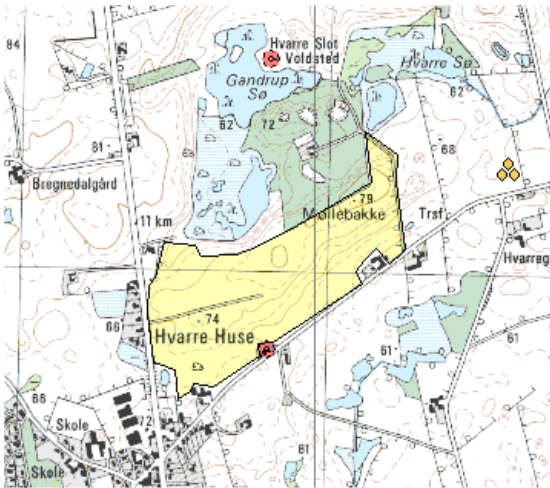
In the tap Line types it is possible to change the configuration of the lines as described in previous sections.

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.

Main	NSA	Noise allowance map	Description
Name <input type="text" value="Noise allowance map"/>			
Calculate			
<input type="radio"/> Standard calculation: <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Noise at Noise sensitive areas (NSA's) <input checked="" type="checkbox"/> Noise map (in report/result layer) 			
<input type="radio"/> Interactive noise lines on map for layout optimization.			
<input checked="" type="radio"/> Noise allowance map			
Noise calculation model			
<input type="text" value="Danish 2007"/>			<input type="button" value="Edit model parameters"/>
Note: If another model is selected, model parameter changes are reset.			
<input type="button" value="Ok"/> <input type="button" value="Cancel"/>			

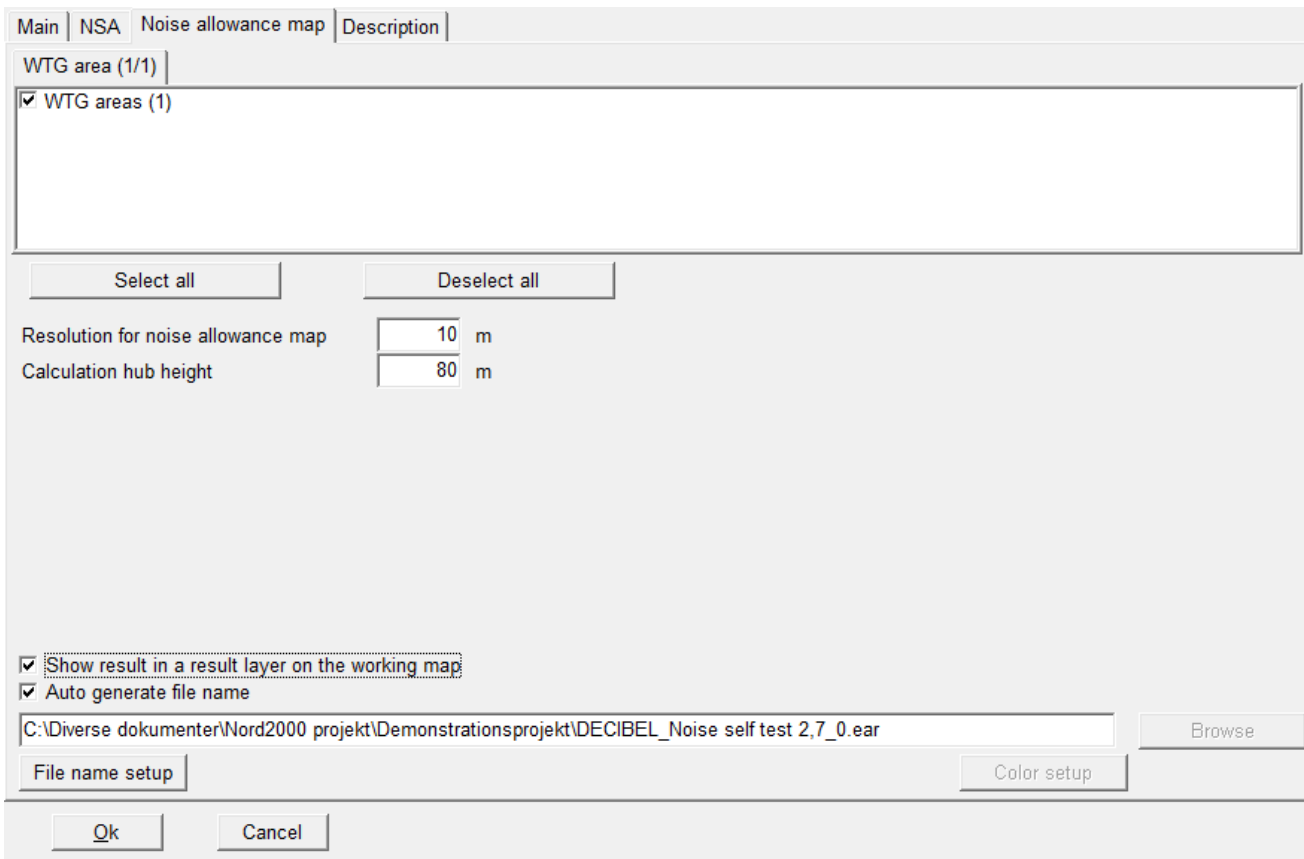
Note that the calculation model is disabled.

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

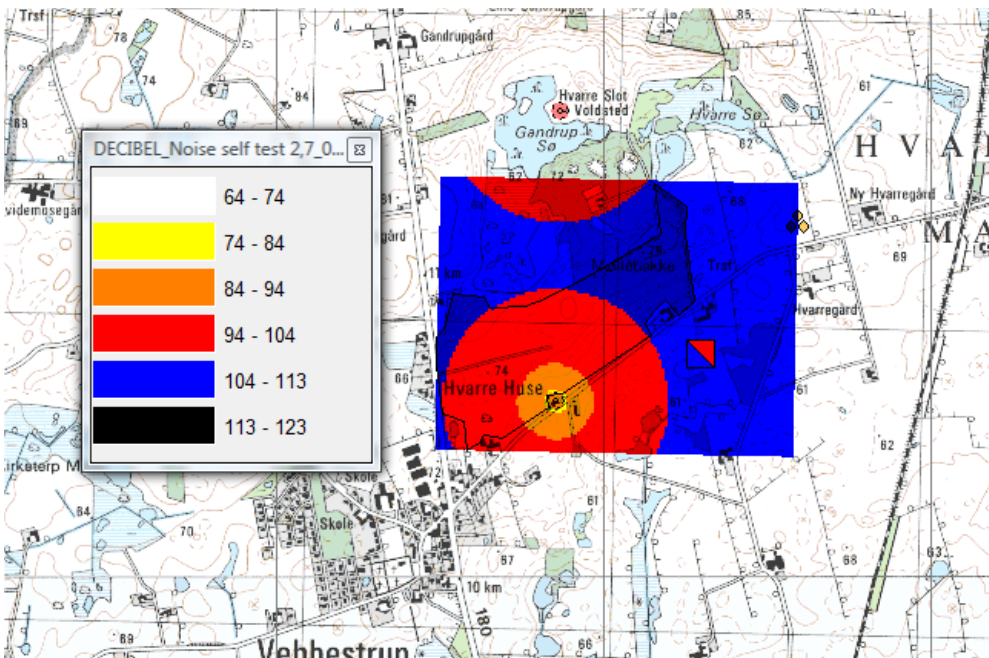
On the NSA tab the noise receptors limiting the site are selected by layer.

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:

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

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_Ω (Needed because the alternative method for calculating ground attenuation, A_{gr} is used)

$$D_C = D_{\Omega} - 0 \quad (2)$$

D_Ω is calculated as:

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

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).

$$d_p = \sqrt{[(x_s - x_r)^2 + (y_s - y_r)^2]} \quad (4)$$

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

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

A_{div}: Damping due to geometry

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

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

$$A_{atm} = \alpha_{500} d / 1000 \quad (7)$$

α₅₀₀: Air absorptions coefficient (= 1,9 dB/km)

The value for α₅₀₀ is based on the most optimal noise emission conditions (temperature 10 Gr. C and 70% relative atmospheric humidity)

A_{gr}: Terrain damping:

$$A_{gr} = 4,8 - (2h_m / d)[17 + (300 / d)] \quad (8)$$

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:

$$h_m = (h_s + h_r) / 2 \quad (9a)$$

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:

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

F: Integrated area from emission point to receptor (immission point)

$$F = F_1 + F_2 + \dots + F_{100}$$

d: distance from emission point to receptor (immission point)

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

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

C_{met} : Meteorological correction which is determined by means of the equation:

$$C_{\text{met}} = 0 \text{ for } d_p < 10 (h_s + h_r)$$

$$C_{\text{met}} = C_0 [1 - 10(h_s + h_r)/d_p] \text{ for } d_p > 10,$$

d_p : Distance between noise source and recipient projected on level terrain.

where the factor C_0 , dependent on weather conditions, can be between 0 and 5 dB. In exceptional cases, values over 2 dB may occur. In WindPRO, C_0 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:

$$L_{\text{AT}}(\text{DW}) = 10 \lg \left(10^{0,1L_{\text{AFT}}(63)} + 10^{0,1L_{\text{AFT}}(125)} + 10^{0,1L_{\text{AFT}}(250)} + 10^{0,1L_{\text{AFT}}(500)} + 10^{0,1L_{\text{AFT}}(1k)} + 10^{0,1L_{\text{AFT}}(2k)} + 10^{0,1L_{\text{AFT}}(4k)} + 10^{0,1L_{\text{AFT}}(8k)} \right) \quad (10)$$

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:

$$L_{\text{AFT}}(\text{DW}) = (L_W + A_f) + D_C - A \quad (11)$$

where:

L_W : Octave noise source for non A-weighted point source. $L_W + A_f$ 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 $D_\Omega = 0$, 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:

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

- A_{div} : Damping due to geometry (= VDI 2714 Distance figure D_s)
 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 $A_{\text{bar}}=0$
 A_{misc} : Damping due to different other effects (growth, housing, industry). Worst case $A_{\text{misc}}=0$

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

$$A_{\text{atm}} = \alpha_f d / 1000 \quad (13)$$

where:

α_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
α_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:

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

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

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

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 Hz	A_s or A_r ¹⁾ dB	A_m dB
63	- 1,5	- 3q ²
125	- 1,5 + G × a'(h)	- 3q(1 - G _m)
250	- 1,5 + G × b'(h)	
500	- 1,5 + G × c'(h)	
1 000	- 1,5 + G × d'(h)	
2 000	- 1,5(1 - G)	
4 000	- 1,5(1 - G)	
8 000	- 1,5(1 - G)	

NOTES

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

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

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

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

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 $d_p \leq 30(h_s + h_r)$

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

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:

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

- 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_{li} : 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 $d_p < 10 (h_s + h_r)$
 $C_{met} = C_0 [1 - 10(h_s + h_r)/d_p]$ for $d_p > 10$,
- d_p : Distance between noise source and recipient projected on level terrain.

where the factor C_0 , dependent on weather conditions, can be between 0 and 5 dB. In exceptional cases values over 2 dB may occur. In WindPRO the C_0 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 *Iden_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 be 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:

$$LS = LW + DI + KO - DS - DL - DBM - DD - DG \quad \text{in dB(A)}$$

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 $DS=10 \log(4 \pi S^2)$

DL : Air absorption figure $DL=\alpha_L S$

$$\alpha_L = 0.00209 \text{ dB/m}$$

DBM : Terrain and meteorological damping figure

$$DBM = \text{Max}(0, 4.8 - (hq+hA)/S(17+300/S))$$

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 added 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:

$$L_{pA} = L_{WA,ref} - 10 \times \log(l^2 + h^2) - 8dB - \Delta L_a$$

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:

$$L_{pA} = L_{WA,ref} - 10 \times \log(l^2 + h^2) - 11dB + \Delta L_g - \Delta L_a$$

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:

$$L_{total} = 10 * \log \left(10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + \dots \right)$$

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.

$$L_{WA,corr} = L_{WA,measured} + k \cdot \Delta v_h$$

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).

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

$$\Delta v_h = v_h \left[\ln(H/z_0) / \ln(h/z_0) \right] \cdot \left[\ln(h/0,05) / \ln(H/0,05) \right] - 1$$

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:

$$L_A = L_{WA,corr} - 10 - 20 \cdot \log(r) - \Delta L_a$$

Here the damping ΔL_a is calculated as:

$$\Delta L_a = 10 \cdot \log(\sum 10^{(L_i + A_i)/10}) - 10 \cdot \log(\sum 10^{(L_i + A_i - r \cdot ai)/10})$$

where L_i is the measured octave-band value and A_i 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.

$$L_A = L_{WA,corr} - 8 - 20 \cdot \log(r) - \Delta L_a + 10 \cdot \log(r/200)$$

where:

$$\Delta L_a = 10 \cdot \log(\sum 10^{(L_i + A_i)/10}) - 10 \cdot \log(\sum 10^{(L_i + A_i - r \cdot ai)/10})$$

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:

$$L_i = L_{WR} - \Sigma D$$

Where L_i is the noise level at the receptor

L_{WR} is the noise level at the WTG

And ΣD is:

$$\Sigma D = D_{geo} + D_{lucht} + D_{refl} + D_{schem} + D_{veg} + D_{terrein} + D_{boden} + D_{huis}$$

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:

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

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:

$$D_{lucht} = 0,002 \cdot d$$

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

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

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

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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:

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

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 Windenergieanlagen" (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 curtilage. 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.

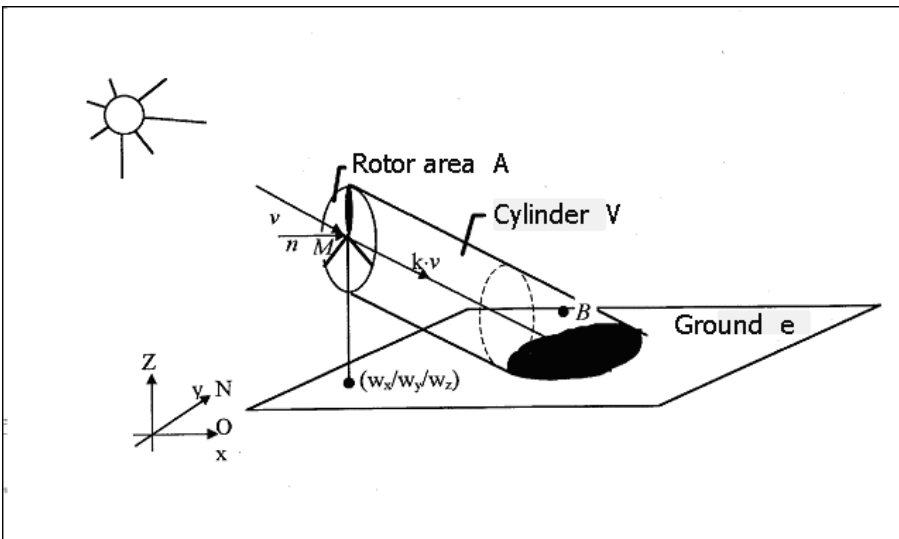
As in the other WindPRO modules, input of data can be based solely on entering coordinates and characteristics for the individual WTG and shadow receptor objects manually.

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

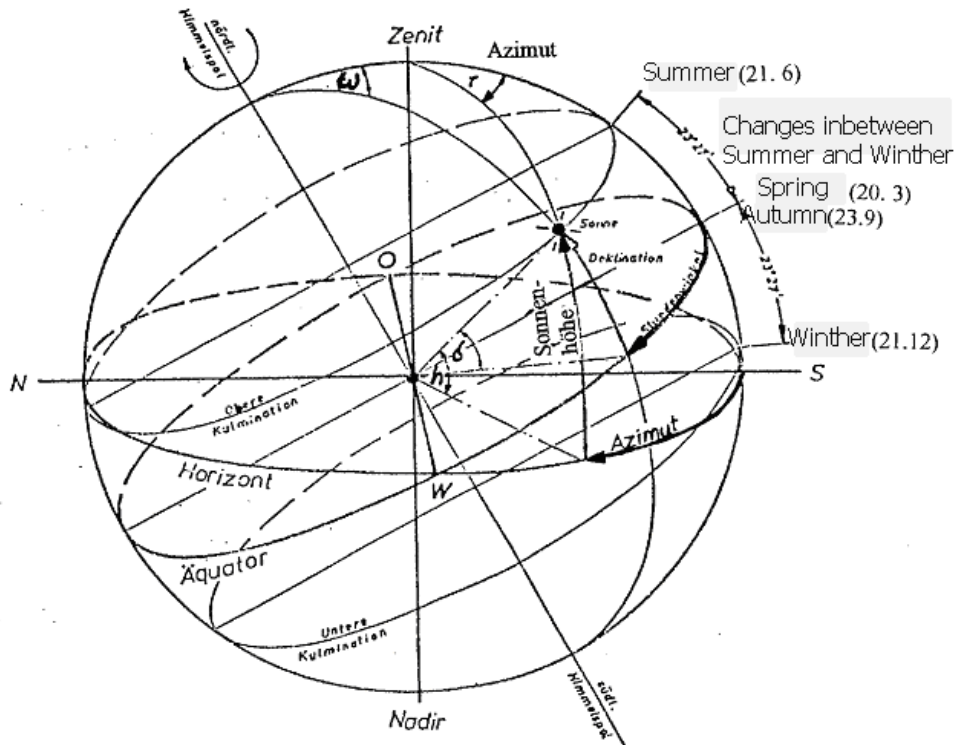
In the shadow calculation model used by WindPRO the following parameters defines the shadow propagation angle behind the rotor disk

- 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

$$\text{Max. distance} = (5 * w * d) / 1,097,780$$

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

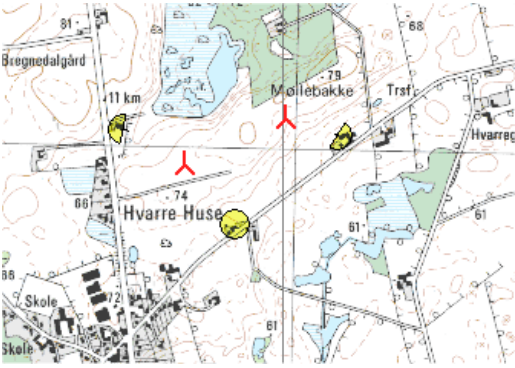
Shadow Receptors are objects for which the potential risk of shadow impact is calculated.



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.

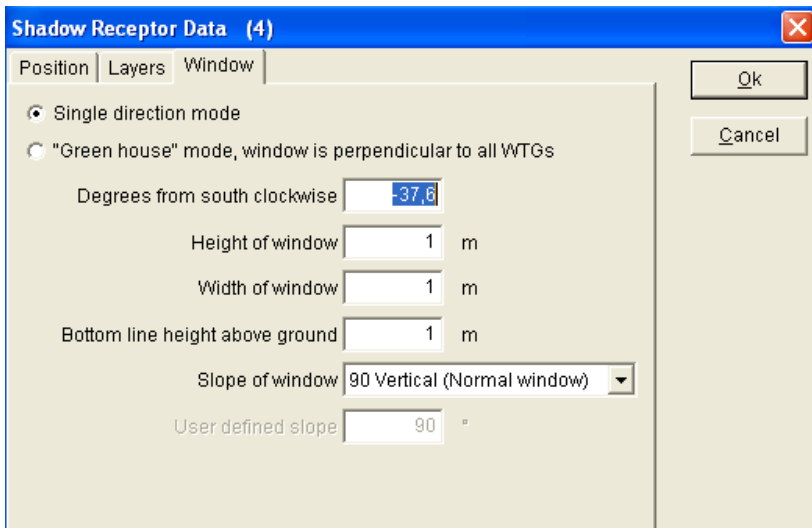
Note: The z-coordinate of a shadow receptor must be entered in the same reference system as the z-coordinate of the WTGs. If the WTGs have been entered with the default value "0", you have to enter the z-coordinates for the shadow receptors relative to the elevation of the WTG foundation, i.e. if the 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.

Main | WTGs | Receptors | ZVI | Description |

Name

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)

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.

Main | WTGs | Receptors | ZVI | Description

Name: Shadow flickering calculation

Calculate:

Flicker at receptors

Worst case

Real case based on statistics

Real case based on time series (Experimental)

Flicker map

Worst case

Real case based on statistics

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)

Limit distance according to blade width

Fixed distance: 2.000 m from WTG

First distance circle of WTG (If ellipse: Major axis is used)

Second distance circle of WTG (If ellipse: Major axis is used)

No limit

Flicker is ignored if sun is less than 3.0 ° above horizon (due to atmospheric diffusion/low radiation/sheltering)

Set reference year

Limit the distance in which flicker is still considered relevant by using blade width data from WTG catalogue to calculate shaded area (more than 20% of the sun covered by blade). If no blade data is available, the selected option below is used:

Ok Cancel

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.

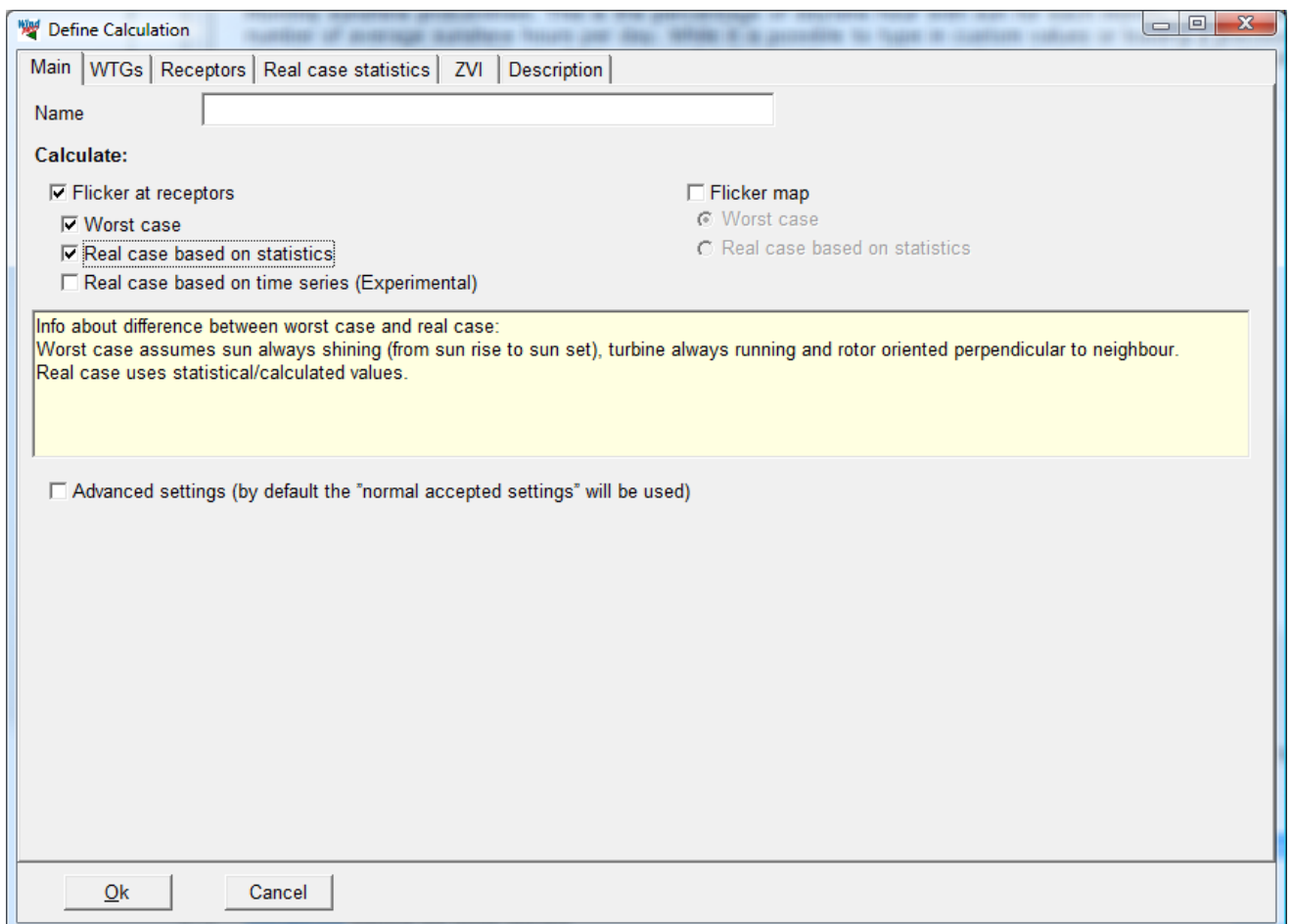
In order to perform the ZVI calculation, there must be a height model available in the form of a line object with height contours. Area objects defining blocking elements like forests or villages and obstacles can also be included.

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.

Define Calculation

Main | WTGs | Receptors | Real case statistics | ZVI | Description

Operational hours

Manual input for each sector Calculate from selected WTG's

Operational hours are calculated from the selected WTG's, using the wind distribution information in following Site data or Meteo data object.

Wishek met mast 7/01 to 6/02 - 30.00 m

User defined idle start wind speed 0.0 m/s Default is cut in wind speed from power curve

Load Save

Monthly sunshine probabilities

Station from database: [BISMARCK] Select

Manual input of S (Average daily sunshine hours)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4.92	5.13	7.45	8.03	10.20	11.21	11.69	10.35	8.68	5.69	4.02	3.69

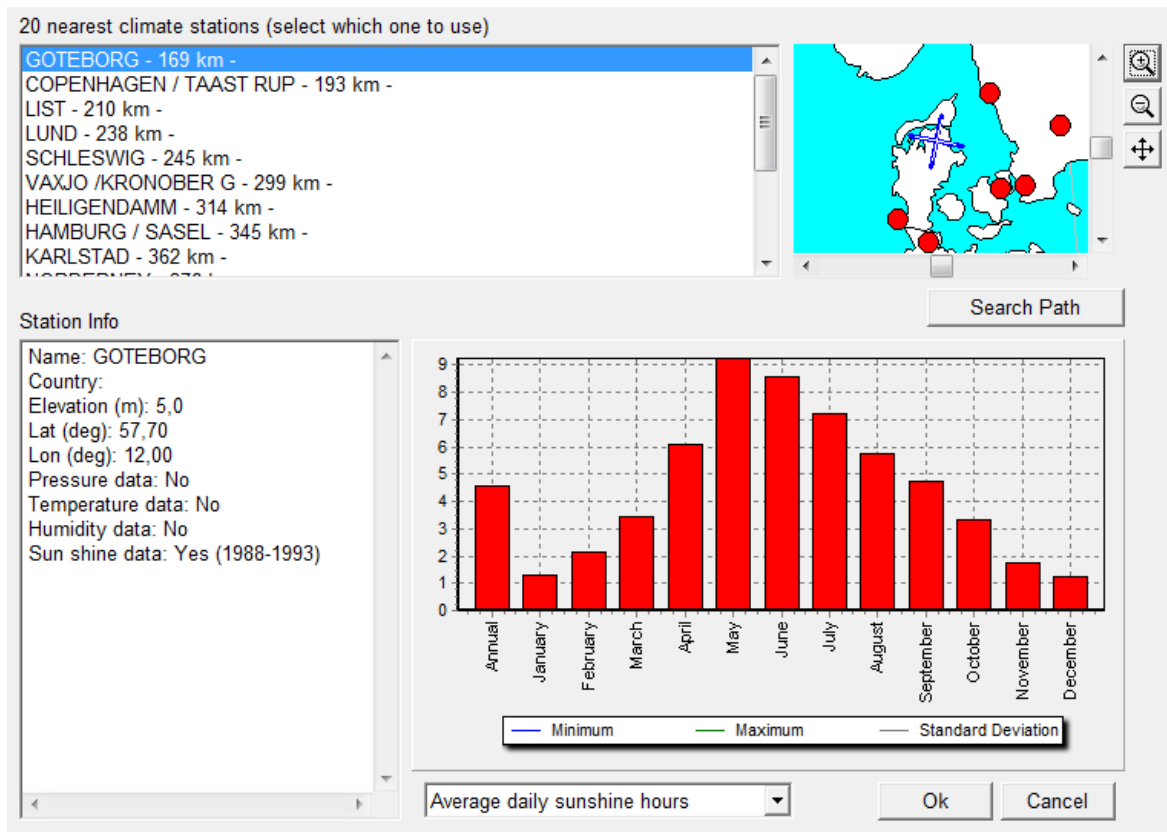
Load Save

Ok Cancel

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.

Main | WTGs | Receptors | **Real case time series** | ZVI | Description

Name

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)

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.

Use generic time variation data (*.WTI)

Use time series from Meteo object

Start date:

Signal used for sun shine:

Sun shines when signal value:

Threshold value:

Mean wind speed in hub height for all WTGs:

User defined idle start wind speed: m/s Default is cut in wind speed from power curve

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

Calculate:

<input type="checkbox"/> Flicker at receptors	<input checked="" type="checkbox"/> Flicker map
<input checked="" type="checkbox"/> Worst case	<input checked="" type="radio"/> Worst case
<input type="checkbox"/> Real case based on statistics	<input type="radio"/> Real case based on statistics
<input type="checkbox"/> 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)

Selecting the Flicker map option enables the flicker map tab.

Main | WTGs | Flicker map | ZVI | Description

Flicker map data

Data are calculated in a rectangle, given by the following distances in km from the Site Center :

 Elevation of calculation plane

[m above sea level]

Use heights from active line object + eye height from ZVI setup

Resolution

Coarse
 Normal
 Fine

Edit

Calculation	Use lines	Edit line setup	Use raster	Edit raster setup	Show in result layer
Hours per year, worst case	<input checked="" type="checkbox"/>	Edit	<input checked="" type="checkbox"/>	Edit	<input type="checkbox"/>
Shadow days per year, worst case	<input type="checkbox"/>	Edit	<input type="checkbox"/>	Edit	<input type="checkbox"/>
Max minutes per shadow day, worst case	<input type="checkbox"/>	Edit	<input type="checkbox"/>	Edit	<input type="checkbox"/>
Hours per year, real case *)	<input checked="" type="checkbox"/>	Edit	<input checked="" type="checkbox"/>	Edit	<input type="checkbox"/>
Shadow days per year, real case *)	<input type="checkbox"/>	Edit	<input type="checkbox"/>	Edit	<input type="checkbox"/>
Max minutes per shadow day, real case *)	<input type="checkbox"/>	Edit	<input type="checkbox"/>	Edit	<input type="checkbox"/>

*) This map is not calculated with current selection on main tab. Settings are only available for editing definitions of standard setup.
Note: These settings are default values for the report setup – when printing the report, settings can be revised.

Template

Load Save as

Save as standard for country

Ok Cancel

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 items below are used for shadow maps only

Time step minutes

Day step days

Grid size m

Resolution

Coarse
 Normal
 Fine

Ok Cancel

The lower part of the tab defines the maps included 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.

Line type	Value	Line width	Line color	Gray scale
1	5,0	2	Magenta	100
2	10,0	2	Blue	100
3	20,0	2	Cyan	100
4	40,0	2	Yellow	100
▶	100,0	2	Red	100

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.

	Start	End	Color 1	Hatching
1	5	10	Magenta	Black
2	10	20	Blue	Black
3	20	40	Cyan	Black
4	40	100	Yellow	Black
5	100	1000	Red	Black

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.

If 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	<ul style="list-style-type: none"> ◀ BASIS (Project data) ◀ Economy: WINDBANK (Financial & Economic analysis) ◀ ELECTRICAL: eGrid (Grid connection design, loss calculation, etc.) ◀ Energy: LOSS&UNCERTAINTY (Loss and uncertainty analysis in a bankable format) ◀ Energy: MCP (Measure Correlate Predict - long term correction - STATGEN) ◀ Energy: METEO (AEP one position, measured wind data) ◀ 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)
Main Result		
Calendar		
Calendar, graphical		
Calendar per WTG		
Calendar per WTG, graphical		
Map		

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.

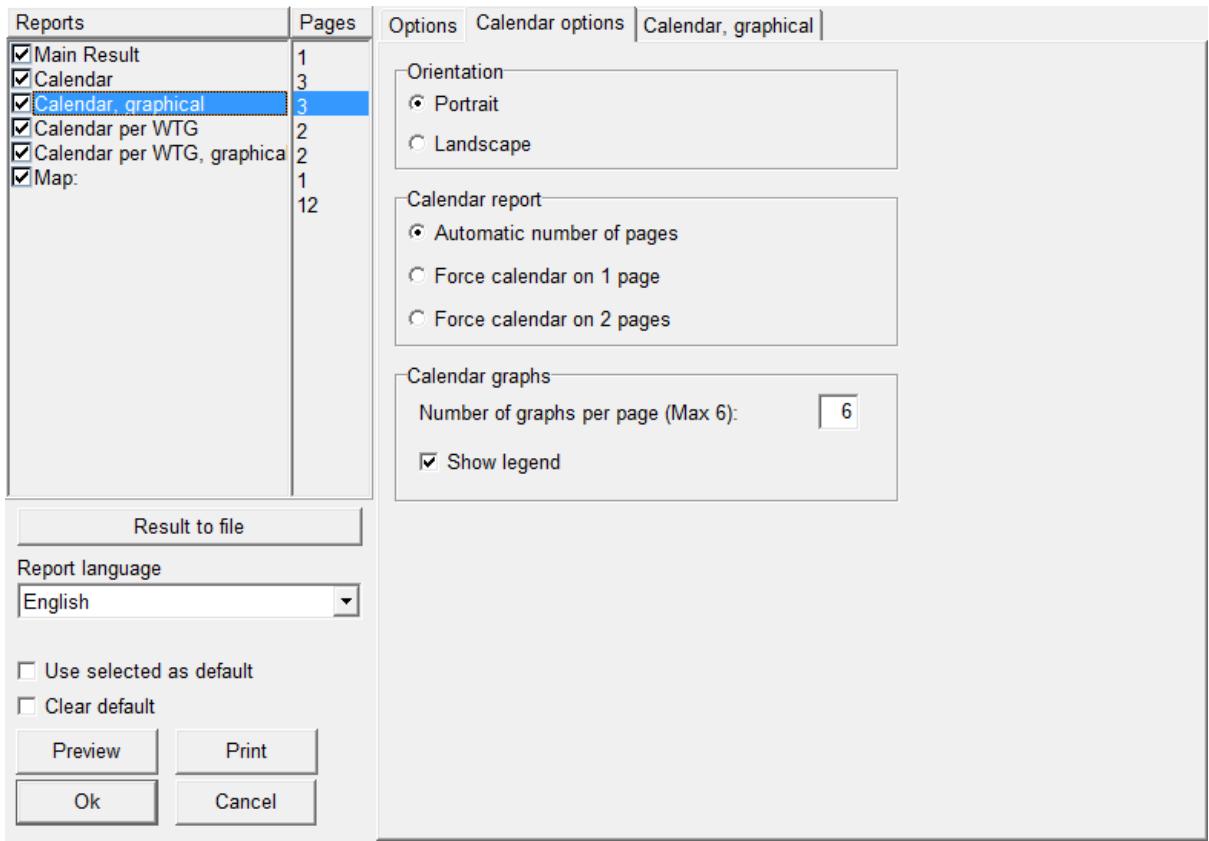
WTG data File name <input type="text"/> <input type="button" value="Save"/> <input type="button" value="Save as..."/> <input type="button" value="Copy to clipboard"/>
WTG distances File name <input type="text"/> <input type="button" value="Save"/> <input type="button" value="Save as..."/> <input type="button" value="Copy to clipboard"/>
Shadow receptor data File name <input type="text"/> <input type="button" value="Save"/> <input type="button" value="Save as..."/> <input type="button" value="Copy to clipboard"/>
Shadow calendar File name <input type="text"/> <input type="button" value="Save"/> <input type="button" value="Save as..."/> <input type="button" value="Copy to clipboard"/>
Shadow calendar per WTG File name <input type="text"/> <input type="button" value="Save"/> <input type="button" value="Save as..."/> <input type="button" value="Copy to clipboard"/>
Time series details File name <input type="text"/> <input type="button" value="Save"/> <input type="button" value="Save as..."/> <input type="button" value="Copy to clipboard"/>
Shadow lines in shape format File name <input type="text"/> <input type="button" value="Save"/> <input type="button" value="Save as..."/>
Shadow details File name <input type="text"/> <input type="button" value="Save"/> <input type="button" value="Save as..."/> <input type="button" value="Copy to clipboard"/>
<input type="button" value="Close"/>

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	Options	Map: Orientation and legend position
<input checked="" type="checkbox"/> Main Result	1	Map	KMS map: DISC06.IT
<input checked="" type="checkbox"/> Calendar	3	Map scale	Auto
<input checked="" type="checkbox"/> Calendar, graphical	3	Print scale / Size of map	Automatic based on used objects
<input checked="" type="checkbox"/> Calendar per WTG	2		
<input checked="" type="checkbox"/> Calendar per WTG, graphical	2		
<input checked="" type="checkbox"/> Map:	1		
	12		

Result to file

Report language
English

Use selected as default
 Clear default

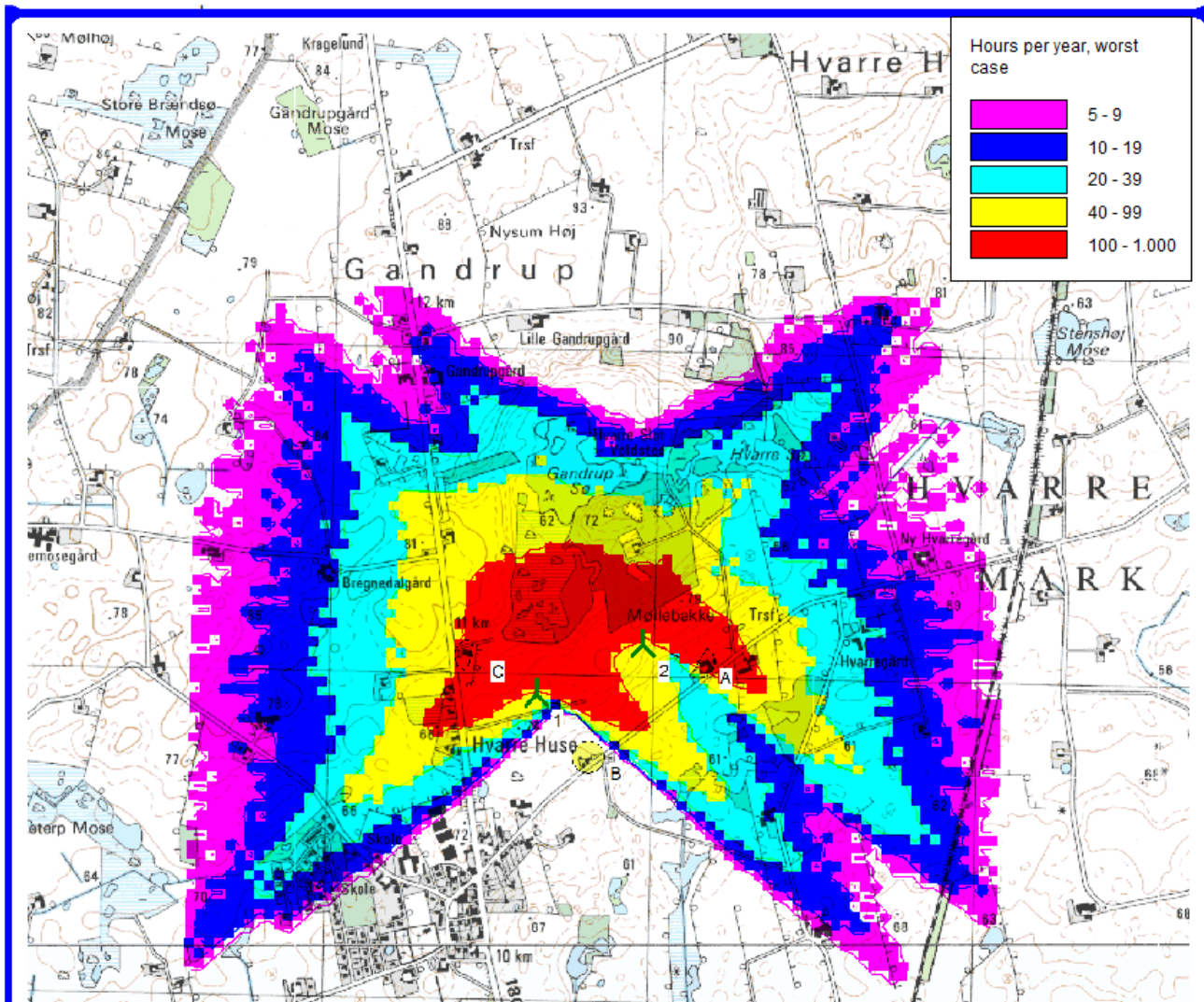
Preview Print

Ok Cancel

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

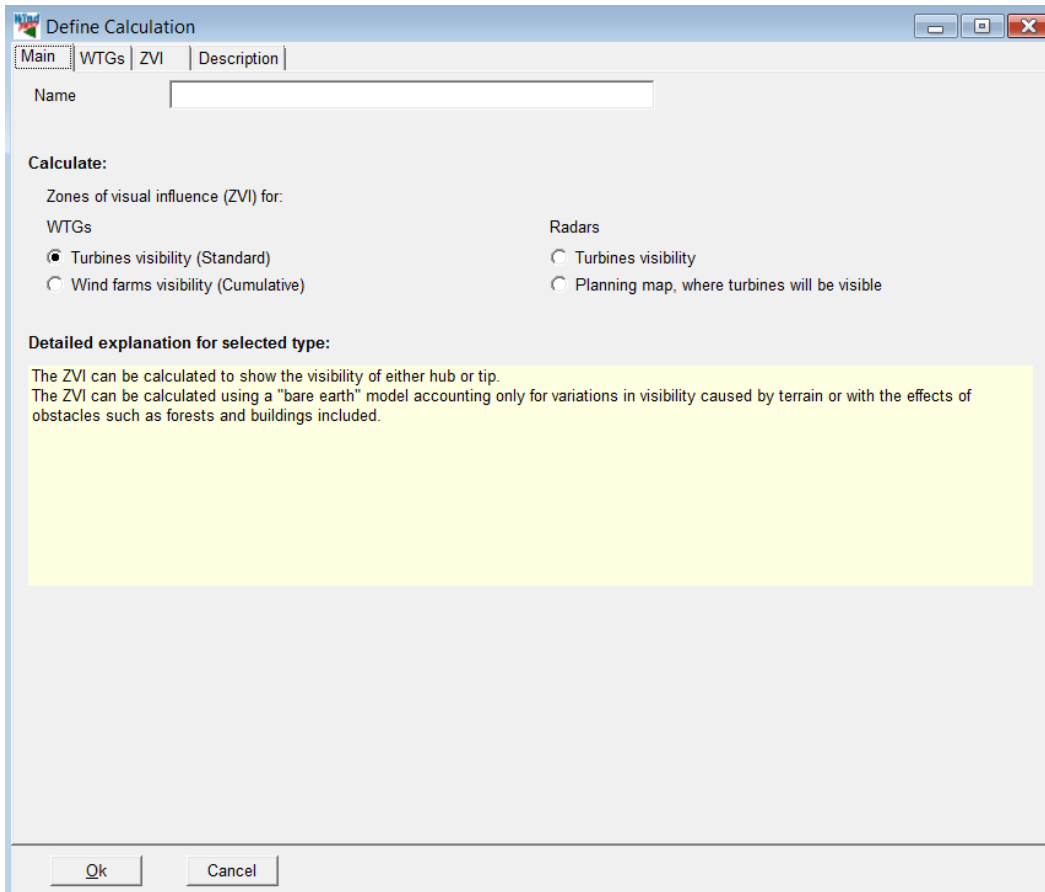


Figure 1 At the Main tab, the type of calculation is chosen.

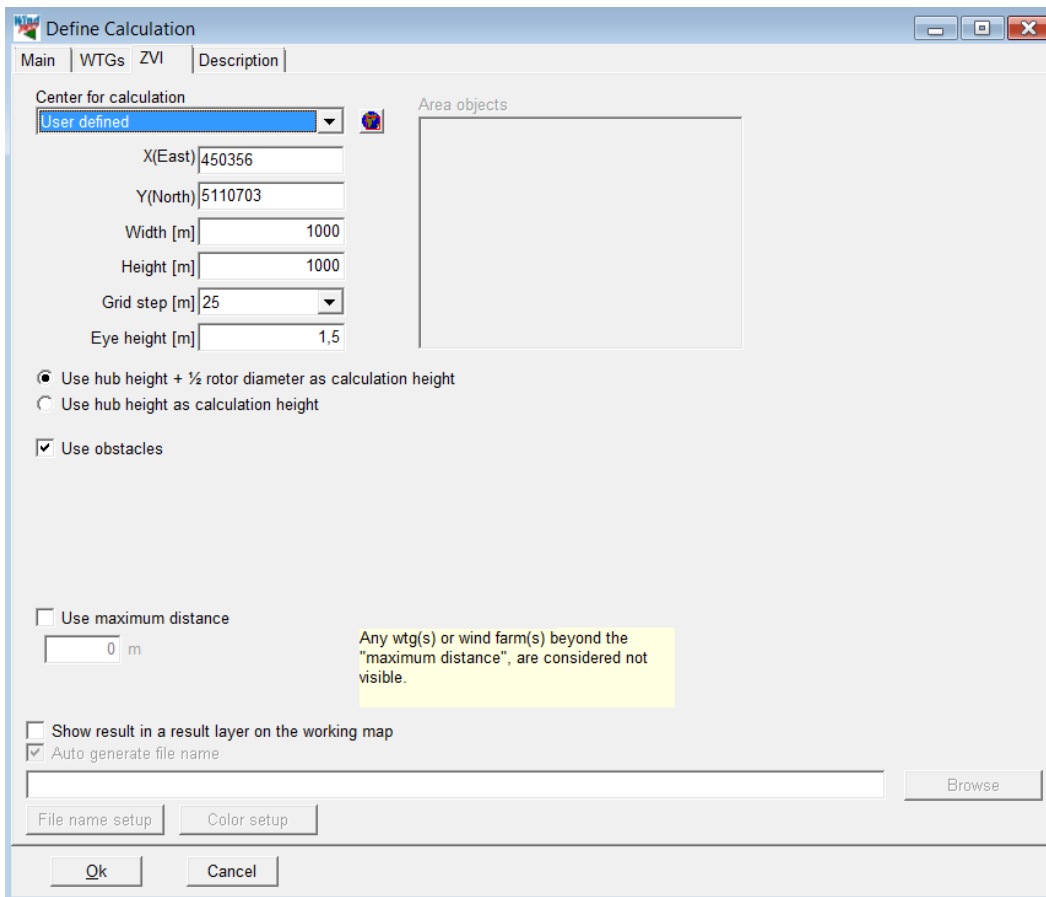
Name of calculation: Here a name can be entered for the calculation to help you recognize it when there are more calculations in the same project.

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.

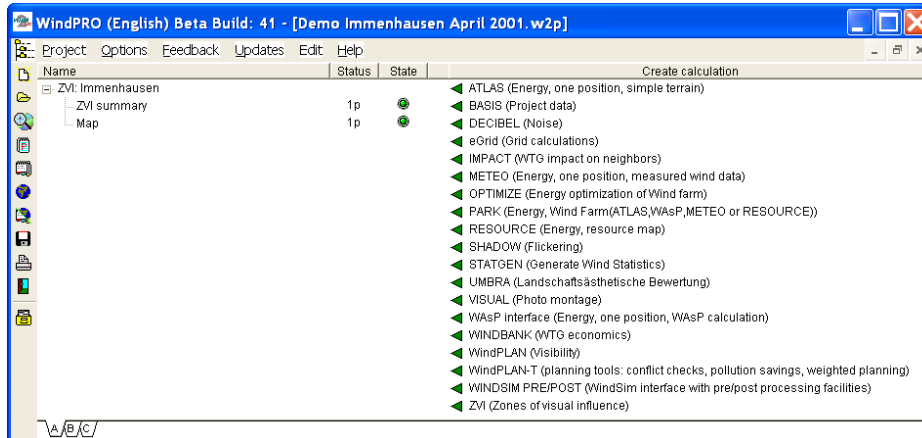
Auto-generate a result layer: This option automatically inserts a result layer object on the map with the ZVI calculation after it is finished. You can choose color setup before starting the calculations, but it can always be changed later on by selecting "properties" of the result layer object.

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.

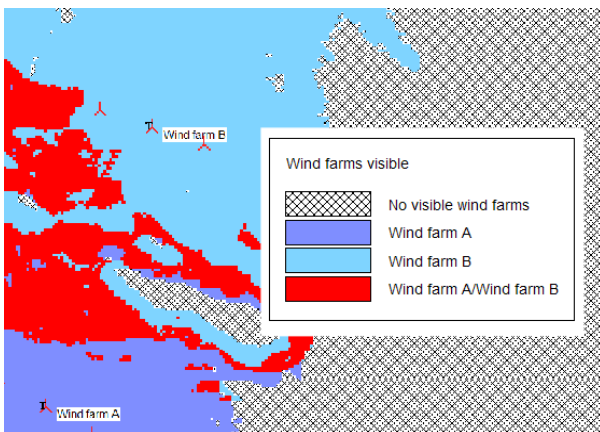
In ZVI calculation, the ZVI for “Wind farms visibility (Cumulative)” should be selected.

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.

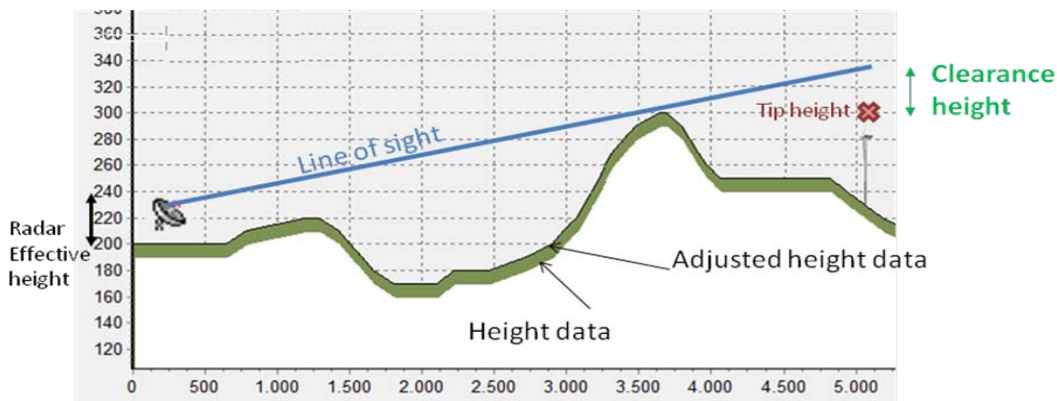


In addition, the display can be manipulated to add or remove colours from any of the legend entries. If you want to see only those areas where wind farm A adds to the visibility of wind farms in the area, then you can

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.

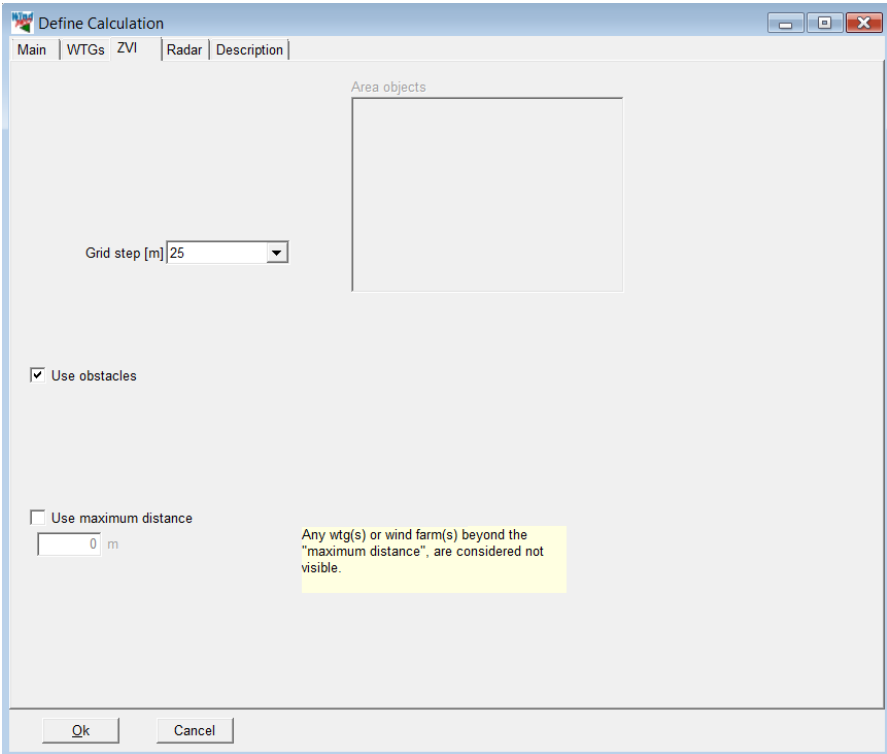


Definition of the clearance height in a Radar ZVI calculation

4.3.5.1 Radar ZVI - Setup

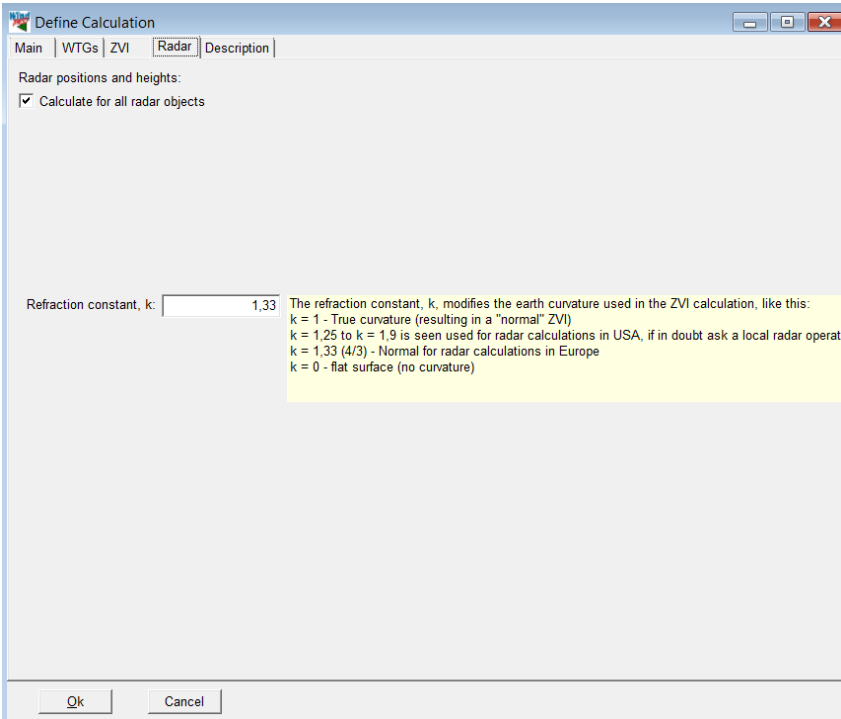
Turbines visibility calculation

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.



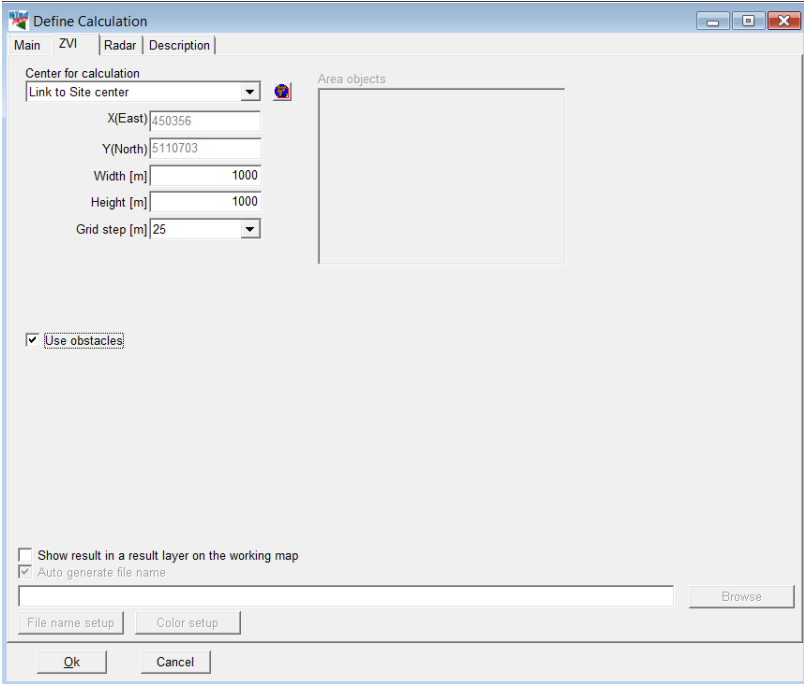
Planning map calculation

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

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

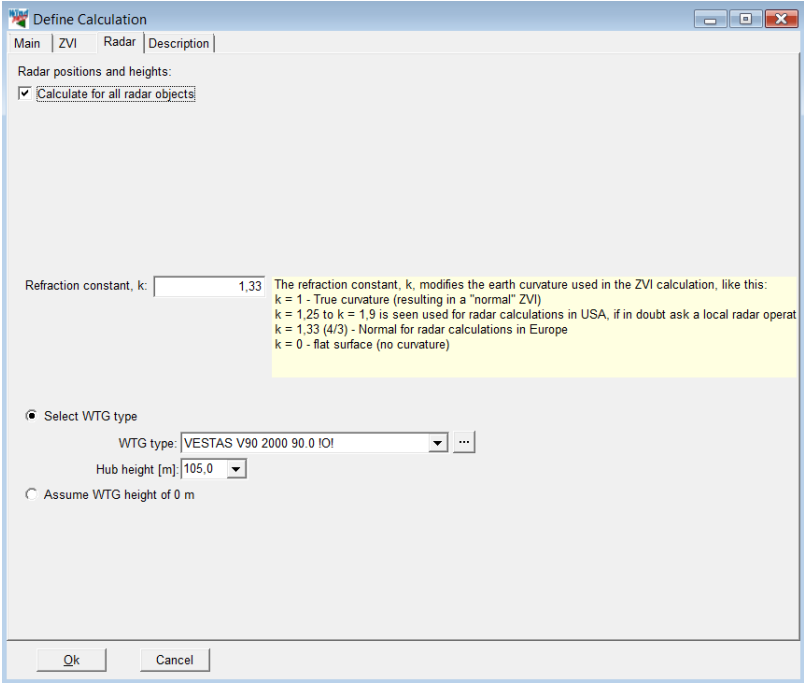
Definition of the calculation area: the area can be selected for the ZVI calculation with a center and an extent for the calculation. Here the site center can be a useful anchor point, but it is also possible to type a coordinate point as the center of the calculation. For a graphical definition of the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

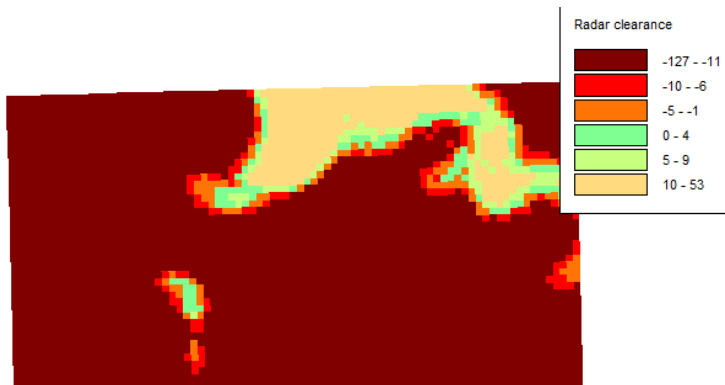
The clearance height between each wind turbine and radar is given in a table. The clearance height specifies the space between the WTG and the line of site of a radar; negative value indicates that the height of the WTG is above the limit.

		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.

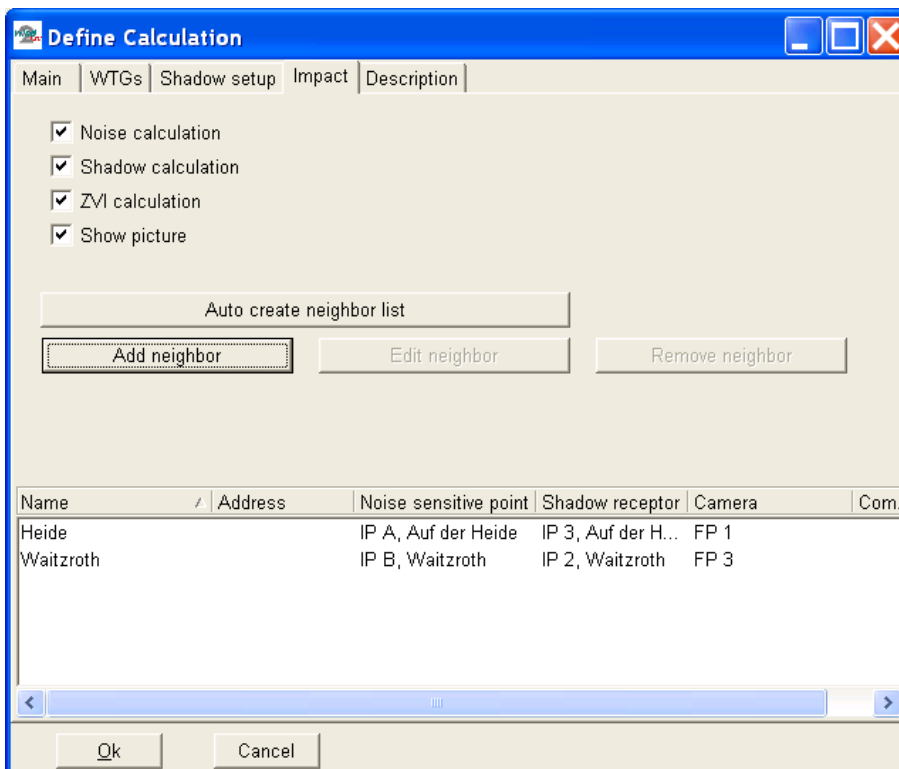
4.4.1 IMPACT - Calculation method and setup

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.

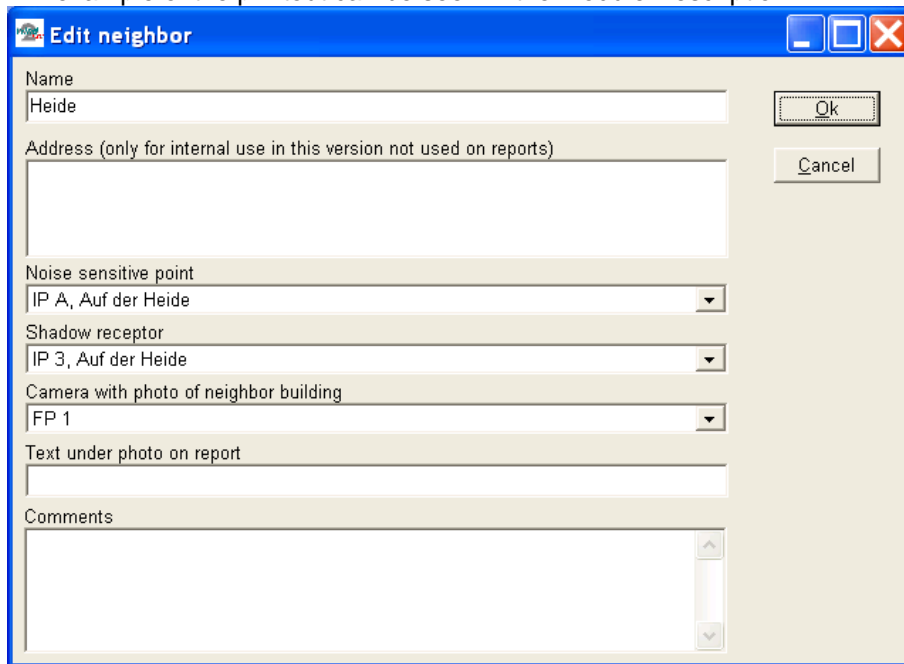


4.2. SHADOW - Flickering • 342

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.



The image shows a screenshot of a software dialog box titled "Edit neighbor". The dialog box has a blue title bar with standard window controls (minimize, maximize, close). The main area is light beige and contains several input fields and dropdown menus. On the right side, there are "Ok" and "Cancel" buttons.

- Name:** A text input field containing "Heide".
- Address (only for internal use in this version not used on reports):** An empty text input field.
- Noise sensitive point:** A dropdown menu with "IP A, Auf der Heide" selected.
- Shadow receptor:** A dropdown menu with "IP 3, Auf der Heide" selected.
- Camera with photo of neighbor building:** A dropdown menu with "FP 1" selected.
- Text under photo on report:** An empty text input field.
- Comments:** A text area with a vertical scrollbar, currently empty.

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5.0 VISUAL – Introduction and step-by-step guide

5.0.1 Introduction to visualizations

The WindPRO turbine visualization modules are tools for the documentation of the visual impact from turbines sitting in the landscape when negotiating with planning authorities about the turbine sizes, the number of turbines and the layout of wind farms.

There will always be different opinions on the visual impact of a turbine project in the landscape, but visualizations can often settle the difference of opinion, and it will thus be possible to ensure the widest possible support for the best project alternatives before the project is implemented.

In WindPRO we have attempted to simplify the visualization process. This is why information on most of the turbines on the market has been entered in the turbine catalogue (as described in chapter 2, BASIS). This way, one only has to place the turbines on a map and select the turbine type. The program will then render the turbines taking into consideration such factors as lighting conditions, position of the sun, wind direction, etc. The turbines are placed in a landscape photo or in a digital landscape model.

Beside turbines, WindPRO can visualize almost everything via the 3D object, which can be linked to a .DXF file or a bitmap file - with certain limitations. Also the line- and area object, WASP obstacle and METEO-object can be used in visualizations, which makes it powerful also for the control of the data used in energy calculations.

Visualizations can roughly be divided into the following types:

A photomontage in which turbines are placed in a landscape photo.

A landscape analysis where turbines are placed in an artificial landscape calculated via digital height contour lines in order to evaluate a project from any position contrary to the above module where the positions are "locked" by the specific points from which photos are available

A "fixed position" animation (2D animation), which makes the turbines rotate on a photomontage, which e.g. can be published on the Internet

A 3D-Animation, which is a landscape analysis where it is possible to move around in the landscape (via the creation of a digital landscape model), and thus evaluate the turbine project from various angles, and even create a "movie" where a prearranged route is followed in the landscape. The 3D-Animation can also be e-mailed or burned on a CD to be played from a remote computer.

5.0.2 Step by step guide performing photomontage

Establish map and proposed turbine project (see basis 2.0.5)

If available, load height contour lines into line object. Use the "Automatic Z value from DHM" for all turbines and cameras (can be applied from the MultiEdit function)

Establish a camera object. Pick red camera object from right menu bar, place cursor where the photo is taken, click once, and click again near the turbine site. Load photo (or switch on "Artificial landscape"), set date, time and focal length if available.

Click OK to launch the photomontage window. Insert control points on the map as reference objects which are visible on the photo.

Calibrate camera model – best by using reference marks – Adjust Pan, Tilt, Rotation and focal length in menu left bar of photo as needed. Remember to adjust z-values to reasonable ones (especially if you don't use height contours) in order to get your sketch turbines inside your photo.

If digital height contours lines are available, the horizon line (yellow) is very handy to check the camera model. Click the render button in the menu bar on the top of the photo. NOTE: Default all turbines in visible layers are rendered, so use the layer structure (see Chapter 2.11 Basis) to select which turbines to render.

Rub out turbine parts that should be behind trees etc.

Export the photomontage as an image or from calculation menu, run Photomontage to generate report and printout.

5.0.3 Step by step guide performing 2D-animation

Continue from 5.0.2 If rotor parts will be behind trees etc during rotation, rub these parts (no turbine part visible, but rub anyhow – render eventually turbine on top of the part to be rubbed in order to make sure, that the right pixels will be removed.

Click at the red button in the photomontage (“Create animation”) in the top toolbar.

Apply information on the animation

Save the animated "movie" in WindPRO format or other and start animation.

When finished, the EMDplayer automatically starts showing the animation.

You can now send the animation file together with the EMDplayer.exe to any PC to be run.

5.0.4 Step by step guide performing 3Danimation

Establish map and proposed turbine project (se basis 2.0.5)

If e.g. aerial photo shall be used as surface, it will be a large advantage to attach it as a map (georeference it with 3 coordinate points or insert as a geo file)

Load height contour lines into line object. Make sure that height contour lines cover the whole region that shall be rendered – extend eventually with an additional line around the project region (often relevant for off shore projects).

Establish a VR object. Pick VR object from right toolbar; place the object in the middle of the region to be rendered. Set size (start eventually with a smaller region max. 1000 x 1000 m to test that everything is working as expected) – reduce eventually the number of triangles from height contour lines by choosing “grid”, if there are many points in height contour lines. Select the texture of the ground.

Click at the video camera symbol at the left menu bar. Click the green arrow that appear in the new window to start rendering the landscape.

Move around with the mouse or the arrow keypads(Move up/down with Page Up / Page Down, look up/down (tilt) with mouse click at top/bottom of render window (alternative u/d keypads can be used). A joystick can also be used.

A 3D standalone animation is automatically created in an independent folder for each VR object and can be e-mailed or burned on a CD so that it can be played by any external viewer via the viewer shareware program. In the render window you find different toolbars and controls that can change the different settings on-line. e.g. the “track” toolbar makes it possible to record a track and replay it. The “run time data” option deals with the 3D alone settings.

Finally you can put in all details describing the landscape as precise as you wish by putting in objects and link those to bitmaps, bitmap objects or 3DA-collections. All 3 types are maintained and access via the 3DA-editor. Turbines, METEO objects, Text objects and 3D objects can be inserted “on-line”, while obstacles, line and area objects need a “rebuild” before changes are shown in the 3Danimation window.

5.1. VISUAL - Photomontage

5.1.0 Introduction to photomontage

A photomontage means to take a photo and then superimpose the proposed changes (the new turbines) on top of this photo. The method has been used for many years to document the visual impact of a planned project of many different kinds, e.g. bridges, power plants, new roads etc.

Another use of the photomontage is to measure or check different elements in the landscape, e.g. local obstacles or positions of measure masts. With good photos and digital height contour lines, it is possible to measure positions with accuracy of around 1 meter, which is far more accurate than GPS loggings with standard GPS equipment. As an extra advantage, the positions relative to the height contour lines and the precision of the height contour lines can be checked, which for measure masts are extremely important.

5.1.1 Calculation methods in VISUAL Photomontage

The technique behind a photomontage is to establish a camera model that can transform any point with known elevation and coordinates from a map to a 2-dimensional photo. Once the camera model is established, the camera model can position a 3-dimensional model of a turbine into the image with the correct proportions. The surface of the turbine is controlled by various parameters. Some of these parameters are linked to the turbine (colour, reflection, etc.), and others are linked to the weather conditions at the time when the photo was taken (sun position, brightness, haziness, etc.). We have tried hard to simplify the set-up of these parameters: The sun position is calculated by the program based on time of day, date, time zone, latitude/longitude and camera pointing direction. The weather is described through simple choices such as: "clear sky", "light overcast", "heavily overcast", etc.

5.1.2 Photographing

When you take a photo you only catch a "part" of the landscape with the camera - thus, make sure to take photos of the adjacent landscape on both sides.

The camera reduces the image quality, so be sure to use a camera with a good quality lens, preferably a single lens reflex camera that generally brings less distortion through the lens. A large format camera gives you a better quality, but it is not crucial for making good visualizations.

The focal length of the camera lens should be between 35 and 70mm. The standard focal length, which preserves the proportions of the photo as close to what the eye sees as possible, is defined as the diagonal on the 36x24mm format which corresponds to approx. 43mm. If possible, use a lens with a fixed focal lens, i.e. not a zoom lens, to make the calibration of the camera model easier. Most of modern digital cameras provide with the information about the focal length. Please refer to the corresponding section thereafter.

To keep the camera in a horizontal position (for a good presentation purpose), you can use a tripod and a level.

The photo has to be taken in "landscape" format and not "portrait".

If you plan to make a photomontage on a stitched photo (panorama), it is important to ensure a perfect stitching of the individual photos. Make sure that all images should be taken from exactly the same viewpoint (center of the sensor) using at least a tripod. More in particular: the camera should be rotated around the 'no parallax point' (sometimes referred to as the 'nodal point') of the lens. For most lenses this point is located near the front element; since it does not coincide with the tripod screw of the camera, you will need to use a so called panorama head on top of your tripod if very high accuracy is important. If the camera is not rotated exactly around this point, parallax errors will occur, preventing a perfect stitch. Check for the horizontality of each photo. Make sure that the images have an overlap of about 1/3 of the width of the photo.

While taking the photo it is recommended to ensure that the elements in the landscape that will be used to calibrate the photomontage are available on the photo. It is recommended to have a good calibration point both on the left and right in the photo and at least 500 m from the camera.

When and where to take the photo:

- Good weather with the sun in the back makes for high photo quality.
- The best distance is within 500 to 5000 m from the planned WTGs.
- Find points the local people are familiar with (roads, viewpoints etc.).

Last but not least, be sure of the exact position at which the photo has been taken. You can use an external GPS or a camera with GPS.

5.1.3 Example of making a Photomontage

In the following, a typical procedure for the photomontage work will be outlined from the point where the photo is stored on the hard disk. Some examples can also be found on the DEMO projects, included in the WindPRO installation. (In folder WindPRO Data\Samples\)

The first step is to establish the necessary project information including links to bitmap maps. Although the visualization can be made without the use of a digital map these should be used whenever possible, as you will benefit from the significant time saving facilities and other advantages, which are linked to the use of maps.

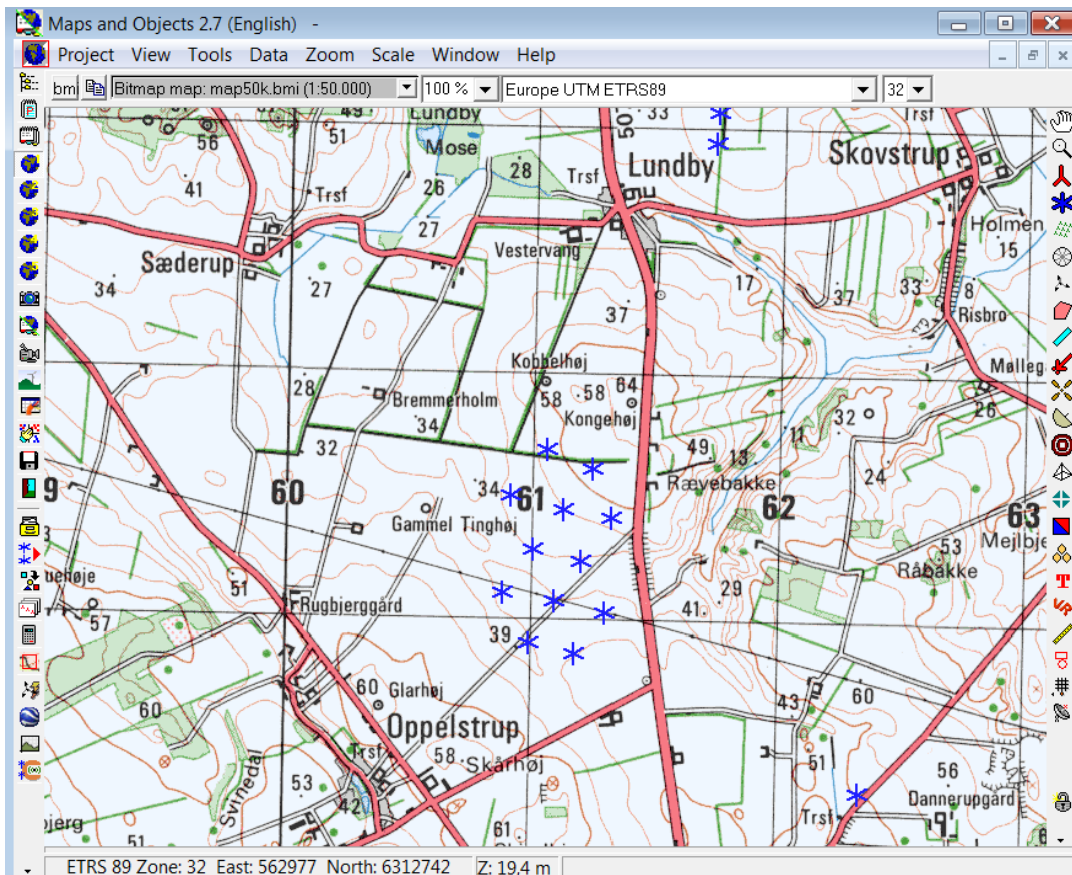
Details concerning input of project information and linking of maps are described in chapter 2, BASIS.

5.1.3.1 Time zone

The program converts the local time into Global Standard Time, e.g. GMT, using the time zone and the local time, which is linked to the photo in question and defined in the project properties. The global standard time, the date and geographical position (latitude/longitude which the program calculates from the map used) are used to calculate the sun position for correct light settings.

5.1.3.2 Entering maps, turbines, areas and 3D objects

Click on the map icon to load the background bitmap map. You can then enter turbines and other objects directly on-screen. See chapter 2.5 BASIS.



You will find a detailed description of how to enter turbines in Chapter 2. Part 5. Lattice towers must be added to the turbine Catalogue as .DXF files before you can incorporate them in the photomontage (see part 6 in Chapter 2. BASIS).



You enter 3D Objects via the same procedure as you enter turbines.

5.1.3.3 Camera Object



The Camera Object plays a central role in the Photomontage. This object holds most of the information needed for the visualization work. The object is created by clicking on the Camera Object on the tool bar and inserting it on the map by clicking on the map at the position from where the photo in question was taken (the Camera Point). Drag the camera line to the target point of the photo and click again to position the object. The properties of the camera object will pop up automatically. You can edit the position of the object at any time by dragging the camera point and/or the target point or manually from the project properties. The contents of the object will be described below.

Camera object – tab sheet Camera

Normal

Normal is to be selected for a photomontage based on a single photo. The film format associated to the focal length will then decide the size of the turbines. WindPRO can automatically calculate the film format width and height corresponding to a 36 x 24 mm film format as the default option "Automatic calculates film format based on picture size" is checked. The focal length of the lens will normally be indicated on the lens or it can be found in the technical manual for the camera (or lens). Very small deviation on the focal length can be necessary to compensate the light distortion that can be due to the transfer or the variation of the temperature. If you use a variable zoom lens it might be necessary to establish the focal length used by the aid of control points (see a later description of this).

General information about focal lengths (36x24mm film format):

- Normal lens, focal length 40-50mm
- Tele lens, focal length >50mm
- Wide angle lens, focal length <40mm

The above formats change for other film formats. If, for example, the film format is 6 x 6 (60x60mm), the normal lens will have a focal length of 80mm

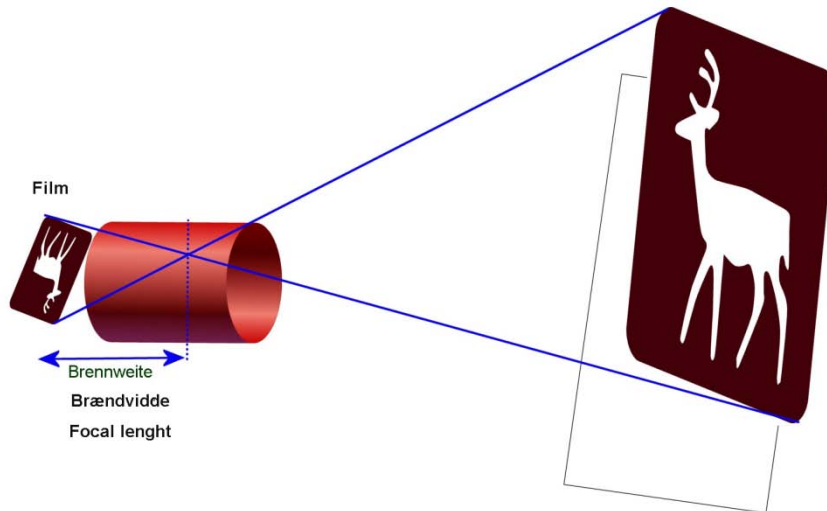


Figure 1 The illustration above shows how the motive will be mirrored through the lens. The focal length is the distance in mm between the negative and the crossover point. This shows that another negative format, will give another focal length for catching the same motive.

The focal length given by a digital camera has to be corrected to the equivalent focal of the traditional 36x24mm film format. The correction factor (typically from 1 to 2,5) can be found in the technical specification of the digital camera. The focal length and sometimes also the corrected focal length can be read automatically by WindPRO from the EXIF properties of the picture file (see Photo/Background tab).

For digital cameras WindPRO can calculate the film format width and height corresponding to a 36 x 24 mm film format. For this, check the "Automatic calculate film format based on picture size" option. You can also add your own definitions in the following form, which appear by unchecking "Automatic calculate film format based on picture size" and by selecting "User defined" in film format:

By typing the pixel width and height of the digital photo, the software calculates the film format with and height corresponding to a 36 x 24 mm film format. The important thing is that the diagonal is the same, as the diagonal in 24 x 36 mm film format – then the focal length corresponding to this film format shall be used. This is normally found in the technical description of the camera. Note: If the camera has a zoom lens, only the outer positions will be known, e.g. 35 mm – 70 mm. If by photographing none of the outer positions has been used, the only way to find the focal length normally is to calibrate the picture with control points. Anyhow, use of control points will be recommended in all cases, while even the focal length of a zoom camera in outer position can change e.g. by temperature.

Scanned images (including professionally scanned photo images on a photo CD) often get the edge of the actual image cut away during the scanning process to avoid possible black edges on the image, e.g. due to misalignment of the photo in the scanner. To compensate for this "cutting", you either have to change the film format or the focal length. It is usually more convenient to change the focal length, which should normally be

increased by 2-5% for photos on a photo CD. Use the control points (which will be discussed later) to establish the precise focal length.

Panorama

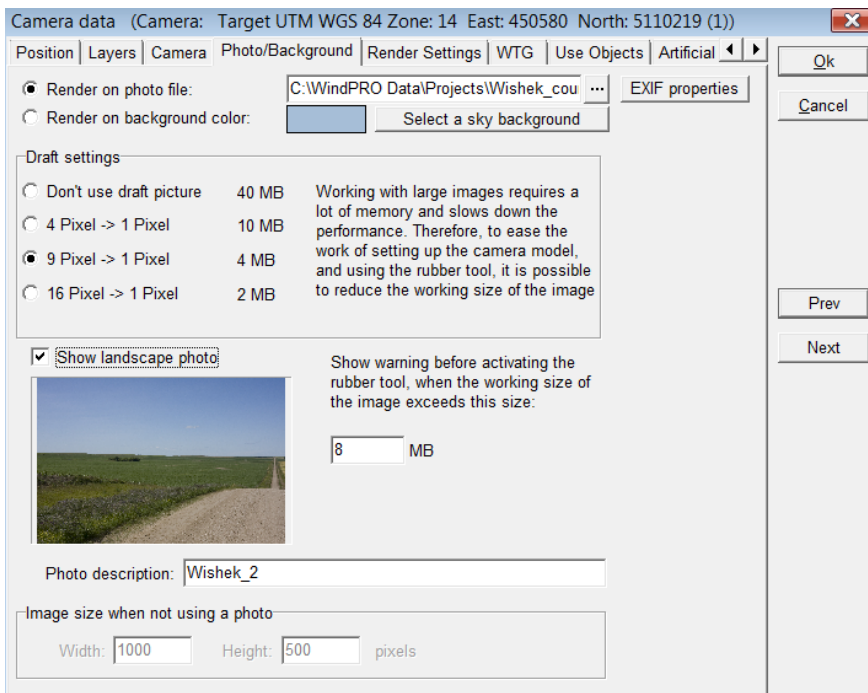
Panorama is to be selected for a photomontage based on stitched pictures. The field of view (FOV) is the main parameters. The dimensions of the photo (number of pixels) associated to the field of view will then decide the size of the turbines. The field of view is the angle formed by the two rays encompassing the horizontal view that can be seen on the photo. The FOV is defined in degrees.

Camera position

The 3-dimensional coordinates for the camera point and the target point (the center of the photo - can be any point on the line of photographing) ends the definition of the camera model. In most cases, you will have to know the exact Camera Position, which help much in the camera model calibration process. It is always a good idea to log the photo positions with a GPS.

The camera model defines how each point in the map is transferred to the image, and thereby also controls the proportions of the turbine you enter. A correct camera model is therefore a basic requirement for a correct photomontage.

Camera object – tab sheet Photo/Background



Select the file with the photo or panorama to be used by clicking on the three points next to “Render on photo file”. If the photo file includes EXIF properties (such as the date and time, the focal, length, coordinates, etc), the EXIF Form window will pop up automatically so you can decide which properties to “Import to camera”. From the form you can for example input the conversion factor to convert of the focal length to the equivalent 35mm focal length. The conversion factor can usually be found in the technical specifications of the digital camera. The conversion factor is saved for the type of Camera if the option “Save conversion data for this camera model” is selected. The conversion data are save in this folder: C:\WindPRO Data\Standards\CameraDB.

Note that working with large photos slow down the performance. So especially in the rough trimming of the camera model using draft mode is recommended. Especially when working with the rubber tool memory consumption becomes very large. You can set a limit in MB photo size, where the software shall warn you before starting using the memory demanding tools. This limit should be set relative to the hardware you are working on. 5-10 MB seems reasonable for today's standard PC. Because the photo might be too large the screen it is recommended to start the calibration of the photo on a draft picture which will reduce the size on the screen and allow to see both sides of the photo (important for the calibration of horizontality). It is then possible to fine tune the calibration using the normal size of the photo.

A short description of the photo can be added, which will then be included on printouts later on.

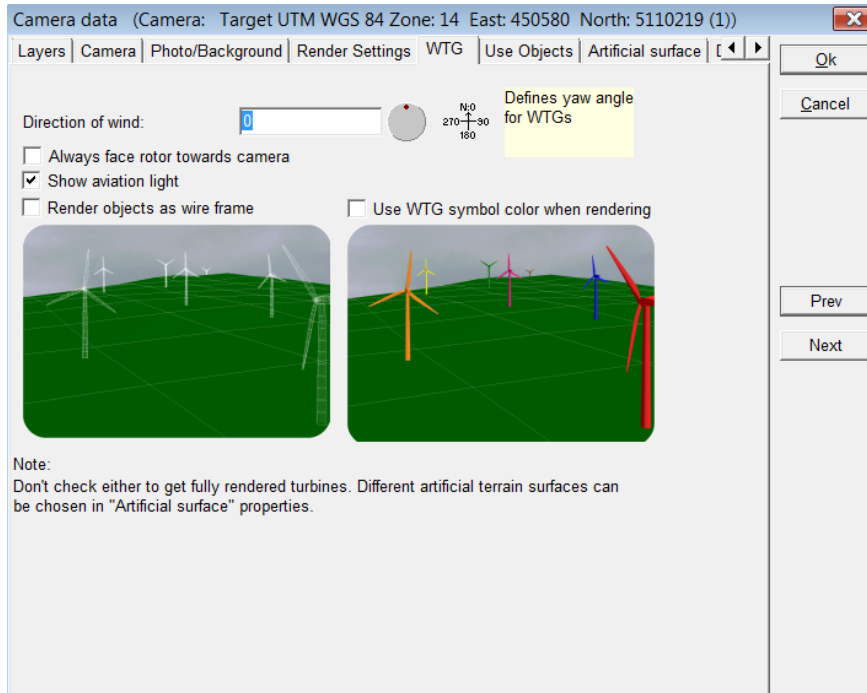
If you do not have any photo from the site, the tool can be used with a background and render artificial landscape based on height contour lines (TIN model). In this case select "Render on background colour", select a colour and alternately a sky background and go the Artificial surface" tab. In following it is assumed that a photo or panorama is available. You can increase the number of pixel (and thus the quality of the picture) by increasing the **Image size** (at the bottom).

Camera object – tab sheet Render settings

The render settings control different details on how the photomontage will look.

Date and time control the angle of the direct light together with the geographic position and time zone.
Weather type controls the light settings when the turbines are rendered into the image. You can also choose to generate only the wire frames of the turbines, e.g. if you wish to emphasize that the image is a photo montage where you want to focus on the proportions only, or if you want to clearly distinguish between existing and planned turbines.
Antialiasing enlarge the photo in order to smoothen the edges between the rendered turbines and the background photo. This can consume plenty of memory, but also improve the result much for a final presentation. So in the “experimental phase” this should be kept low and put on maximum at rendering the final result.

Camera object – tab sheet WTG

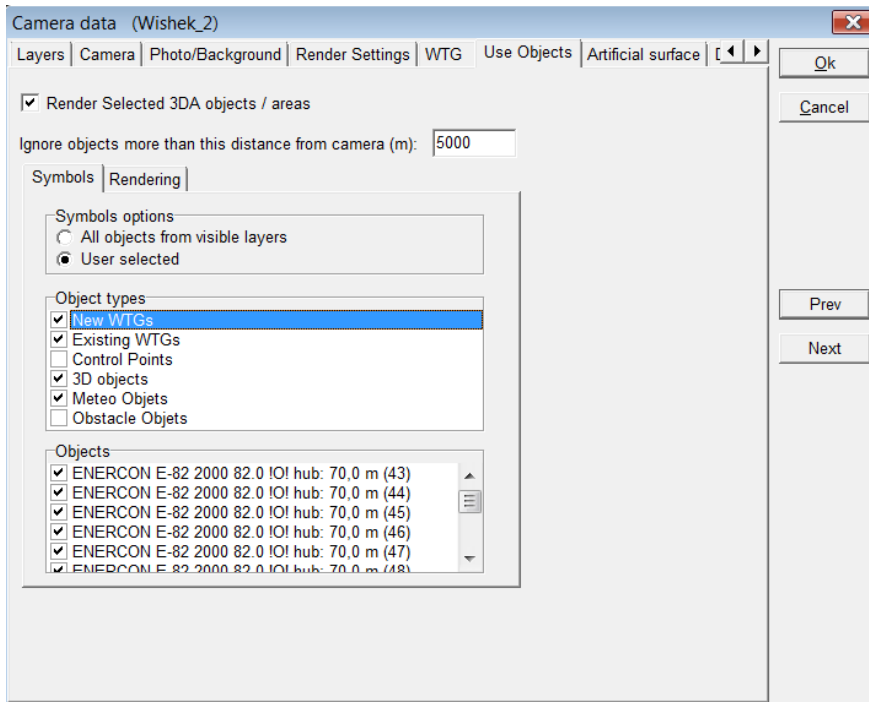


Direction of wind controls the yaw angle of the turbine nacelle. If the photo includes existing turbines or other objects, which indicate the wind direction, e.g. flags, then the actual wind direction should be entered. Otherwise, use the predominant wind direction to make the image as realistic as possible.

It is also possible to select “Always face rotor towards camera” so that all the turbines will be facing the observer. Although this does not happen in reality, the purpose of this option is to make a photomontage with a maximum visual impact.

The “Show aviation light” option enables to include aviation light(s) as long as they have been defined for each turbines (cf. section 5.1.3.17). This option can also be selected on the top bar of the photomontage window. WTG objects can for special purposes be rendered as wire frame models or as colour turbines. If e.g. more different wind farms clearly should be identified on a photo, the turbines can be given different symbol colours which will be transferred to the photomontage by checking this option.

Camera object – tab sheet Use Objects



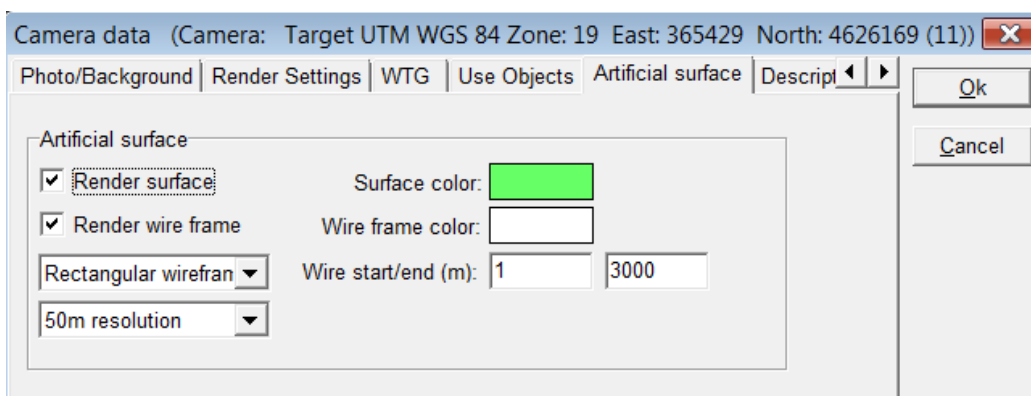
Render selected 3DA objects/areas shall be ticked so that 3DA objects such as roughness areas, 3D objects or obstacles created with visual properties are to be rendered on the photomontage. Beyond the default distance of 5000m, 3DA objects will be ignored, saving some rendering time.

Some objects you might only use as WTG control points, not for rendering (e.g. existing turbines), while other might be used for both (e.g. new turbines). With this menu it is possible to select freely. Default setting is “all from visible layers”, so by using the layer structure it is very efficient to take in/out objects.

Following objects can be used in photomontage:

- Existing and new turbines
- Control points (only as control points)
- 3D Objects
- Meteo objects
- Obstacle objects
- Area objects (only for rendering)

Camera object – tab sheet artificial surface



When rendering the artificial surface or wire frame, this is limited to the distance given in this form. The default value of 3000 m is often too short if there are some hills at a longer distance that should be included. But the

processing time will increase much with distance; therefore the default value is kept rather low. More on artificial landscape is explained later.

Camera object on the map

Notice that the Camera Angle is rendered on the map - approx. 45° for a focal length of 50mm and 60° for a focal length of 35mm. Click with the right mouse button on the Camera Object to extend the Camera Angle Lines. This gives you access to controlling whether or not the lines on the map correspond to the edge of the photo.

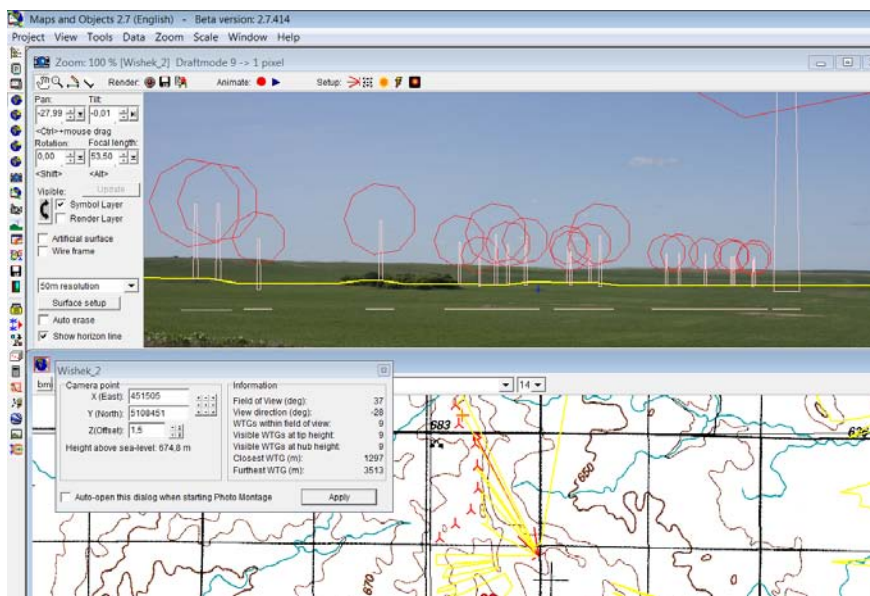
5.1.3.4 Photomontage window



When the data has been entered into the Camera Object you click OK, and the photomontage window will pop up automatically. You can open an existing camera model/photomontage with a click on the Camera Icon at left menu bar or from the map by selecting the camera object, right click and Show photomontage. You can then arrange the photo and the map horizontally above each other. The next image shows how the camera model initially arranges the turbines.

From the photomontage window top bar, the following tools can be used :

- | | |
|--|--|
| | Move around the photo |
| | Zoom in and out on the photo |
| | Add text, lines, arrow on the photomontage |
| | Delete invisible parts of rendered objects |
| | Start rendering the objects (wind turbines, 3D objects...) |
| | Save the photomontage in a file (jpeg, tiff...) |
| | Copy the photomontage to the clipboard |
| | Starts Animation |
| | Properties of the Camera objects |
| | More Adjustment tools |
| | Set up Manual light |
| | Auto optimize the Camera model |
| | Aviation light on/off |



The left part of the photomontage window has the following relevant options:

Pan:	Tilt:
<input type="text" value="-71,80"/>	<input type="text" value="-0,31"/>
<Ctrl>+mouse drag	
Rotation:	Focal length:
<input type="text" value="-1,06"/>	<input type="text" value="45,90"/>
<Shift>	<Alt>

Settings used for the calibration of the Camera model

Symbol Layer
 Render Layer

Symbol layer and render (=result) layer

Artificial surface
 Wire frame

50m resolution

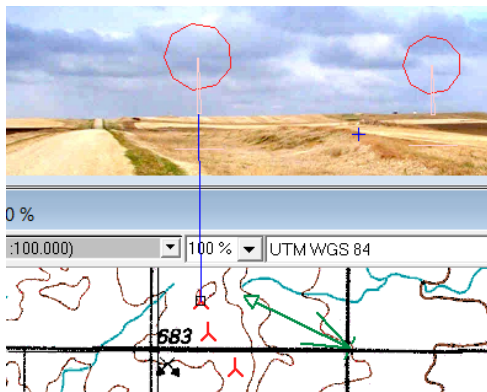
Surface setup

Selection of artificial surface/wire frame

Auto erase
 Show horizon line

Auto erase and Show horizon line options

It is possible to identify a WTG from the map onto the photomontage: select the WTG on the map, press Control down and move at the same time the mouse over the symbol; a blue line will link the symbol on the map to the photo.



5.1.3.5 Calibrating the Camera Model

In order to have WindPRO to calculate the correct position and dimension of the WTGs, the camera model needs to be calibrated. The calibration consists in finding the exact properties of the camera which were been used to take the photo: the position, direction, Pan, Tilt, angle of the camera and lens used.

Having entered the relevant reference (horizon line, control points ...cf following sections) you have to adjust the camera settings until the references are on the right place on the photo. This can be done in different ways.

Firstly, the left area in the photomontage window offers a wide range of adjustment features.

An even easier way is to drag directly on the photo:


Holding <Ctrl> down, mouse drag on photo adjusts both Pan and Tilt angles. You can simply drag the symbols to the right spot on the photo.

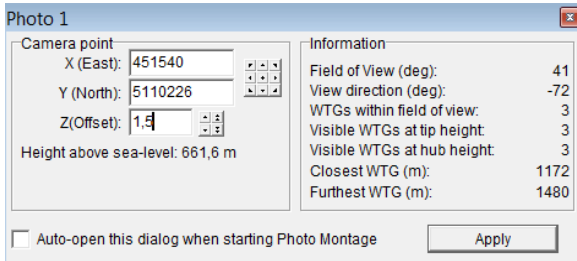
Holding <Shift> down, rotate the camera, so a skew-recorded photo can be corrected. Note drag near the edge of the photo to set down the sensibility.

Holding <Alt> down, mouse drag on photo adjusts the focal length. Again

Pan:	Tilt:
<input type="text" value="-71,80"/>	<input type="text" value="-0,31"/>
<Ctrl>+mouse drag	
Rotation:	Focal length:
<input type="text" value="-1,06"/>	<input type="text" value="45,90"/>
<Shift>	<Alt>
Visible:	Update
<input checked="" type="checkbox"/> Symbol Layer	
<input type="checkbox"/> Render Layer	

dragging near the edge decreases sensitivity.

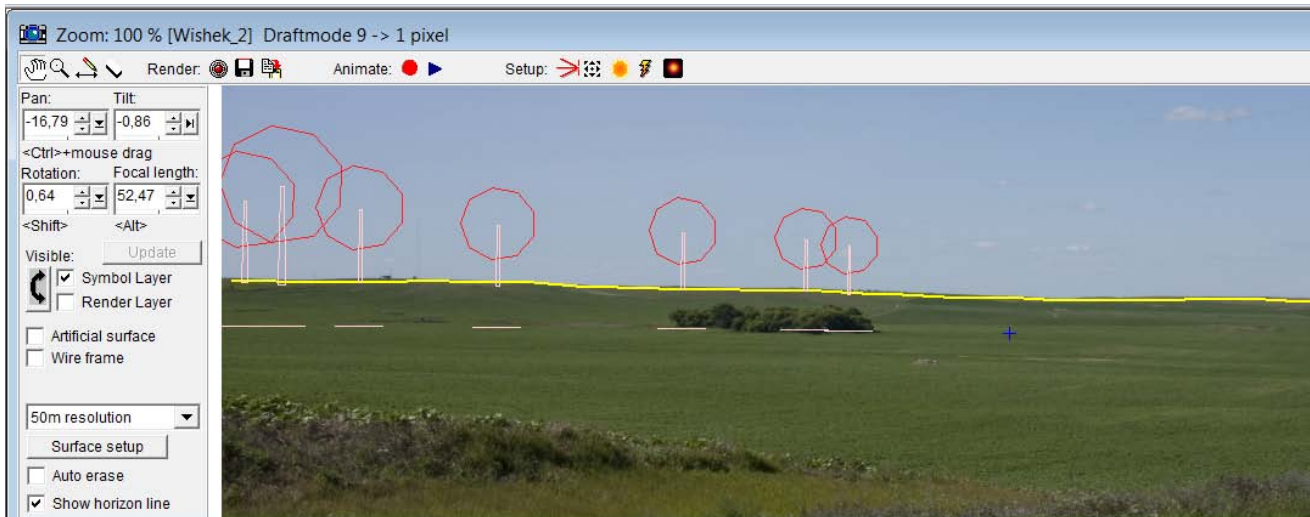
The position of the camera object can be defined in the properties of the object but also from the below window which pops up below the photomontage. The photomontage calibration gets updated with the changes made from this window with the Apply button. If the window is closed, it can be opened again by clicking on this icon  in the top bar of the photomontage.



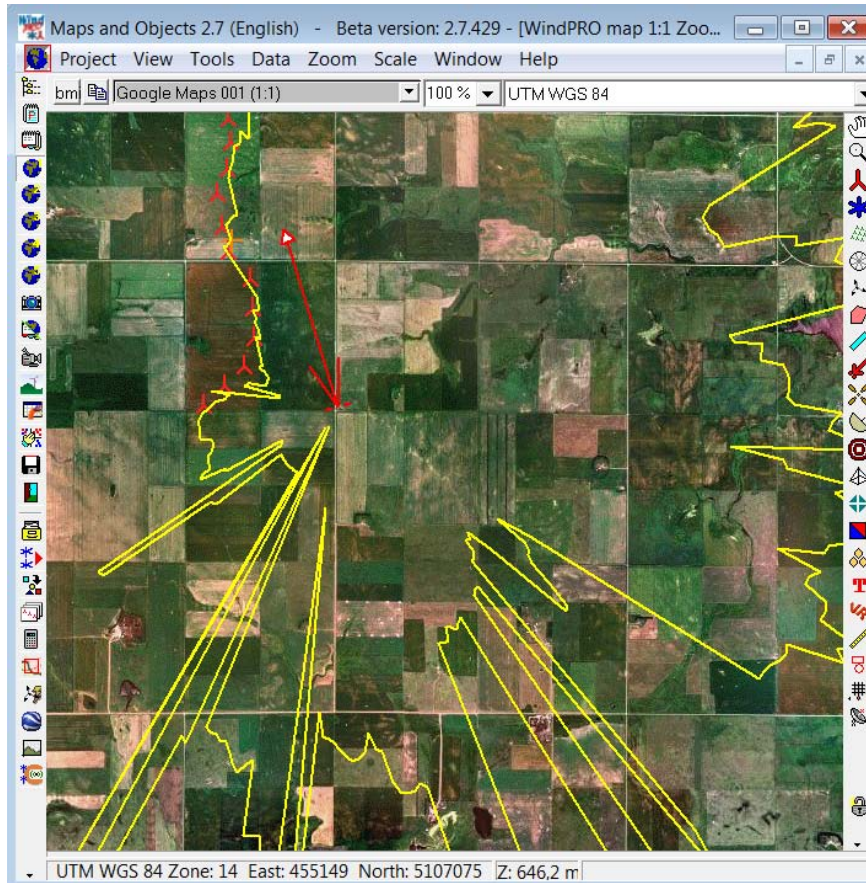
Some information is also shown: the field of View also known as the angle of view, the View Direction is the direction at which the camera is pointing at, the WTGs within the field of view, the number of visible WTGs at tip height and at hub height, the distance to the closets and furthest WTG.

5.1.3.6 Calibrating the Camera Model – Horizon line

By checking “Horizon line” at the bottom of the left pane, the horizon line is drawn in yellow on the photo and on the map provided that height contour data have been loaded. The horizon line consists of the blocking points of the line of sight calculated for each degree from the Camera position. The horizon line is a powerful tool to calibrate the Pan, tilt and rotation parameters of the photo. Be aware that the horizon seen on the photo must be covered by height data (TIN).



The horizon line is simultaneously drawn in yellow on the map.



In addition to the horizon line, a 0 m line is shown as a part of the WTG symbol. This line can be used for offshore photomontage. If the turbine is behind horizon -> the line turns red and the part below the horizon will not be rendered. This is illustrated below.



Figure 2 The large rightmost has same colour at the horizon line as the symbol colour :This wind turbine is in front of horizon. The first of the group on the left, is just at the horizon, while the following symbolized with the red colour is behind the horizon. For all turbines the user shall just make sure that the lines follow the horizon, then the rendering takes care of the rest, see next photo with the rendered turbines.



Figure 3 Rendering offshore turbines with automatic adjustment for the horizon. Note: it is of course possible to define nice offshore foundations in the turbine catalogue (as extension of tower).

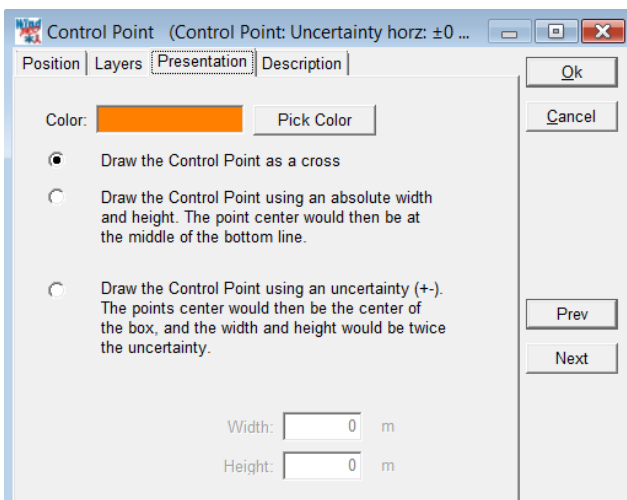
5.1.3.7 Calibrating the Camera Model - Control Points



Control Points can be used as reference point to calibrate the camera model. Control points are objects that can be identified precisely on both the map and on the image. The best Control Points are those furthest away from the camera (some kilometres away and preferably at least one in the left and one in the right part of the photo). If you do not have an exact location of the Camera Point, you will also be able to use Control Points, which are situated closer to the camera.

Control Points are used to control the accuracy of the Camera Model as well as to establish any missing/uncertain information in the Camera Model. Please notice that the more unknown/uncertain parameters you have in the Camera Model, the more Control Points you will have to enter in order to be able to establish a correct Camera Model. Exactly how many Control Points you need depends on the positions. Control Points close to the planned turbines gives accurate positioning of the turbines in the image. Control Points near the edge of the image, on the other hand, gives you good control over the focal length which in turn results in accurate image proportions. The Control Point Coordinates may be established by using GPS equipment or from a reliable background map (aerial photo)

Control Points are inserted via the Map Tool Bar and information about z-coordinates is added. The z-coordinate is not the height of the object, but the elevation of the object's base. Each Control Point can optionally be assigned a dimension.



High objects like chimneys and high buildings can be shown using a wide and a height. In that case the point should be placed at the centre of the button line of the object.

You can measure the height of an obstacle, e.g. a fence, by using the commonly accepted “drei-eck” method, i.e. using a 45° triangle with two equal legs. When base and top are flush with the triangle, then the height of the obstacle equals the distance to the obstacle.

5.1.3.8 Calibrating the Camera Model – Obstacle object, meteo object & existing wtg

Please refer to the BASIS chapter about how to define these objects.



The obstacle object is a convenient reference for squared elements such as houses, straight roads when these can be defined from the real dimension as seen on an aerial photo background map. The symbol of the obstacle will appear as a light blue cube shaped objects.



A measurement mast can also be used as a reference point. The height of measurements defined in the meteo object is also reported on the orange symbol.



Existing turbines will have a symbol with a blue rotor. The dimension of the hub height and the rotor will be reported in the right proportions.



5.1.3.9 Calibrating the Camera Model – Wire frame

By checking “Wire frame”, a wire grid is shown on top of the photo in order to help you editing the camera parameters. See example below.

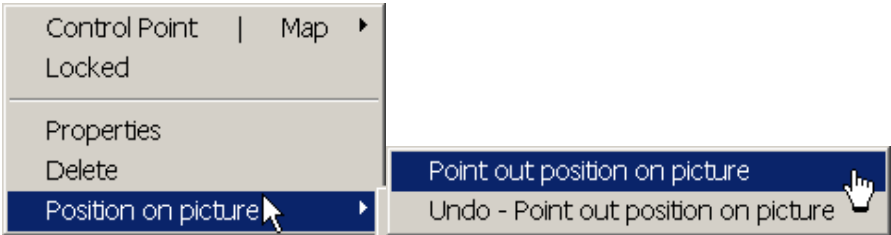


5.1.3.10 Calibrating the Camera Model – Auto Optimisation

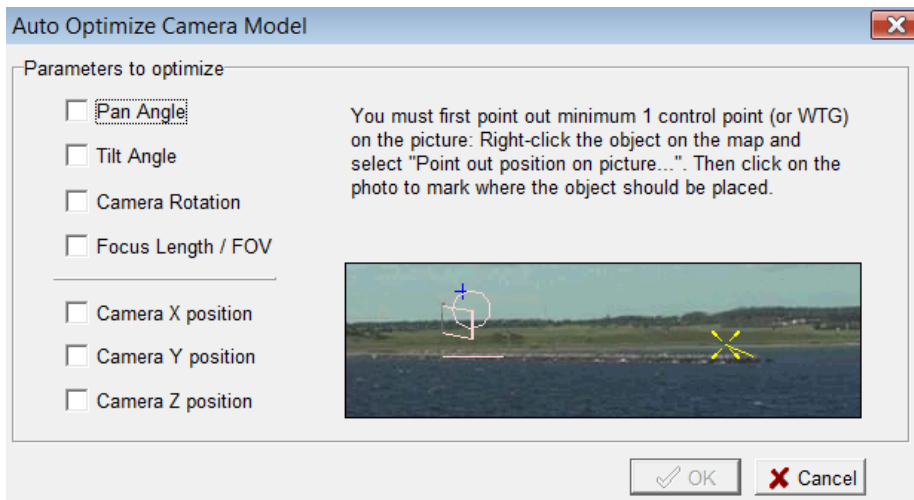


Finally there is a possibility to let the computer calculate the camera model.

Before using this, objects (turbines, control points and Meteo objects) have to be linked to the photo. From the map, right click on the object you want to link (where you know the exact position on photo), select “Point out position on picture”, and click on the picture the corresponding position of the object. Below you can see how the silo on the right is linked to a control point and the turbines on the left are linked with either top or bottom point or both.



The more linked objects you got, the better possibilities the software have to find the best fitting camera model – and the more settings of the camera model you already know, the better the unknown can be estimated. The parameters that can be auto optimised are: (Menu appears when “Auto Optimise Camera model” is chosen):



All seven parameters can be optimized in one operation, but then you need several good linked objects. Only the ones you check will take part in the optimisation.



After running the Auto Optimise Camera model, the control objects fit very well on the background photo.

But, be careful with this feature – with too few good control points, many solutions can give the optimum for just these points, but still give a totally false camera model. So you must always evaluate the result critically.

5.1.3.11 Rendering



Click on the red button to begin the rendering of the turbines into the image. When the control lamp turns green the rendering is finished. If you change the data on which the renderings were based, the control lamp will turn red again, and you have to render the image again.

By default you will render all turbines and other “renderable” objects **visible on the map** (from visible layers, see section 5.1.4.3.4 Camera object – tab sheet Use Objects and see section 2.11 on layer structure)



Figure 4 New turbines rendered on top at the existing ones - here the new is rendered as white, while the existing is gray.

Having rendered the turbines, you have to decide whether or not they look realistic. If, for example, the turbines are dark and the photo is taken in glaring sunlight, you have probably made an error in the photo time setting. Also, the weather parameters can be incorrect. If the proportions are incorrect you have to check the Camera Model once more and maybe add more Control Points to it. Finally, the information in the turbine Catalogue could be erroneous (see more on this subject in chapter 2, BASIS) and you would thus have to open the actual turbine in the turbine Catalogue and check the data.

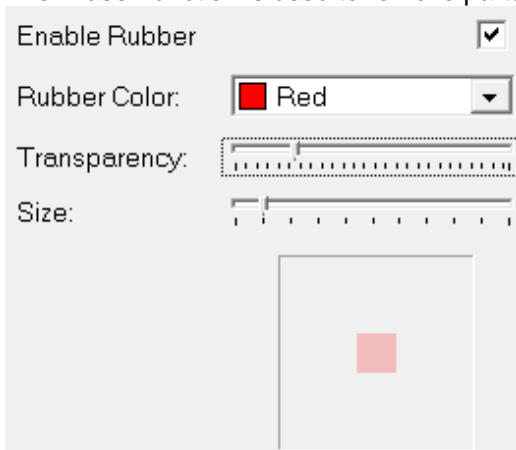
5.1.3.12 The Erase Tool (the Rubber)

Auto erase

If height contours are available in the project, they will be used with Auto erase to delete the part(s) of the WTGs hidden by the terrain. It might be necessary to refine the deletion with the erase tool as the height contours might not be precise enough.



The Erase Function is used to remove parts of turbines behind fences, buildings, hills etc.



After activating the rubber tool, you can set-up the size of the rubber and how to show the rubber on the photo. You can then easily see where your rubber has been.



Figure 5 The rubber tool simply "paint" the rubber areas, where you do not want rendering. In that way you can rub a whole hill so even though you slightly move the turbines to be rendered behind the hill, there will be no visible parts in front of the hill.

NOTE: You can also un-erase or undo rubber areas by right clicking.

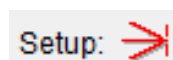
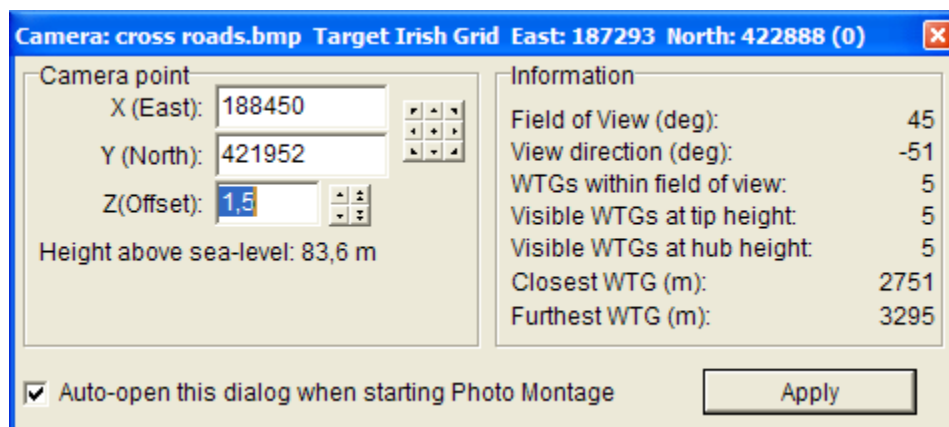
Left mouse button - erases pixels

Right mouse button - re-establishes erased pixels

5.1.3.13 Adjust camera position/ information



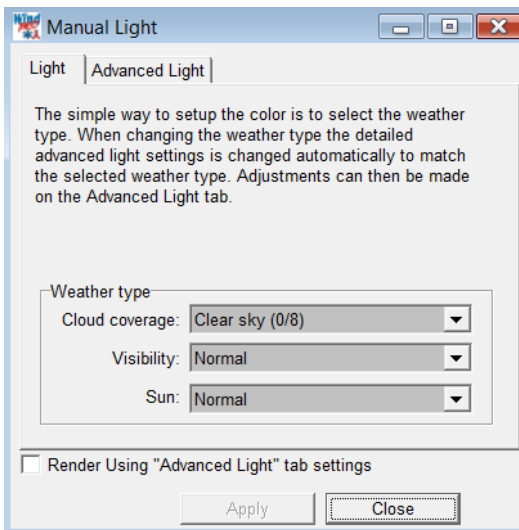
With the "adjust" icon you can open a window for some extra adjustment and information features that often can be comfortable to have on top of the photomontage.



You can also activate the complete Camera Object and adjust any or all parameters.

The Z-coordinates of the turbines and other objects can be found in the digital Terrain Model (DTM) (see Chapter 2. BASIS, part 8). This is a very powerful option, which is advantageous to use when visualizing in complex areas.

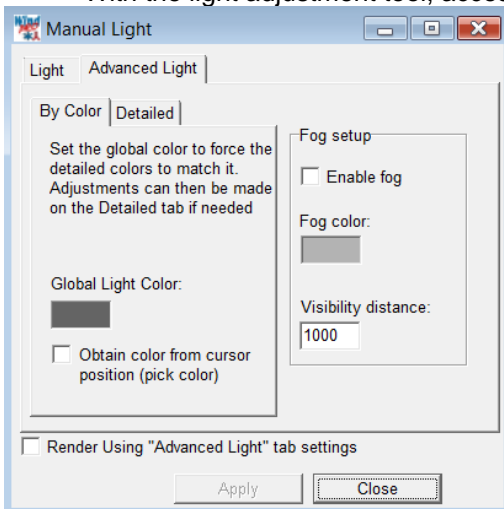
5.1.3.14 Adjust light (colour)



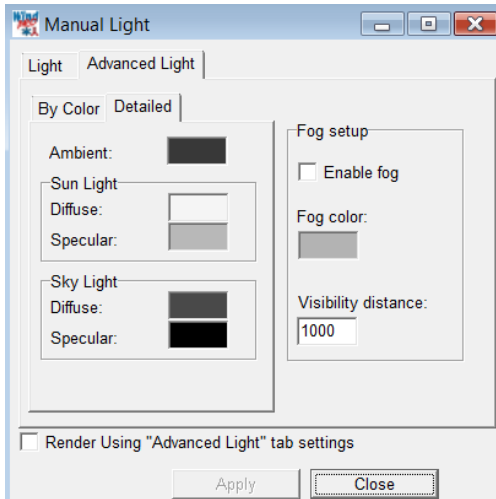
Light (or colour) adjustment is in general made by selection of weather conditions in the render set-up. But for some purposes, a more detailed adjustment can be needed, e.g. if some new WTGs are added to a place with already existing WTGs. Here it would look better if the new WTGs match the colour of the existing as good as possible.



With the light adjustment tool, access will be given to “Advanced light”.



In the advanced light setting, the global light colour can be set, which is the colour you wish to give the WTG. Therefore it is possible to “pick” the colour from the photo. But it is not that simple. A colour is not just a colour, but a mix of many pixels with different colours. This mix cannot be taken into the render model. Therefore it will only be an approximation. Another complication is that the colour is “not just painted”, but generated dependent on distance, angles etc. So behind the render model, there are more “lamps” that together makes the colours. At the detailed tab sheet, you get access to the all lamps directly to give the full freedom of colour setting input to the render model.



The detailed settings, where all colour parameters in the render model can be set. But be careful – it is very difficult to adjust all these handles and can be very time consuming and not very logical how the result react on your input.

5.1.3.15 Bitmap elements integrated in the photomontage

Bitmaps, e.g. photos of any object (tree, building, vehicle etc.) can be integrated in a photomontage. This can be used if there is no landscape photo to make a semi realistic photomontage (see next chapter) or it can be used to add other elements in the landscape than turbines if a photo from site is available.

This feature makes it also possible to use the WindPRO photomontage features to visualise any project, e.g. a new power plant, planned forest etc.

The methods of integrating bitmap elements in a photomontage are detailed described in the 3DAnimator manual part, see chapter 5.3.4 and 5.3.5.

Take a look at an example, where we have visualised a planned new lake in Northern Jut land, including a reed forest at:

5.1.3.16 Text elements integrated in the photomontage

A text on the map can be rendered as a billboard, see example below.



Remember to turn on “render selected 3DA objects” in the properties of the Camera object.



With the drawing/test tool you can draw or write direct on the photo.



Finally you can copy the result direct to clipboard for paste into a text or other document, see example below.

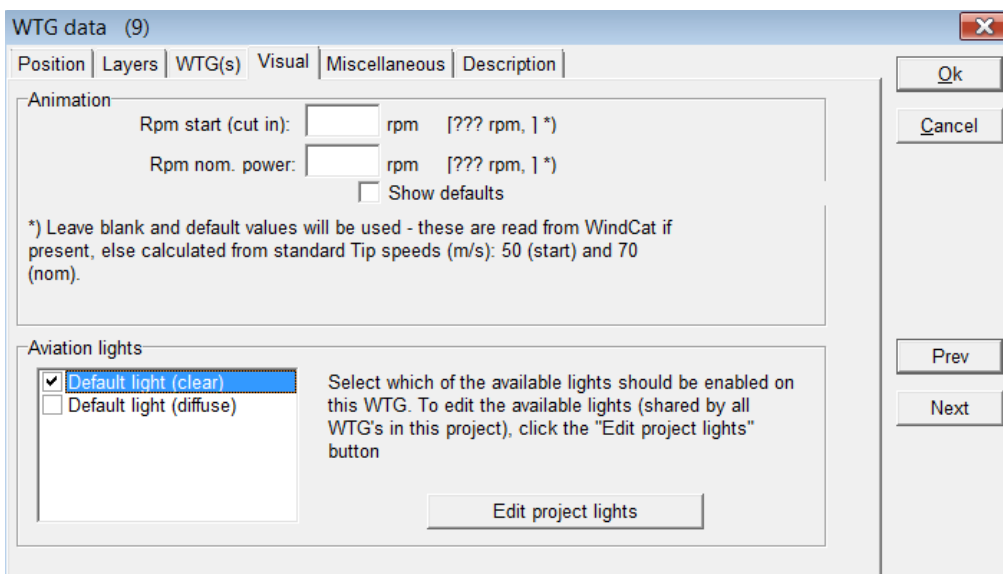


5.1.3.17 Aviation lights integrated in the photomontage

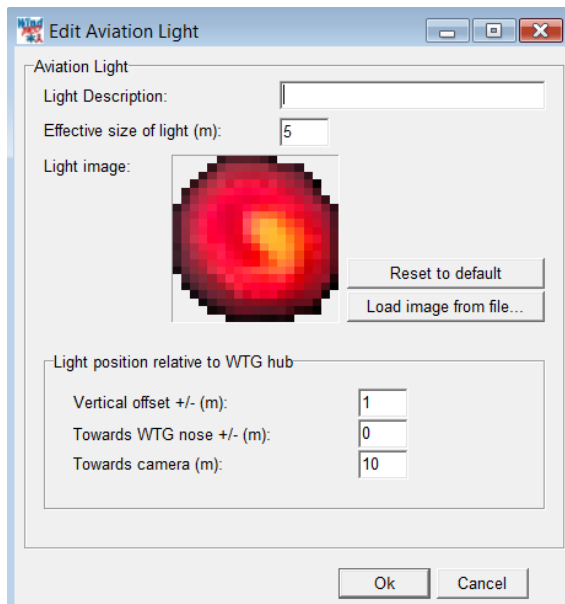
Lights can be added on the top of the nacelle or on the tower of the WTGs. The visual simulation of the light is based on a bmp files which is scaled down in size according to the distance to the Camera object. The change in light intensity is not calculated by the model in the current version of WindPRO.

The aviation light has to be selected for each turbine. This is done from the Visual Tab in the properties of the WTG. It is also possible to select all turbines and use Multi Edit/WTG properties.

By default two types are available as bmp files.



It is possible to adjust each light properties by clicking on **Edit project lights** and then on + .



In Edit Aviation light the following properties can be found:

Light description : name of the light settings so that same settings can be used for other WTGs.

Effective size of light (m): decides how big the light should appear relatively to the turbine. It is up to the user to change the effective size of the light to give a realistic result.

Light image: preview of the bmp file which can be loaded from a file.

Light position relative to hub: the light can be moved vertically along the tower either downwards (-negative vertical offset) or above the tower (positive vertical offset). A **vertical offset** of 0 m corresponds to the light being on the top of the nacelle. The light can be moved horizontally by changing the value in **Towards the WTG nose**. When the **Towards the WTG nose** is 0 m, the light is at the hub. To get the light at the end of the nacelle, the length has to be input as a negative value. **Towards camera** enables to move the light in the direction of the camera. It is usually used with positive value in order to bring the light closer to the camera, which is an artificial way to insure that the light is not hidden by a blade or the nacelle.

Once an aviation light is selected in the WTGs properties, make sure that the camera model is set up for “show aviation light” on the WTG of the Camera object or that the symbol for aviation light is on. Then click on Render. The aviation light can be switch on/off via the symbol and a new rendering.

5.1.4 Photomontage with artificial landscape as background

Photomontage with artificial landscape is usable in complex terrain where the shape of the terrain and the fitting of the turbines are more essential than the local terrain with trees, buildings, etc. Nevertheless, a photomontage with an artificial generated landscape via height contour lines also gives the possibilities to analyse a project without series of photomontages. Finally having a photo, an artificial landscape model also gives a unique control of the camera model, as errors are unveiled clearly in the camera model or the height contour line when the artificial landscape smoothly fits the real landscape in the photo. The artificial landscape model can also be used to see if the Wind turbines are behind or in front a hill because WindPRO will automatically erase the part of the wtg hidden by the terrain.

5.1.4.1 Establishment of height contour lines

As a condition when establishing an artificial landscape is that the height contour line is loaded into a line object. Please see chapter 2. BASIS part 8 Line object, for a detailed description how to establish height contour lines either by digitising on-screen or through import of height contour lines from internet or height contour line file information in various formats (shp,.gtx, .dxf, .ntf etc.)

Important when creating the height contour line object:

DHM (Digital Height Model) has to be selected and ticked in the tab sheet “POSITION”.

The object has to be centrally placed in the area to use.

Set the TIN-radius under the tab sheet "PRESENTATION" to ensure that the yellow circle, which will appear around the height contour line object, covers the site where to create the artificial landscape.

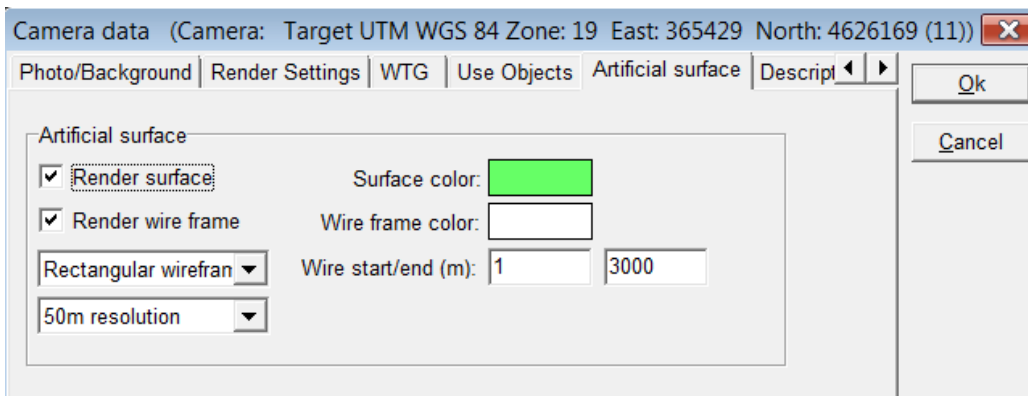
5.1.4.2 Camera model: Artificial landscape

Settings of the camera model are as described in photomontage VISUAL but with exceptions:

It is not necessary to select a photo (file name) neither to calibrate the model.

To prevent a time-consuming render especially when experimenting you can set the Antialisation to "none".

"Artificial surface" is where all the relevant parameters concerning the above are set.



You can choose to render an artificial landscape by ticking the "Render surface" checkbox.

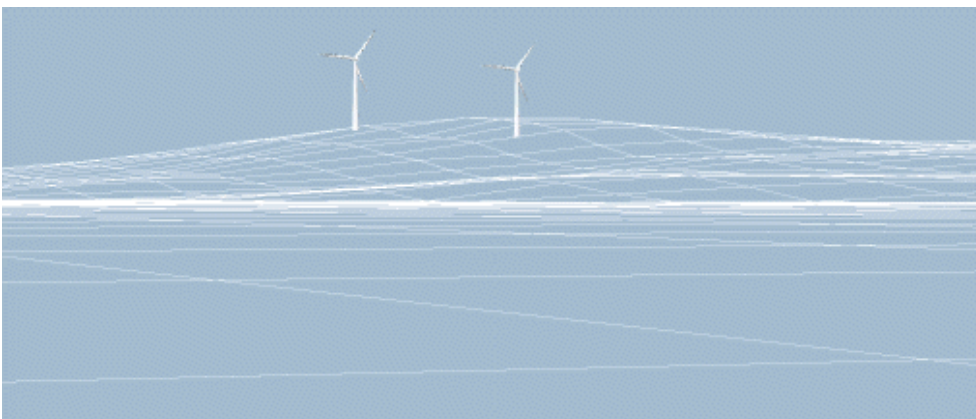
Landscape possibilities:

Grid type: "Triangle" or "rectangular".

The triangle is based on calculated triangles (TIN) from the DHM and is therefore the fastest and the most accurate one.

But based on rectangular grid calculated from the TIN it is often easier to see the contours of the landscape (see following).

Render as a wire grid creates a wire rid landscape without surfaces as shown below.



A wire grid model with a landscape photo, as background is very suitable for checking the camera model. Please note, that the wire-grid model reveals everything (included hidden lines), which later will be an option that can be changed. The colour of the grid can be changed.

If wire grid is not ticked, a surface will be rendered based on the selected colours as basis. The rendered surface will be done with respect to the sun position.

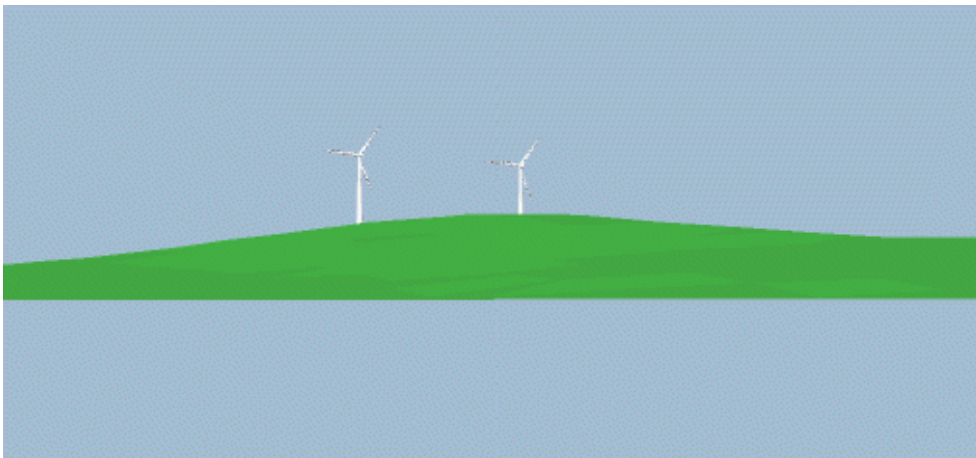


For calculation of a photo choose the size of the site. The program suggests normally a reasonable value. In "special situations" enter the values manually.

The distance in front of the camera where the rendering "starts" and "ends" can be changed.

The "start" point can often and with advantage be set for "1" if the turbine is within a distance of 3 kilometres from the camera. On the contrary, you can utilize the value to give an impression of the waters in front of the turbine by reducing the landscape site to generate. See following example.

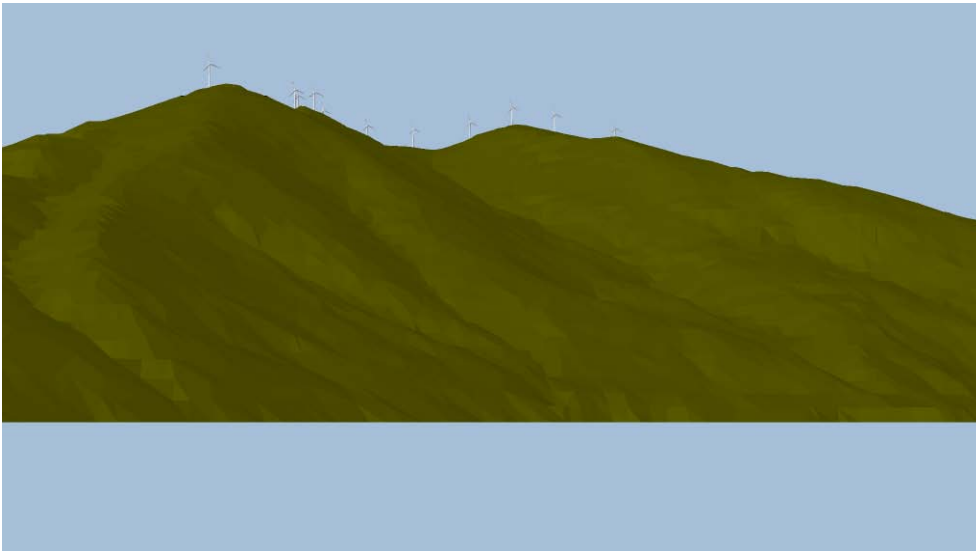
Where the site "ends" is a more complex matter as it depends on the landscape and the height contour lines for a site. If there is a mountain landscape behind the turbine it might be important to include this though it requires a substantial enlargement of the calculation and data site (TIN radius in height contour object).



The model for generation of an artificial landscape is improved in connection with development of the new module 3D-Animator. It is now possible to input more landscape details through different objects, see 5.1.4.8.



Above the real photo regarding the above example is shown (only the existing turbines are seen).



Above an example from Greece with “real” mountains is shown as an example of getting a quite realistic view based on artificial landscape rendering.

See also: 5.1.3.10 Bitmap elements integrated in the photomontage, which make it possible to build up any landscape you wish.

5.1.5 Printing or exporting the final image

You have two options to get the generated image out:

- In the print menu of WindPRO you can define the printout settings yourself, e.g. include several images on one page, combine an image with a map, print a full-paged image or a full-paged map including camera point and turbines, etc.
- In the export menu you can export the image as a graphics file, which can be imported into other documents or be used for professional printouts.

Below you will find some general comments on how visualizations may be presented:

- On a PC display
This is straight forward option. You bring your PC along with you to wherever the result is to be shown and have no problems with “presenting it”.
- On TV/Video

When the image is transferred to TV/video you will experience a loss in quality since these media use significantly lower resolutions than the PC display. We do not have any experience with this option so far.

- On paper prints
Printing directly on paper is probably the most commonly used option. You have several options ranging from using your own colour printer (either a cheap but good jet-ink, or a somewhat more expensive colour laser printer), to having a professional photo laboratory doing the job by using expensive colour laser printers, jet-inks or sublimation printers capable of making photo realistic prints
- As slides or overhead film
Slides/overheads can be made at a professional photo laboratory directly from an image file, which, of course, gives the best quality. Overheads can also be made simply by printing directly on OH film or by copying from a paper print directly on OH film, e.g. by using a colour-copying machine.

When the image with the turbines has been rendered into one of the 4 above options it can be used for a presentation of the result.

Ad a)

Ad b)

Ad c)

Ad c)

5.2. VISUAL – animation (2D)

Animated visualization consists in rotating the turbine blades in a sequence of renderings called an animation. The animation, which is stored as a file, can then be shown on any computer having the necessary animation player installed, i.e. not necessarily on a computer running WindPRO. The animation player developed by EMD comes with the software. (EMDplayer.exe is found in the WindPRO program installation folder) or can be downloaded from www.emd.dk. This software is freely distributed to anyone).

The animation has the advantage that it shows the rotating blades, the dynamic appearance that characterizes a turbine – contrary to other objects in the landscape. By this it is easier to evaluate alternatives like e.g. many smaller but faster rotating turbines and less big but slower rotating turbines.

It is also possible to export the animation as a file that can be published at the Internet and shown in a standard browser (Internet explorer, Firefox).

5.2.1 Calculation methods in 2D animation

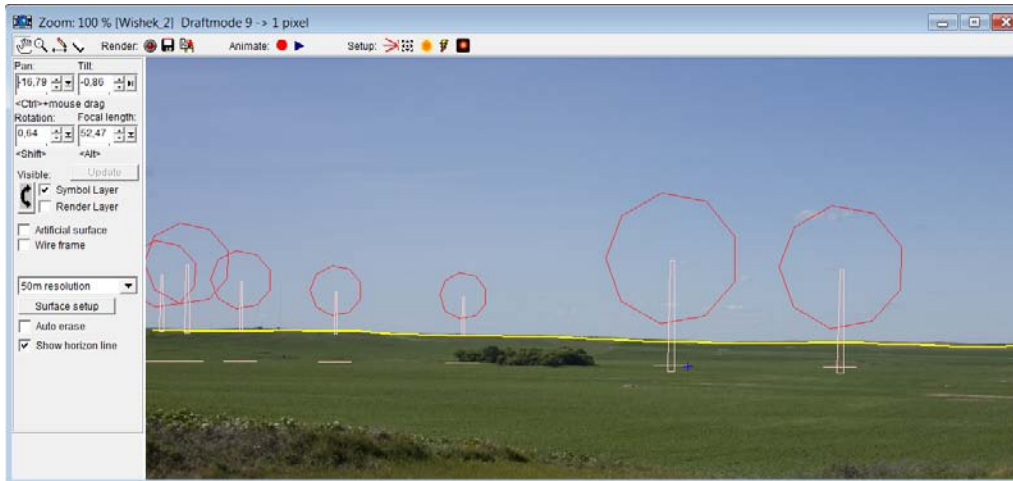
The technique behind an animation is as follows: the program renders a sequence of photomontages of the turbines in which the blades of the turbines are rotated slightly on each rendering. When a complete cycle of renderings has been made, the sequence can then be played repeatedly to make a continued animation of the turbines with rotating blades.

The program automatically creates the necessary number of renderings for a complete cycle. A build-in routine allows the rotational speed to be adjusted within 5% in order to keep the number of renderings close to the minimum required in the animation set-up parameters, thereby reducing the rendering time and necessary storage capacity considerably.

The file format and the film player have been developed by EMD on the basis of a once used but now outdated format for Windows 3.11. The new film players on the market today turned out to have critical errors or demanded each user to have separate licenses. Therefore EMD chose to develop those components in-house.


5.2.2 Preparation – individual speed for each turbine

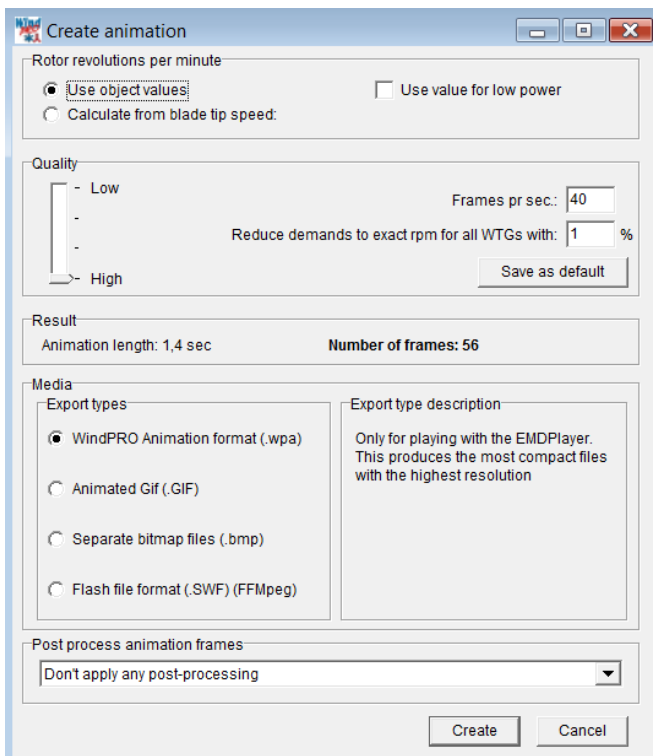
Before creating an animated visualization a photomontage has to be made. This is described in detail in paragraph 5.1. VISUAL – Photomontage. But also remember to rub out, not only the rotor parts that are behind e.g. trees but also the ones that during rotation might become behind.



Next, ensure that the rotational speed settings in the turbine Catalogue for the relevant turbines are correct. Alternatively, the rotational speed can be entered together with the turbine data.

5.2.3 Generating an animation

In the photomontage window, click on the red button next to “Animate”  and the photomontage window below will be shown.



In the above figure enter the necessary information in order to generate an animation.

Speed

Choose speed information for each turbine object to be used or if you want new calculated values based on a different rotational speed, state this. The latter is indeed usable if you want to try out how it works with different speed levels.

It is possible to choose between 2 rotational speeds, to simulate either the rotational speed at "cut in" (small generator) or at "normal" operation (rated rpm.).

Quality

The quality of the animation depends of 2 parameters:

1) The number of frames (renderings) per second

The number of frames per second should be selected between 20 and 50 – standard TV uses approximately 25 pictures per second. A problem when choosing a too large number of pictures per second is that a slow computer cannot keep up with the real time player speed. On the other hand too few pictures per second will result in flickering.

2) How much can the speed diverge from the specified if there are turbines with different rotor rpm?

If the turbines have different speed levels it might be necessary with a large number of frames (longer rendering time) before a whole cycle is generated. An optimisation routine which allows the rotor speed of the individual turbines to vary within 5-10% (which is hardly visible in the animation) drastically reduces the number of frames needed and thereby the rendering time.

Based on the entered values for the above two parameters the program calculates and shows the necessary number of frames together with information on the length of the animation sequence.

Output Media

Finally the output media can be chosen. There are two choices:

1) a .wpa file, a WindPRO animation file that can be shown with EMD's animation player (EMDplay.exe). The animation player is distributed with the program and can be copied freely to other users.

2) animated Gif for playing in standard web browser and thereby be published on web pages.

3).bmp files, i.e. standard bitmap files that in themselves do not show an animation. If you have a recording tool of your own capable of using the .bmp file format it is possible to create the animation based on these files. For example the Paint Shop Pro Animation shop can create an animated .GIF file based on these.

5) Flash – is the right choice for presentation of the animation in a web browser.

When all the selections are made click on "Create". You will be asked for the folder to hold the animation and the calculation will start.

5.2.4 Recording and play a 2D animation

When the calculations are completed the animation will show in a separate window on the screen. You can control the view of the animation and you can play another animation by dragging it from the animation menu.

The recording speed should only be changed for experimental reasons since it changes the rotational speed of the turbines too, thus resulting in a false, unrealistic animation.

If you want to play the animation on another computer you need to copy both the animation file (.wpa) and the animation player EMDplay.exe both found in the folder: Program Files\EMD\WindPRO2\

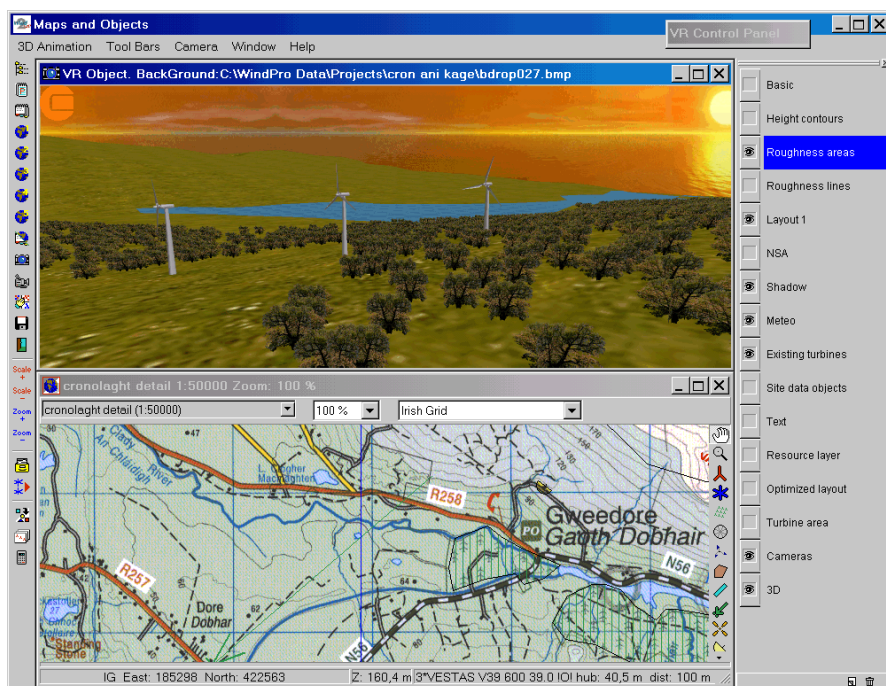
You start the animation by opening (left double click) the EMD player and select "Play".



5.3. VISUAL – 3DAnimator

With the 3D-Animator you can build an artificial landscape based on height contour lines and a texture wrapped on top of this. Use a map, flight photos, satellite photos or simply a bitmap texture. On top of this landscape model the WindPRO objects, e.g. the Area object gives a realistic scenario specifying forests, cities, and animals etc., which are rendered. Last but not least the turbines that of course will be rendered with rotating blades.

In this artificial world you can walk, drive or fly around, controlled by the mouse. A specific track can be recorded and played. A 3D animation can also be played aside by any external person via the viewer shareware program.



5.3.1 Calculation methods in 3DAnimator

The technique behind an animation is as follows: The software converts all data into triangles specified with three 3 dimensional corner coordinates. On top of each triangle a surface is drawn. This surface is adjusted for light settings. The camera position, focal length, pan and tilt angle now decide what shall be shown in the render window. This information is updated while the camera is moved or its properties are changed. A render engine called Morfit is used to control all this. Morfit is, among other purposes developed, for PC games.

5.3.1.1 Hardware and Operating System Recommendations

The following software and hardware recommendations apply to the 3DAnimator module only. Other WindPRO modules may run on less powerful computers.

A 3D-animation is much like a simple PC-game, and is thus very hardware demanding. The actual hardware requirement depends much of the setup of the project and especially the number of polygons that the computer must process and render. An old computer, e.g. a 600 MHz Pentium III with a 3D video card, may run small projects with a limited rendering area (say, 1000 x 1000 m² with only a few turbines). The version of operating system is also of major importance. The 3DAnimator must run on a Windows 2000 / XP/ Vista or a later release.

For an optimum 3D-performance with the WindPRO 2.7, we recommend a software/hardware setting as shown in the table below.

Hardware	Minimum	Recommended
Processor	1 GHz Pentium 4	>= 2 GHz Pentium 4
Video Card	3D card with 32Mb ram	Nvidia 3D card with >=256 Mb ram and hardware antialiasing
Memory	256 Mb	>= 1 Gb
Operating system	>= Windows 2000	Windows XP/Vista/7 or later

5.3.2 The VR object



The VR object is mainly used for specifying the information about the size of the area to be rendered and the texture to be put on the top of the landscape. Besides this many options can be set from the VR object, but these can also be changed from the menus that appear when the 3D-animation is running.

The two left most tab sheets: Position and Layers are common for all objects and therefore not described here – see chapter 2 Basis for detailed information. (2.5.2.2 for position and 2.11 for layers)

5.3.2.1 Set-up tab sheet

3D Animator form (3D-Animation (1))

Position | Layers | Setup | Background | Use Objects | Lights | Runtime

Direction of wind: 270

Exaggerate Z-value in DHM: 1

Texture on ground

Color Automatic based on heights

Use Map

Use Bitmap C:\WindPRO Data\3DA Data\Su ...

Bitmap Height (m) use 0 for "stretch to fill": 500

Bitmap Width (m) use 0 for "stretch to fill": 500

Use Color

Area width (m): 500

Area height (m): 500

Force straight VR area border line (slower)

Use grid as surface

Area Grid Wide: 100

Area Grid Height: 100

Polygons in grid:

Set Maximum allowed polygons in landscape

Exaggerate Z-value is used to make the changes in the z-levels (elevation) more visible, and thereby help the user to see the differences in the landscape elevations more clearly. To make a “realistic” presentation, this value shall of course always be set to “1”.

Texture on ground is used for draping a picture on the top of the digital height model (DHM). The purpose can be to make it look realistic – then a flight photo will often be preferable, but in e.g. a mountain region, a simple bitmap showing a ground with rocks can be working quite well. There are four options:

1) Auto colours based on heights – this simply gives a colour change with elevation – this is often powerful for a “first study” of the site and show very clearly where the proposed turbines are sited relative to the highest elevations. And this is a very PC-power “inexpensive” solution.

2) Use map covers many options. This allows to drape one of the attached maps to the project on top of the DHM, and can give a very informative presentation, where e.g. place names are shown in the 3D-animation. But this is also the way to use e.g. aerial photos to drape on the top of the DHM, which often gives the most realistic presentation. Before an aerial photo can be used, it has to be georeferenced, which is done by attaching the photo as a map (as described in chapter 2.x Basic).

3) Use bitmap simply places a photo or other texture on top of the landscape. This can be stretched to cover the whole area or it can be tiled (repeated) more times over the region by giving the dimensions of the rectangle the bitmap is supposed to cover.

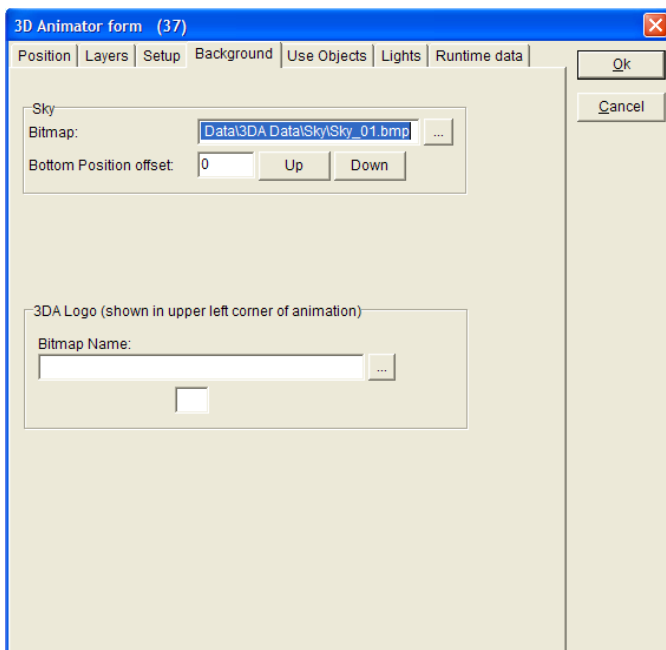
4) Use colour is finally the very simple solution where nothing better are available – or for very “stylistic” presentations.

Area width and height simply describes the region to be rendered. Depending on the complexity of the terrain-model, the area should not be too big (bigger than e.g. 5000x5000). If a big area is required, simplifying the used height-contour using the EMD-editor, is highly recommended.

Use grid as surface is an option, which can speed up the render process very much. Especially if very detailed height contour lines (and thereby detailed TIN) are used, the number of triangles to be rendered will be very large. This can be reduced much by just taking one point for each e.g. 50m – and often the realism will be just as good.

Maximum allowed polygons in grid is used as a safety-net when running the 3D-Animator. It is very easy accidentally creating a world containing a huge number of polygons, causing the program to spend hours creating a world, that is too large to run on the computer anyway. This feature is offered to save the users time and nerves, and to give helpful information regarding where the overflow of polygons comes from (which object). Do not set the value too high! The turbines are NOT included in this test!!

5.3.2.2 Background tab sheet



At this tab sheet the bitmap used for showing the “Sky” is selected. This is only an option – if no sky bitmap is selected, the colour outside the render area is used as background.

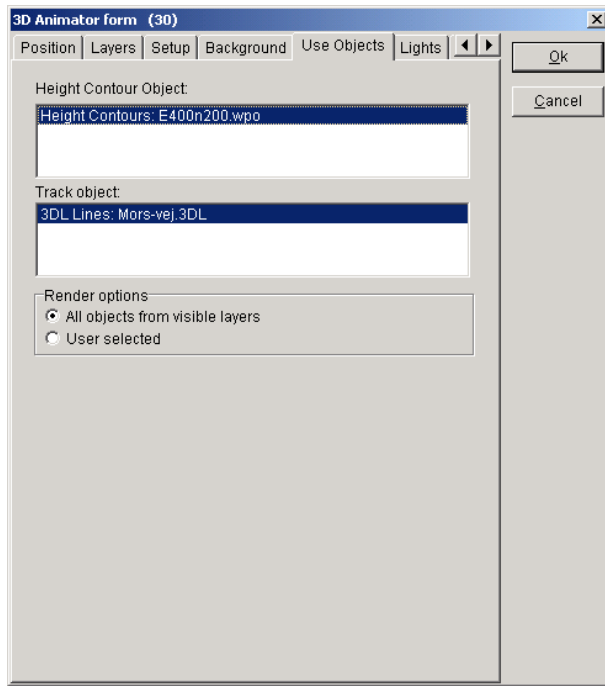
There will be some “sky-bitmaps” in the library included, but you can also use your own photos. Just notice that the width/height relation of your photo might need to be adjusted between 1.5-3.

The bottom position of the sky bitmap can be adjusted in case the sky bitmap does not “fill” the background in a proper way, e.g. there is a “blank” part between the ground and the sky bitmap. This normally is adjusted after the landscape is rendered and there will be a menu for this adjustment in the 3D-animation window.

The colour outside the render area is simply the background colour used where there are no surface or sky bitmap.

Also a logo to appear at the left top of the 3D-animation window can be set here.

5.3.2.3 Use object tab sheet

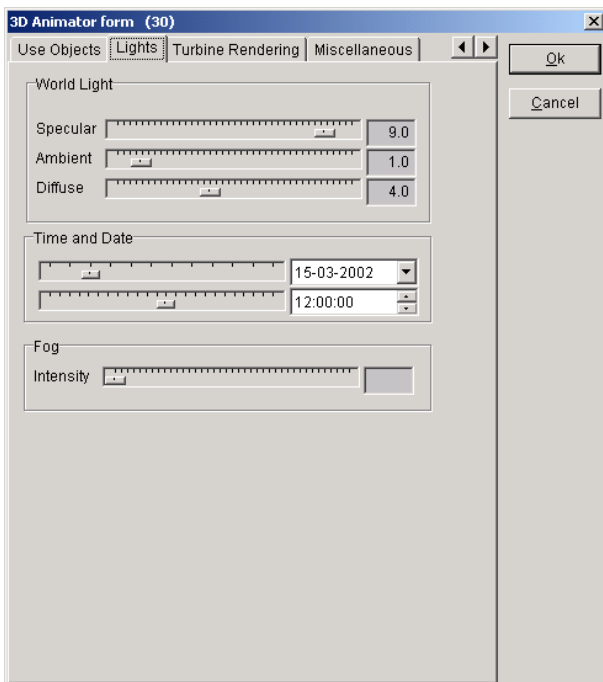


If you have several height contour line objects, you must decide which one to use for creating the DHM – only one can be chosen, but notice that you can merge two or more height contour files in the line object (see chapter 2.8, Line object, Basis).

If you want to use a “track”, normally a road to link your camera to, you can select here which line object will be used for this purpose.

Finally you can decide which objects that shall be rendered. The default setting is “all object from visible layers”. In that way you can use the layer manager to decide what to be visible. But you can also manually select object by object.

5.3.2.4 Lights tab sheet



In the lights tab sheet you can set the light at the landscape rendering. Note that when the 3D-animation is running the light setting can be made “on-line” from the toolbar menu, where you see the changes at once. Here only the initial settings are given.

The 3 “types” of lights that can be changed are:

Specular: Comes from a particular direction but is reflected of the surface depending of the surface specular value. The ground surface gives almost no reflection.

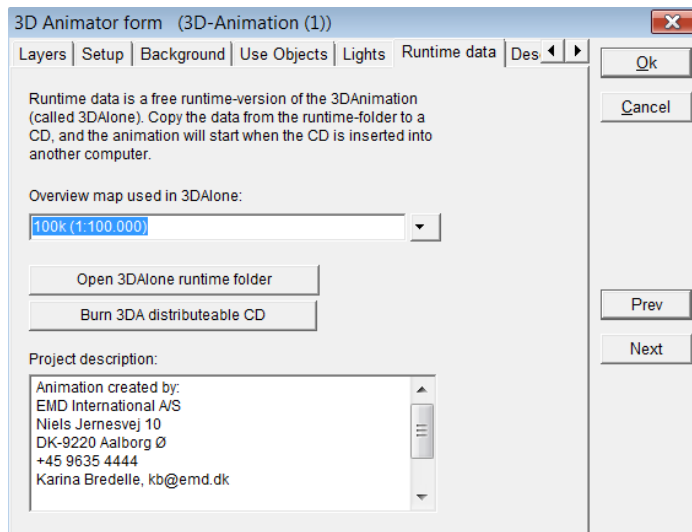
Ambient: Background light. Has no direction, and covers all surfaces.

Diffuse: Comes from a particular direction but is reflected evenly of all surfaces. Gives less contrast compared to specular light.

On top of this the date and time graduates the light in combination with the location on earth (and time zone). The sun position and strength is simply calculated at specific place, date and time.

Finally there can be simulated fog, where the intensity can be adjusted.

5.3.2.5 Runtime data tab sheet

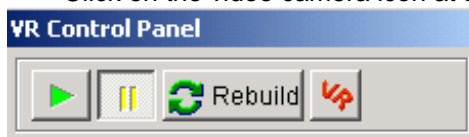


The Runtime data tab sheet concerns the stand alone 3D animation which will be created with the current VR object (see chapter 5.3.7). In this tab sheet, you can select the map where the location of the viewer in the stand Alone version of the 3D animation will be displayed. The “Open 3DAOne runtime folder” button opens the folder which has been created after the first generation of the 3D animation of a VR object. The “Burn 3DA distributeable CD” will enable you to start the burning on a CD. The project description of the runtime data tab sheet makes it possible to add a small text in a frame below the 3D animation.

5.3.3 Generating and controls of a 3D-animation



Click on the video camera icon at the left menu bar and the 3DA window will appear.



Then click on the green arrow in the VR control panel to start building the artificial landscape. From this part of the controller the animation can be paused (yellow ||) and started again at the green arrow.

Rebuild is used to recreate the whole 3Danimation. Only WTG's, sky and light settings are updated immediately. All other changes require a rebuild to take effect. Since the animation is stored for the runtime version, the rebuild is faster if only a few changes are made, because it re-uses the unchanged parts from the runtime. This means that the rendering of e.g. a big forest may take 10 min. the first time and 20 sec. the second time it is built.

The VR button is used to open the 3DA properties dialog.

5.3.3.1 Main control of a VR flight/drive


The arrow keys at the keypad are the “basic” keys for controlling the drive/flight around in the landscape.




Move forward (hold down)



Move backwards (hold down)

 Turn left (hold down)

 Turn right (hold down)

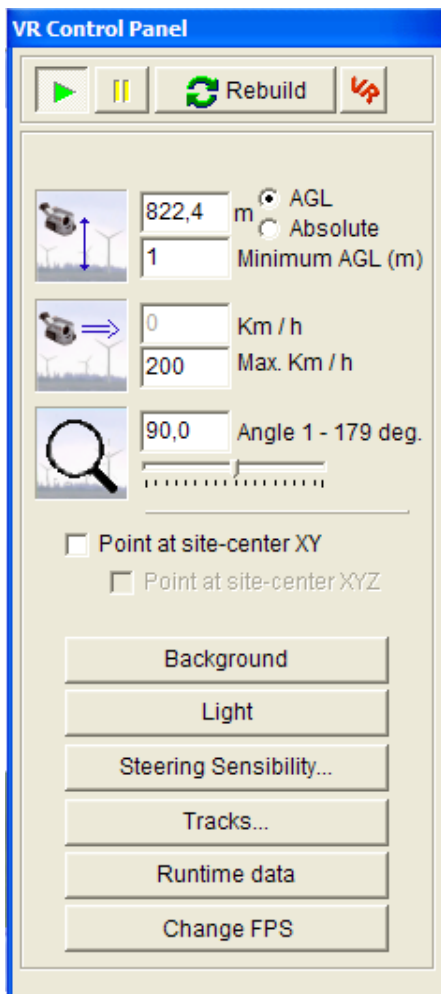
The **<PgUp> – <PgDn>** “lift” the helicopter and takes it down again. (Scroll wheel on a mouse normally has same functionality)

Look up/down (tilt) with mouse click at top/bottom of render window (alternative **<u> - <d>** keypads can be used).

Look left/right (pan) with mouse click at left/right of render window (alternative **<l> - <r>** keypads can be used).

A joystick or a mouse can also be used.

5.3.3.2 The VR Control panel



From this panel following settings can be controlled/surveyed:

Height of camera can be set either Above Ground Level (AGL) or absolute. The last option typically by virtual flights, where the plane then follow a “direct line” instead of changing elevation with the terrain below the plane. The minimum height AGL can be set – to avoid that the camera goes “below” terrain surface in rough changing terrain, the value can be set a little up.

The height is (besides by entering values here) controlled by:

The <PgUp> keypad for "up"

The <PgDn> keypad for "down"

Or typically by the scroll wheel at a scroll mouse (depend on windows setting on scroll wheel)

Finally a joystick normally will have features for this function.

Speed of camera can be entered as a maximum speed. When the Arrow up keypad is held down, the camera relative fast reach this maximum speed – at release it decelerate again fast to zero speed.

Camera angle (focal length – or zoom) can be set free from 1-179 degrees.

3DA Camera angle compared to Photomontage

V: Angle 3DA (typical value 90 grader)

F: Film Width (typical value 36 mm)

B: Focal Length (typical value 50 mm)

$$V = 2 * \text{ATan}(F/(2*B)) \Leftrightarrow$$

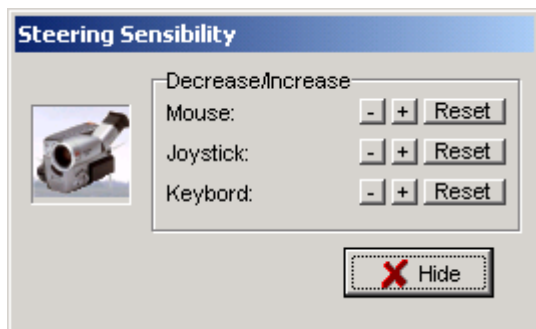
$$B = F / (2*\text{Tan}(V/2))$$

$$F=36, B=50 \Rightarrow V = 40 \text{ degrees}$$

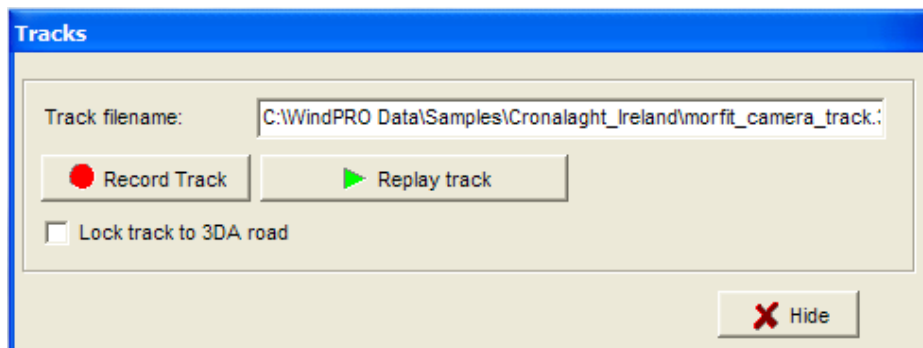
Point at site-center XY(Z) – with this checked, the camera always point towards the site centre.

The 2 following buttons are for opening detailed control menus for Background and Light. These are explained in 5.3.2.

Steering sensibility makes it possible to change the sensibility of the controlling device.



Tracks makes it possible to record a track, replay it or create an .AVI file based on the recorded track see 5.3.6 for further details. Note that the camera track can be locked to a line object created as a "road".



Runtime data opens the properties of the stand alone 3D-animation as explained in 5.3.7

Change FPS makes it possible to change the number of frames (pictures) rendered per second. This is used for setting the compromise between the capability of the PC, the complexity and size of landscape and the "smoothness" of the "video" presentation. A normal television works with 25 (CHECK) FPS.

5.3.3.3 Brief note on video quality

The video quality heavily depends on the performance of the graphics card in your computer. The best results and performance are obtained if you use a 3d-graphics card with hardware antialiasing properties enabled, such as the nVidia GeForce 2,3 or 4. To illustrate this matter, see the pictures below.



Rendering with antialiasing



Rendering without antialiasing

5.3.4 Objects that can be used in 3D-animation



New and existing turbines can be used. The data in the turbine catalogue is used if there are “visual” data in the catalogue. If there are no data specified for visual, a default turbine is rendered based on hub height and rotor diameter.



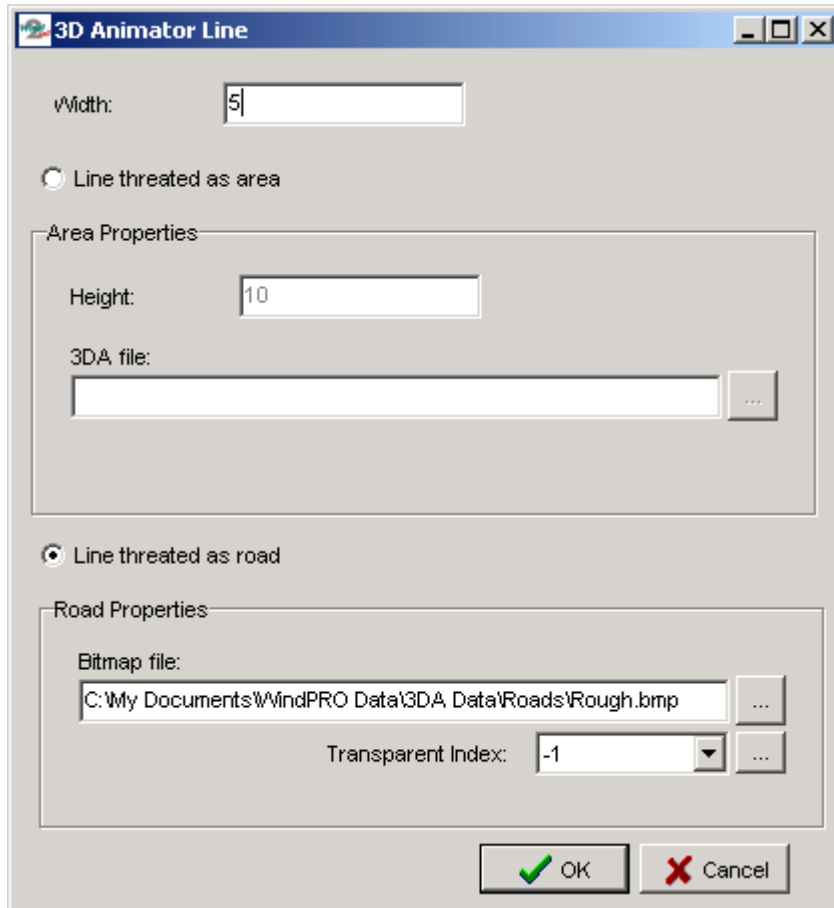
A Meteo object is rendered with a mark for each measure height there is created in the Meteo object. The colour of the Meteo mast reflects the “purpose”, Black means “no data”, blue mean “set for energy calculation” and finally orange means “set for STATGEN” purpose.




A WAsP obstacle can be used for creating a rectangle with the specified height. A 3DA file can be attached, where as well “free bitmaps” as boundary box (button, sides and top bitmaps) or a combination can be attached. (See next chapter for 3DA file description).





A line object can used 2 different ways:
 As a road, where a bitmap showing a “road part” can be attached
 As an area, where a 3DA file can be attached – e.g. a long row of trees.



Common for the line object in a 3D-animation is the width, which is entered. Additionally a 3DA file or road bitmap is attached.

 The 3D object can be created as a row of more with equivalent distance. For each object a bitmap object can be attached. This can be a simple fixed, rotating or crossed bitmap or it can be a simple house. See details on bitmap objects in next chapter.

 The Text object can be used in 3D Animation as billboards, which link a specific point on the map to the artificial landscape. See in chapter 5.1.3.12.

 Finally the area object is an important object for 3D-animations. Larger regions as water, forest or cities can typically be incorporated through an area object. A 3DA file can be attached, where as well “free bitmaps” as boundary box (bottom, sides and top bitmaps) or a combination can be attached. (See next chapter for 3DA file description).

5.3.5 3DA editor and browser

The 3DA editor makes it possible to attach predefined landscape elements and to create your own elements.

There are “3 levels” of elements:

The bitmaps (simple pictures)

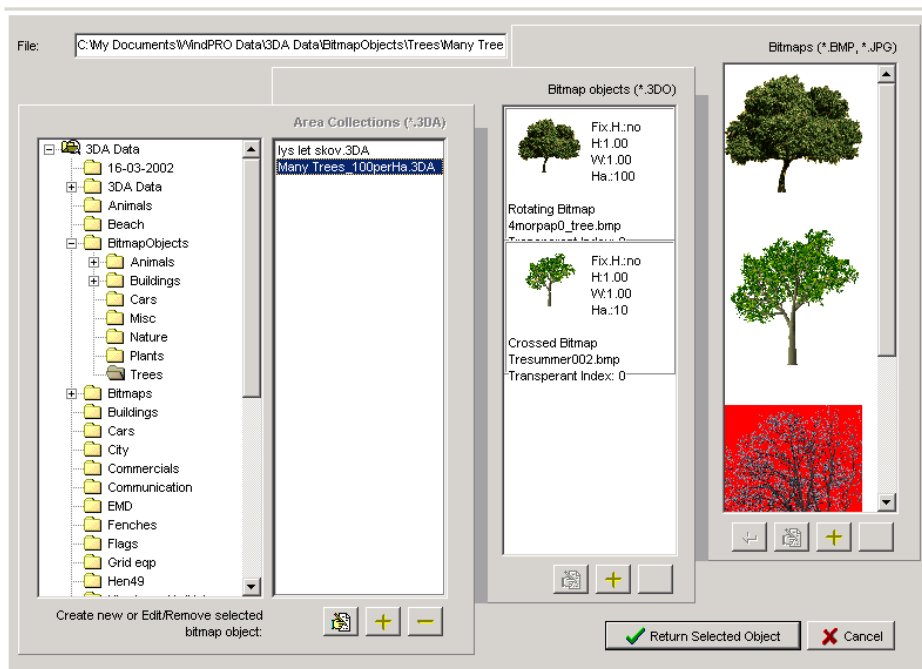
The bitmap objects, which are bitmaps given properties as dimensions, how to view (e.g. rotating bitmaps, always facing camera) and which colour that might be transparent. Also a “simple house” which is a 3D presentation with width, height, debt and roof angle, see detailed explanation in 5.3.5.3.

The 3DA object, or Area collection, is typically used for larger areas, which can be described by a “boundary box”, where bitmaps on bottom, sides and top can be attached. For water surface only the bottom surface are given, while e.g. a forest only are described by sides and top. But also individual bitmap objects can be input for a 3DA object. Many trees can describe a forest instead of a side and top bitmap. This often gives a more realistic presentation, but it is also setting much higher demands to the PC while the number of objects to be rendered increases.

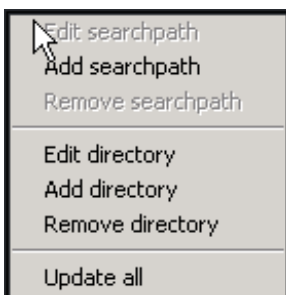
5.3.5.1 Browser for 3DA elements

The 3DA editor works as a browser, where all 3 types of elements mentioned above appear at the same time – but only the relevant type can be selected. It makes it easy to create bitmap objects based on bitmaps or 3DA objects based on bitmap objects if the needed element not already appears in the browser.

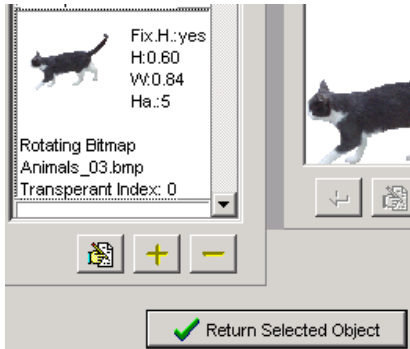
Below the 3DA editor in “browse mode” is shown.



The default folder to be browsed is: WindPRO Data\3DA Data\ - but more folders can be browsed by adding a search path.



By right click in the path column (leftmost) in the 3DA editor/browser, a menu appears, which enable adding or editing the paths for the browser.

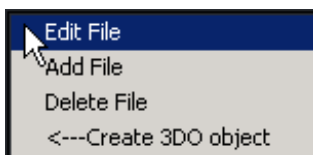


Clicking on one of the items (files) in the relevant column (column with blinking header) makes it possible to “return selected”.

5.3.5.2 Edit or add 3DA elements



The 3 buttons below any of the 3 columns in the 3DA Editor/browser, makes it possible to **edit, add or delete** an element to the given column.



By right click on a bitmap, it is possible to use this for creating a bitmap object (3DO object).

5.3.5.3 Bitmaps add and prepare for use in 3DA.

To prepare a bitmap for use in 3DA, there are 3 important rules:

The size of the bitmap shall be reduced to a minimum – typically not more than 100 kB file size after reduction. Another measure is that no more than 300 DPT (Dot per inch) should be used – 75 DPI will normally be fully enough.

The number of colours should not be more than 256.

The background colour MUST be one uniform colour.

To fulfil these demands, a photo editing software tool will be needed. There are many possibilities, e.g. the Paint Shop Pro (Enclosed on WindPRO install CD) or Adobe Photo Shop.

The resize and colour reduction options should be simple to find and use, so here just the more refined functionality, for making the background colour uniform, is described.



Assuming the biogas tanks from the photo above shall be used. Step one is to cut out the relevant part and reduce the numbers of colours to 256:



Now the background sky shall be given a uniform colour. In this case the lasso tool seem the best solution – if there are only vertical and horizontal lines, a rectangle selection tool would be preferable.



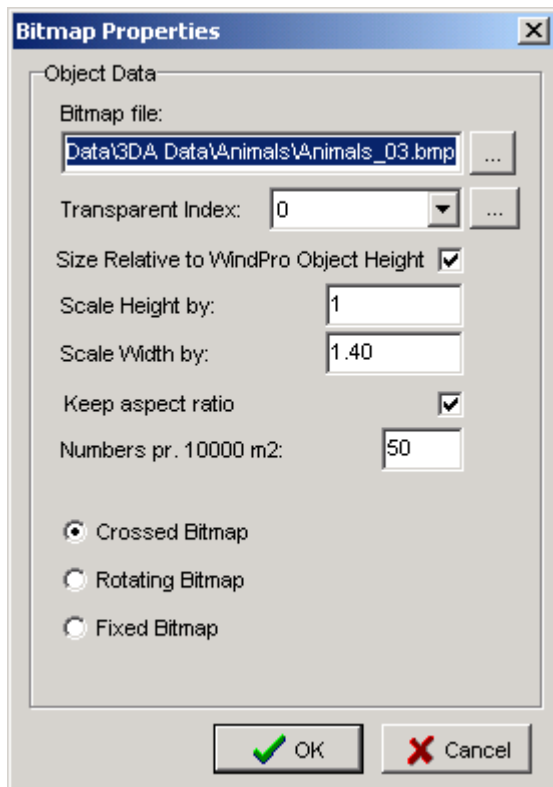
With the lasso tool, there is drawn around the background sky piece by piece and the background is simply “deleted” (which means that the default background colour will appear).



After marking all background, it is a good idea to cut out a piece, so the edges are ignored (while these often not are “caught” with the lasso).

Note that the “magic wand” tool often can be a very fast tool for selecting the background if the colour is different from the colour of the object on the photo to be used.

5.3.5.4 Creating a bitmap object from one or more bitmaps



A bitmap can be given some properties “once for all”, so it is not necessary to tell the program the height of e.g. a horse every time this bitmap is used. In general the properties given, is considered default values, and some values can be overruled by the properties of the object it is called from.

The transparent index normally will be “0”, while this is the colour that appears most times in the bitmap. But in some very special cases, e.g. a barn with a very clear colour it can happen that the colour of the element to be visualized is the one with the most dominant colour, and the background then is the second most used colour. Then the index shall be set to “1”. With 2 more dominant colours in the bitmap than the background, the index shall be set to “2” and so on. With a click on the browse button next to the selection field, the transparency colour can also be selected by clicking on the picture.

Size relative to WindPRO object height checked means that the height of the bitmap object is scaled automatically. This is typically used for trees, so they used from e.g. an obstacle, will appear with the height the obstacle are given in the obstacle object.

If the above is checked, it is possible to give a scale factor on height and width – otherwise here the “real life” height of the bitmap is given here.

Numbers pr. 10000m² (Ha) is used as default value, when the bitmap object is used in a 3DA file (object collection), where the bitmap object is placed random in the object region (area, line or obstacle).

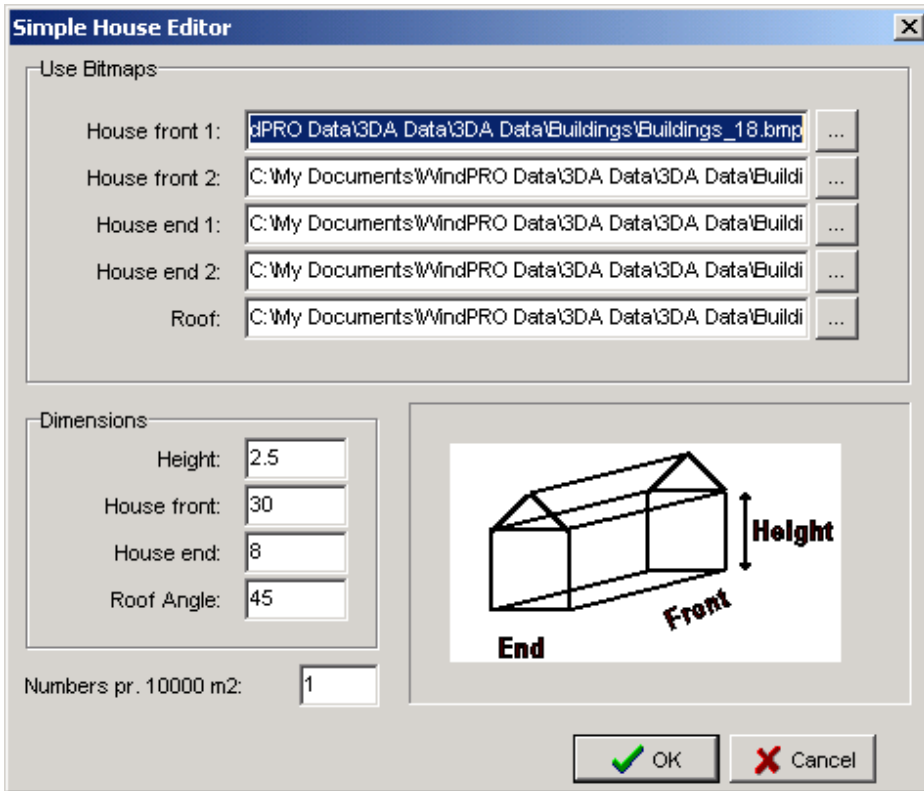
Finally the way the bitmap is shown in the 3D-animation can be selected.

Crossed – 2 bitmaps crossed typically used for trees.

Rotating – always facing camera typically used for animals or symmetric elements, e.g. some type of buildings (towers, lighthouses etc.). This kind is the slowest to render.

Fixed – most used for elements of a certain distance from the path where the 3D-animation are shown, e.g. a village at a certain distance.

Especially buildings can not often be shown properly with one of the above options. A house, which shall be passed closely in the 3D-animation, will often give a poor presentation as a single bitmap. Therefore a first step for compensating for this is the “simple house”, were a 3 dimensional house can be build based on 5 bitmaps.



The front (and back), the two ends and the roof can have each a bitmap. Besides this the dimensions of the house can be given as shown in the definition window above.

5.3.5.5 Creating a 3DA file (bitmap collection) from one or more bitmaps and/or bitmap objects

A 3DA file or object collection, are based on one or two main elements, where both describes the area covered by the object from which it is used:

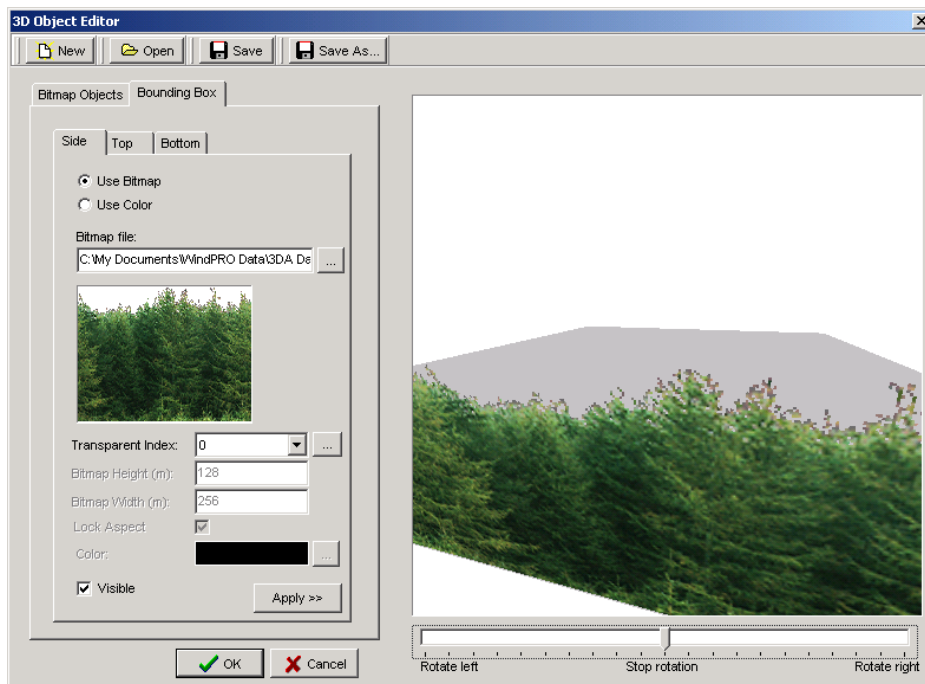
- Bounding box (bottom, side and top) of the area
- Free bitmap objects random distributed in the area

Both elements are entered when a 3DA file is added or edited from the 3DA bitmap editor/browser by clicking on one of the 2 leftmost symbols:



When 3DA file is added or edited, the 3DA file editor above show up.

Bounding box

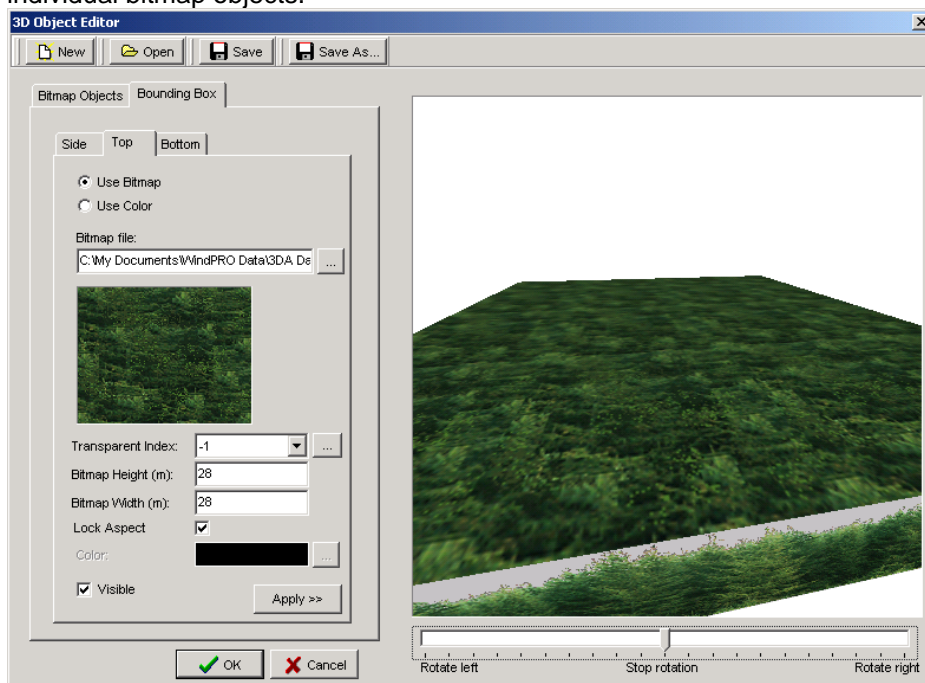


The bounding box (the right tab sheet), gives 3 sub tab sheets, Side, Top and Bottom.

Each can be given a colour or a bitmap. In the example above a side is added. Note that sides always will be tiled and the object it is called from will control the height.

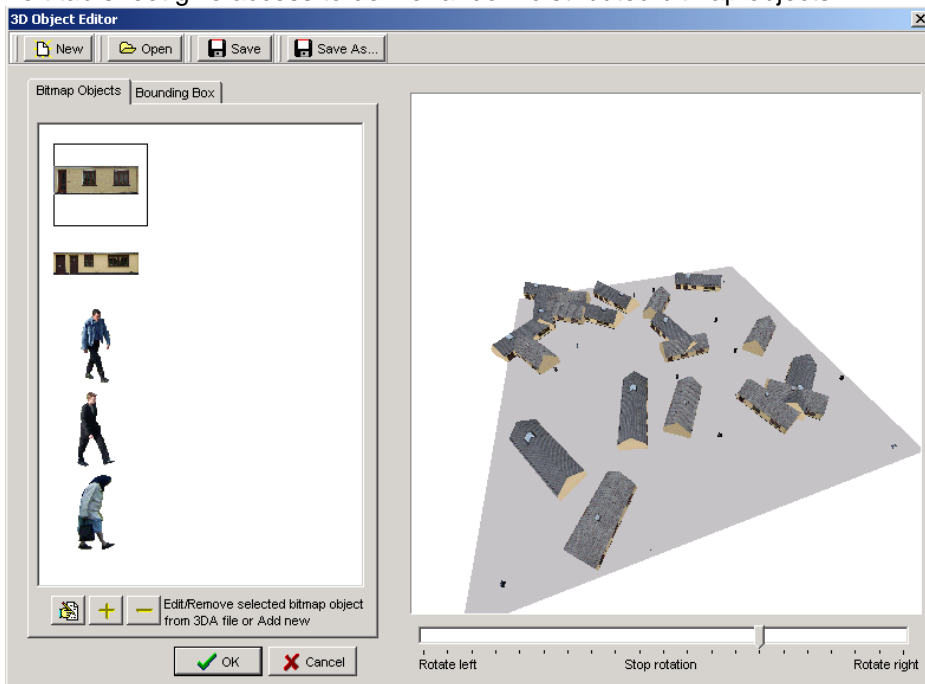
The bottom and top bitmap needs to be given a “real world” size. This information is used for tiling the bitmaps.

Below an example on a top is added. Note that there is gab between sides and top, while the side bitmap has a transparent part in the top of the bitmap. This is one reason for using bitmap objects like described in next paragraph instead of boundary box for a forest. But note that the bounding box work much faster (especially in a not to complex terrain), and if you only see it from the road, the boundary box is just as good as the individual bitmap objects.



Bitmap objects

Left tab sheet give access to define random distributed bitmap objects.



Here the edit-add-remove buttons are used to change which bitmap objects shall be included:

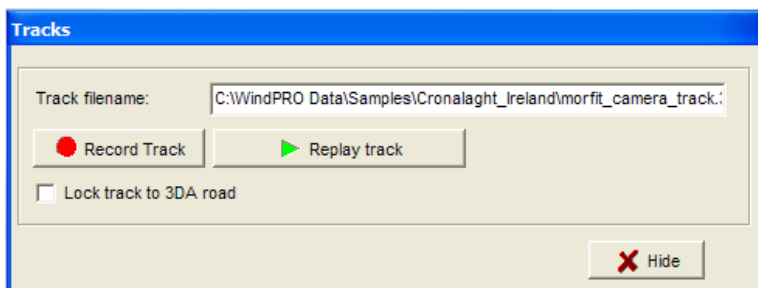


The edit and delete button are only active when one of the bitmap objects in the graphic list are selected.

By right click or double click on one of the bitmap objects, the bitmap object properties can be adjusted, e.g. the number of objects per 10 000 m2 (Ha).

5.3.6 Tracks

With the “Track” button on the VR Control panel, it is possible to start recording a track.



As soon “Record Track” is clicked, the recording starts. You can now move freely around and the 3DAnimator register all movements, including pan, tilt and zoom. Click again at the “record” button, and it stops recording.

Now the “replay track” can be used to let the PC automatically run through the same track again and again until the user stops by clicking again on “replay track”.

3D-animation

It is possible to change the name of the file where the track is stored, and in that way to create and store different tracks.

5.3.6.1 Lock to track

As described in section 5.3.4 a line object can be given the special purpose “road”. This gives 2 possibilities:

It can show a road bitmap in the 3D animation
It can be used as a track the camera “lock” to.

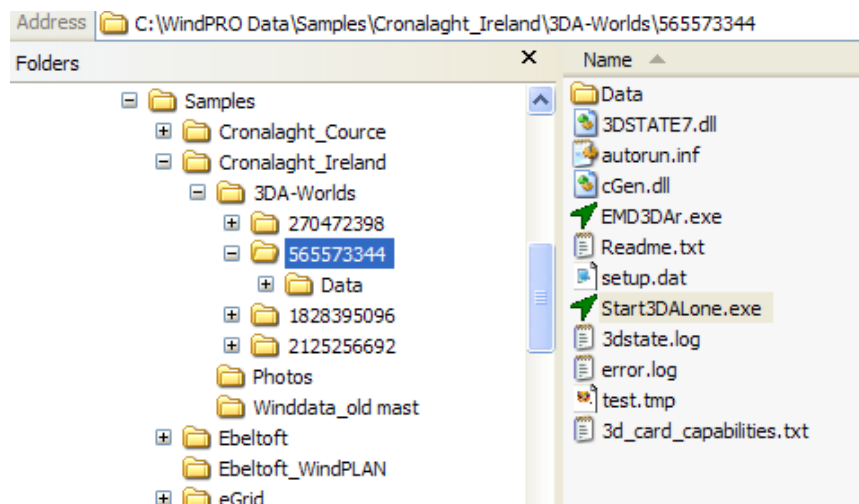
Both can be used individually, but of course also in combination, so you see the road you follow.

When the track is locked to 3DA road, the camera moves to the starting point of the 3DA road (also if it is outside render area), and the normal move functions works, except for the “turn left/right” functions – these are locked to follow the road. Instead the “Pan left/right” can be used.

5.3.7 Stand alone 3D-animation

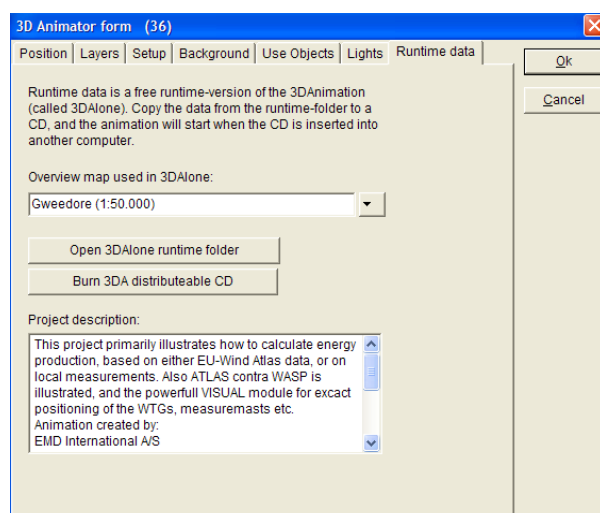
3D animation created in WindPRO 2.7 can be played remotely from WindPRO with full user control of views through the EMD viewer shareware program.

Whenever a 3D-animation is created from a VR object in WindPRO (see chapter 5.3.2), a folder containing all the needed files is automatically created.

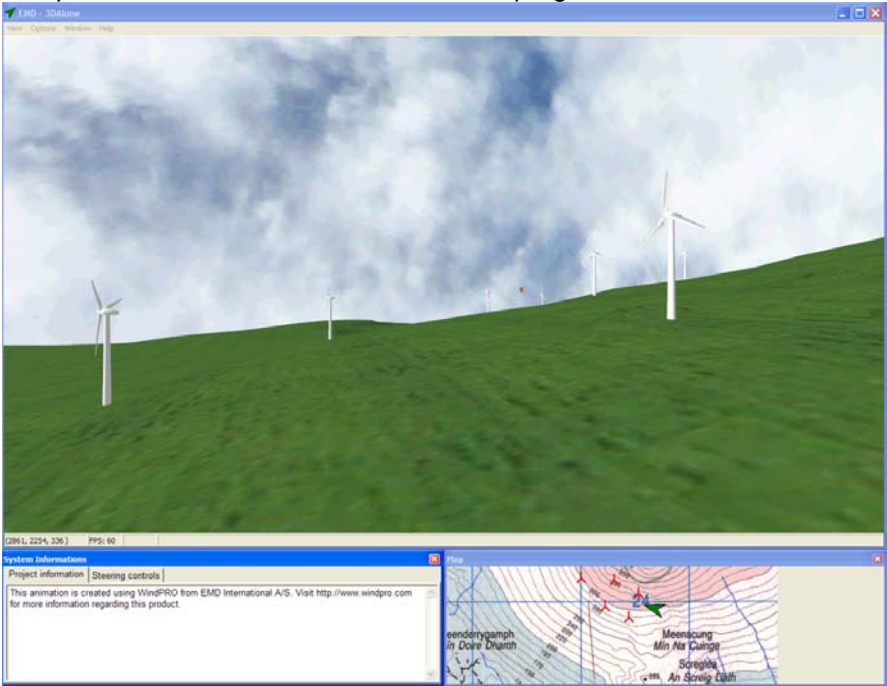


The folder is created under a 3DA-Worlds folder in the current WindPRO project folder. To run the animation, the viewer has to select Start3DALone.exe.

This folder can be mailed to make the 3D-animation run independently on any computers. It is also possible from the Rundata tabsheet of the VR object properties to burn the 3DA directly on a CD.



The picture below shows how the 3D Alone program will run the animation externally of WindPRO.



The animation is displayed in the upper frame where the user can fly in the 3D world in the same way as this is done in WindPRO (with the arrow keys, the mouse or a joystick). But it is also possible to define the steering controls manually from the frame at the bottom on the left. The project description made by the creator is shown in this left part of the program. On the right at the bottom, the viewer can follow the moving on the background map. These settings are described in chapter 5.3.2.5 Runtime data tab sheet.

Note that WindPRO has to be shut down to be able to run the Stand Alone 3D animation program.

Please note that your monitor may give resolutions up to 1024x768 pixels or higher – a very high resolution compared to other ‘traditional’ video sources.

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6.0 WINDBANK – Introduction and step-by-step guide

6.0.1 Introduction to WINDBANK

The financial evaluation of a wind energy project may be the most important project development task. It is, in the end, when all needed approvals are settled, the financial circumstances of the project, which decide whether or not the project will be realized. With the WindPRO module WINDBANK such a decision will be taken on a well-documented basis.

All the documentation, as well as a survey with few key figures and a complete budget, which will satisfy bankers and other qualified office managers, can be printed.

The WindPRO module WINDBANK is, in the present version, furnished with a line of specific facilities which correspond to the Danish tax law, but it will operate under more general conditions when investor is located in other countries.

WINDBANK handles 4 different “owner constructions”:

Cooperatives - where special calculations for each coop can be generated

Private owned – where the owners private tax issues can be mixed with the wind farm investment

Company owned – “standard” company investment

Company coop – more companies has shares in the project, prints for a specific share possible.

WINDBANK can also be used for economic evaluation (the value for the community), it is just a question of proper selection of the relevant input data.

The WINDBANK module is based on templates, which makes it fast to define a new calculation based on previous calculations, where only minor corrections has to be made.

6.0.2 WINDBANK Step-by step-guide

- ❑ Calculate the energy production with PARK or METEO/MODEL (to be able to transfer WTG-type, size and energy production automatically)
- ❑ Start the WINDBANK module – load a template from "Standard" or other previous calculation.
- ❑ Go through all tab-sheets in order to define all parameters.
- ❑ Calculate and Print reports.

6.1 WINDBANK – Calculation methods and key figures

6.1.1 Calculation methods

As previously mentioned, WINDBANK is furnished with special features which are constructed for calculations based on Danish regulations (especially tax regulations), but in all other cases, WINDBANK operates after the often standardized general taxation and depreciations regulations which are used in most other countries. Facilities for calculations based on specific regulations in other countries but Denmark will be developed upon request.

Basically, an annual account is divided into the following items (based on general accounting principles):

Operation budget:

+Income (sale of electricity + evt. value of replaced consumption generated by the WTGs)
-Expenditures (O&M + Book Depreciations = reduction in the value of the Installations)
=Working Profits, Ordinary, before tax and interests

-Financing (Interests only)
-Taxation

=Working Profits

Balance budget:

ASSETS

Installations (value of hardware after Book Depreciations)

Cash Balance (amount on account where the annual liquidity is accumulated)

LIABILITIES

Net Worth (own capital)

Debts

The Annual Liquidity consists of the annual growth of the cash balance. It is important to face the difference between “operation budget” and “liquidity budget”.

The liquidity budget (or cash flow) gives the year by year amount available for investor including taxation. The operation budget expresses the year by year value of the project. Here the depreciation reflects the annual loss in value, whereas in the liquidity budget, the depreciation is “replaced” with the annual repayment of loans and thereby the amount that “in real” is withdrawn from the cash balance.

Operation budgets as well as liquidity budgets can be printed.

6.1.2 Key figures

An essential print from WINDBANK is the RATIOS. With these a fast look will tell if the calculation setup is reasonable or some unit has been wrong leading to wrong result.

Below an example of key figures (ratios)

RATIOS				
		/kW	/m ²	/MWh
Preliminary expenses	US\$	1,967	-	770
O&M costs	average US\$/years	53,2	-	20,8
Energy production	kWh/Years	2.554	-	-

Minimum life span for redemption of loan	13,2 Years
Simple pay back time	9,9 Years
Acc. liquidity, deflated	105 [mio. US\$]
in % of investment	35,5 %
Net present value (Interest rate=6,0%)	51 [mio. US\$]
Internal rate of return	8,5 %
Return on investment	35,5 %
Production price at calculation interest 5,0%	9,9 cent/kWh

Key figures, explanations:

Minimum life span for redemption of loan is the year, where accumulated liquidity (amount on saving account for all liquidity) exceeds the remaining debt.

Simple pay back time is the number of years needed to pay back the investment + operation costs within pay back time. Finance costs, tax and inflation are not included.

Acc. liquidity, deflated, is the total accumulated profit at the end of the project (includes tax etc.), deflated. Same in % of investment is a good indicator of the expected value of the project for the private investor.

Net present value (interest rate

Internal rate of return is the discount rate that results in a net present value of zero for the cash flow. Here is included all payments; investment, O&M, sales of energy etc., but not tax and finance. Should minimum be X as defined above.

Production costs at calculation interest X% is calculated as investment + discounted costs over life time with interest rate X divided with energy production over life time. The calculation interest X is defined as above.

Apart from the text above, following evaluations can be performed based on “modern turbines” > 500 kW:

Preliminary expenses (investment) should be (ultimo 2009 based) 1300 – 2500 US\$ or 1000 – 2000 € per kW for onshore projects. Very deciding is the specific power – large rotor area per kW is in the high end. E.g. A Vestas V90 (90 m rotor diameter) is sold with as well 1.8 as 3 MW generator, the first mentioned will have an essential higher cost per kW.

Price per MWh should be between 400 – 800 US\$ or 300-600 €.

O&M costs should be 15-25 US\$ or 10 - 20 € per MWh.

Energy production 1500-6000 kWh/year/kW (full load hours) – this is a wide span reflecting that wind recourses can be very different over the world.

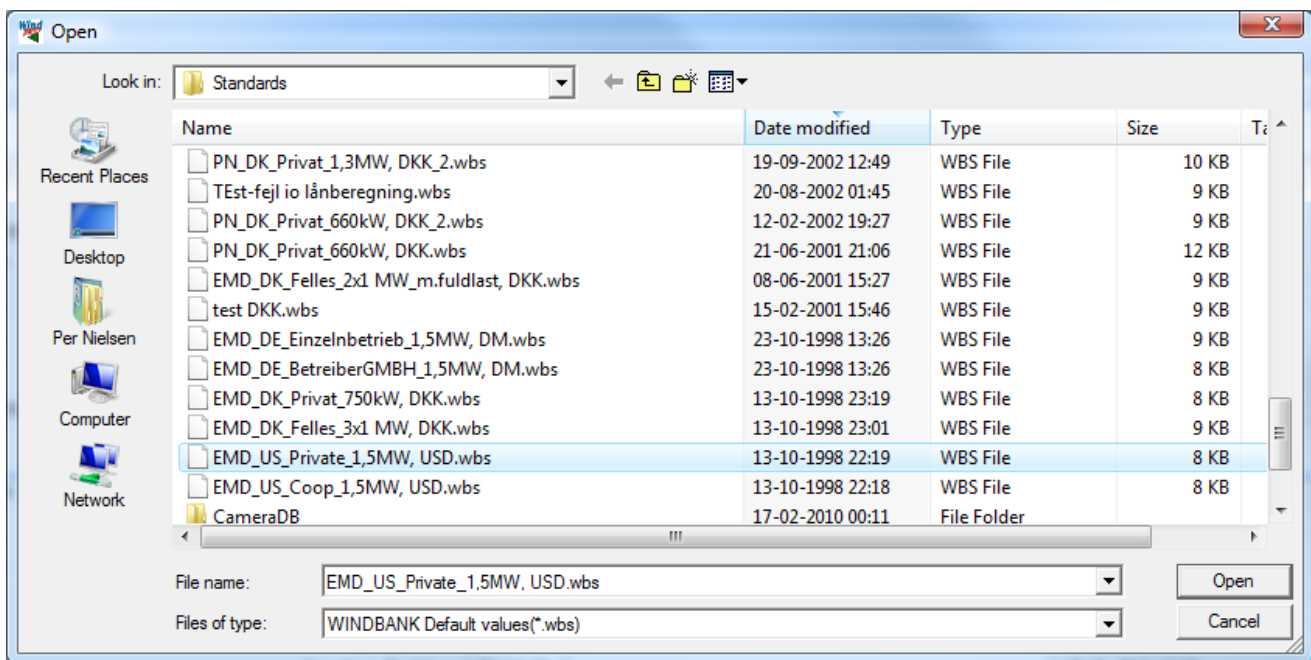
See http://www.emd.dk/files/Vindmøllers%20økonomi_EMD-Feb2010.pdf for more info on as well on as offshore project statistics and key figures.

6.2 WINDBANK – Entering data

6.2.0 Start the WINDBANK module

Click the green (or yellow for DEMO-mode) arrow in front of the WINDBANK module in the WindPRO main menu, and the input form will appear. But before you do this, you must enter some basic information in WindPRO Project properties (country, etc.) (See Chapter 2.BAISIS for further information on how to create a WindPRO project).

6.2.1 Open a template



The first item that will appear is the option of selecting a Template. A Template is a file, which contains some predefined data, which makes it faster to fill-in the input forms.

Some demonstration templates is offered in the folder WindPRO Data\Standards\

You can always save your own current WINDBANK calculation as a Template and load from another project.

Templates can, of course, be copied and distributed to other users. This will ensure uniform presentations and calculations. Make sure not to delete these templates when WindPRO is installed/reinstalled or you tidy up in the file structure. We recommend that you save a backup of these templates.

6.2.2 Setup

In Setup you specify:

Country, project; The name of the country for the project location in question has already been selected under Project Properties.

Country, Investor – gives at present only any difference if the investor is located in Denmark, while this gives access to specific Danish tax regulations.

Currency can be entered freely - this is only a text, which is appended to all printed figures. The choices for amounts/reports shall reflect the size of the project you are going to calculate.

Type of project refer to the owner type, which for some input options gives access to different features.

Edit input for economy calculation

Setup | Project | kWh Price | Budget | Loan | O&M | Inf. etc. | Taxation | Description

Template: C:\Users\per.EMD\Documents\WindPRO Da Use every time

Country, project: United States Country, investor: United States

Currency:	Base	1/100	* 1,000	* 1,000,000
Amount (Budget/Loan)	<input type="radio"/> US\$	<input type="radio"/> cent	<input type="radio"/> 1000 US\$	<input checked="" type="radio"/> mio. US\$
Amount (O&M)	<input checked="" type="radio"/> US\$	<input type="radio"/> cent	<input type="radio"/> 1000 US\$	<input type="radio"/> mio. US\$
Reports, project	<input type="radio"/> US\$	<input type="radio"/> cent	<input type="radio"/> 1000 US\$	<input checked="" type="radio"/> mio. US\$
Reports, share holders	<input checked="" type="radio"/> US\$	<input type="radio"/> cent	<input type="radio"/> 1000 US\$	<input type="radio"/> mio. US\$
Elec. price	<input checked="" type="radio"/> cent/kWh	<input type="radio"/> US\$/kWh	<input type="radio"/> US\$/kWh	<input type="radio"/> US\$/MWh
Energy	<input type="radio"/> kWh	<input type="radio"/> MWh	<input type="radio"/> MWh	<input checked="" type="radio"/> GWh

Type of project

Cooperative WTG Business WTG in shares
 Privately owned WTG Company owned WTG

Buttons: Next, Ok, Cancel, Advanced, Save template

If you mark the 'use every time' under Template you will always begin with this template when you activate WINDBANK.

If you mark 'Cooperative owned' as project type, you must enter the size of a share (in kWh) and number of shares for the "typical" Coop you wish to make a calculation for.

6.2.3 Project

The name of the calculation will appear on all the printed pages. This can be used to specify the particulars of the calculation in question - e.g. High Inflation Rate, Low kWh Price, etc.

The data regarding the production of the WTGs can be entered in various ways:

- User defined: All data input are free.
- Use WTG from object list: You get a list box with the names of the WTGs established as objects in the project (if any).
- Use WTG from WindCat: You get a list box with the names of all the WTGs in the WTG Catalog.
- Load from Energy Calculation: You import information from an already performed Energy Calculation into this project.
- Link to Energy Calculation: As the above option, but with an automatic update of the calculation whenever the information in the Energy Calculation is changed.

The field 'Calculated Production - 10%' will often be used to balance the uncertainties of the Energy Calculation. The 10% will often not be sufficient, as the estimated figure depends heavily on the terrain conditions and the available Wind Data. The 10% can be set to other value in the energy calculation and will by "load from energy calculation" be transferred to WINDBANK.

You can choose to perform calculations on "existing WTG", meaning that instead of Expected life span, you are asked to enter Remaining life span. The life span of a turbine project is normally 20 years, while the design basis of turbines typically is 20 years.

Installation date is very important to know how works: If the month 12 is used, the project is assumed installed the 31.12 and thereby there will be tax savings due to depreciation for the year "0" (installation year), but no income or costs – these will be 12 months based for the year 1. If another month is used, it will be the

end of the month installation is assumed. So installation in month 1 will give 11 months income and costs. There will be 12 month based depreciation

6.2.4 kWh Price

Number of decimals in electricity prices: 4

No	Name	Share of production	Price [cent/kWh]	Properties	Hours / edit / Ann inc
1	Sales price	100 %	7,0000	Input annual increase	2
2	Subsidy, 10 Years	100 %	3,0000	Annual values	

You can construct your own specific profile for the expected kWh price over the life span. If a part of the electricity is used for own consumption and another part is sold, both parts can be given individual pricing profiles.

The options for each input line are:

Name; e.g. Market price or Subsidy etc.

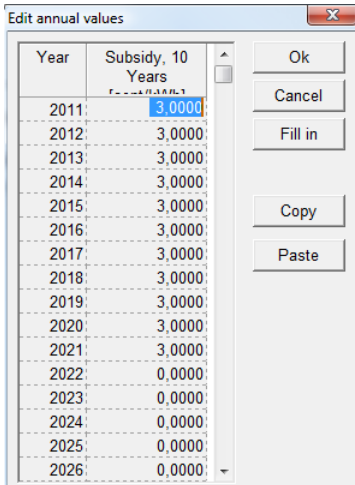
Share of production; If production is sold to different purchasers, or some of the production is used by owner specific prices can be given for specific parts of the production. In most cases there is only one and 100% is used.

Price; remember to input in the right unit as specified in tab "Project".

Properties, the options are (in combination with the field **Hours...** to the right):

- Input annual increase – input the annual increase percentage in field to the right.
- Inflated – the inflation specified at the "Infl. Etc" tab is used for increasing the annual price.
- Annual values – freely defined annual values, see below.
- Limited by full load hours - input the number of full load hours with the increased price in field to the right.

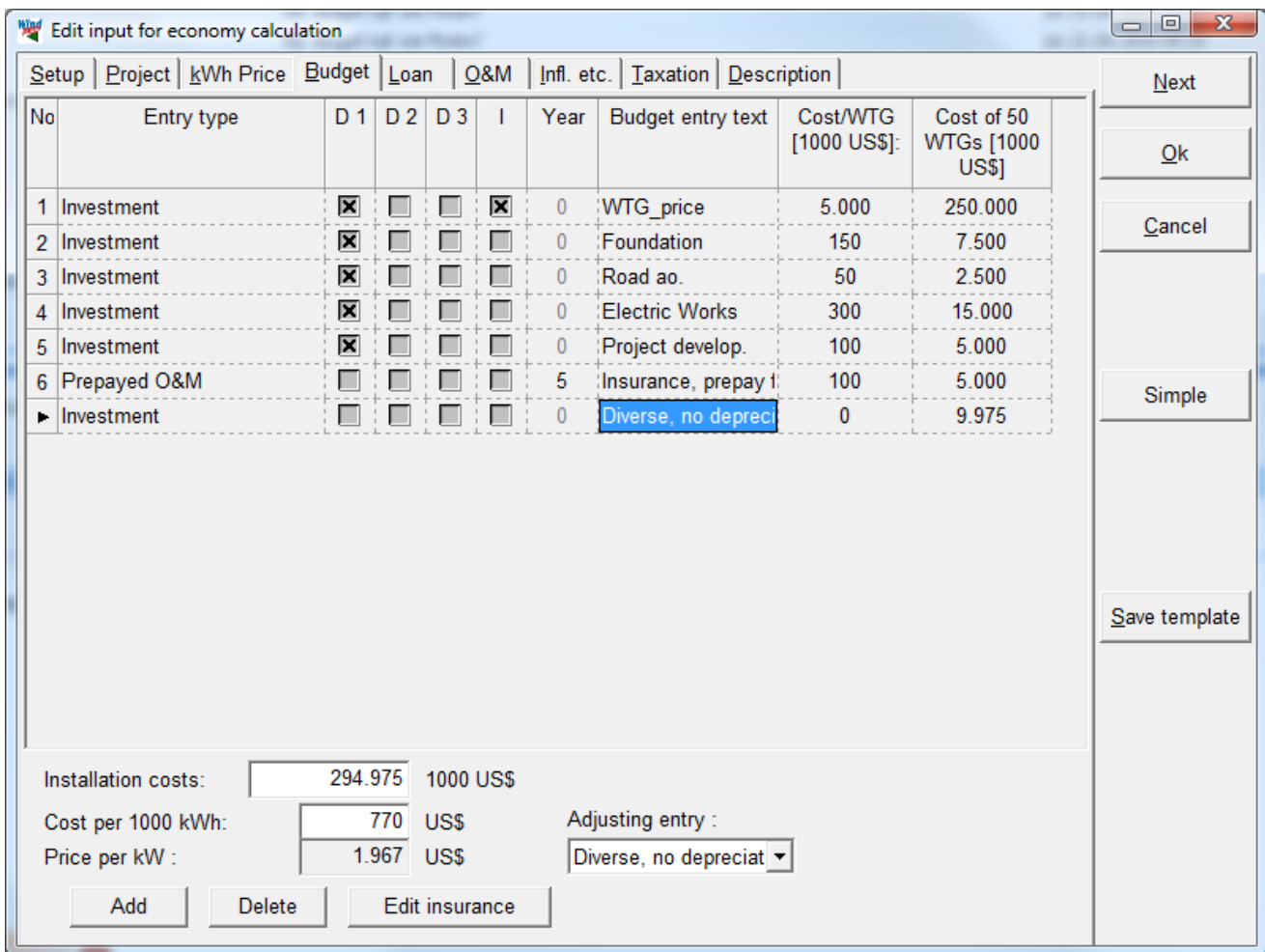
When "Annual values" is chosen, the input form below appears:



Here year by year values can be entered. With the “fill in” button, the current (selected) field value will be filled down to all remaining fields.

To review/edit annual values, just click in the field to the right.

6.2.5 Budget



A simple budget can be entered, or you can activate the “Advanced/Simple” button to get access to a detailed description of each budget line (see the above figure). The following items can be specified:

Entry type:

- Investment - normal
- Prepaid O/M - e.g. Service and Insurance for five years (which is included in the budget, but treated as O/M costs) – filled in combination with the “Year” column!
- Automatically calculated Insurance - An AUTO- Insurance calculator can be loaded (see below).

For each entry type, different properties are available:

- D: Depreciations: 3 different depreciation methods can be chosen. These can be defined at the “taxation” tab, where different percentages etc. can be chosen.
- I: Insurance: - specifies whether or not the component shall appear in the insurance calculator

Adjusting Entry: One of the budget components can be chosen as an “adjusting entry” item. This makes it easy to get a nice round figure for the total budget price.

6.2.5.1 Insurance Calculator

Calculation of insurance premium

All prices and productions apply to 1 WTG. Prices are stated in US\$

Name:

Nc	Type	Text	Percent	Basis	Amount
1					
	▶ % of amount	WTG_price	1,0000	5.000.000 =	50.000
3	% of amount	Foundation	2,0000	150.000 =	3.000

Total insurance: Premium covers: years

Any budget entry marked under “I” under “Advanced” will appear, and can be multiplied with entered multipliers. It is not unusual to calculate insurance amounts in this way.

6.2.6 Loan

WIND Edit input for economy calculation

Setup | Project | kWh Price | Budget | **Loan** | O&M | Infl. etc. | Taxation | Description

Total investment : 294.975 [1000 US\$]

To be financed as follows:

Type of loan	Share [%]	Amount [1000 US\$]	Term [year]	Terms per year	Annual interest rate [%]	No repayment terms
Annuity	60	176.985	10	1	4	0
Cash credit	40	117.990			5	0

Buttons: Add, Delete, Next, Ok, Cancel, Simple, Save template

Cash payment: 1000 US\$ (payment which does not yield interests)

Cash balance 1000 US\$ (payment which yields interests)

Interests on negative cash balance %

Interests on positive cash balance %

Value of tax credit is used to reduce debt

For a non-coop project only this type of loan can be selected. For coops project, this loan means that it is taken individual by each coop.

The following types of loan can be selected:

- Annuity (constant annual payment =(repayment + interest))
- Series (constant annual repayment)
- Index series (inflation adjusted principal)
- Cash Credit (repayment will automatically be calculated as the total profit each year).

Under 'Cash Credit' no Term shall be entered - it will be calculated automatically and 'Terms per year' will automatically be 1.

'Cash Payment' can be calculated with or without an Interest Calculation.

You can enter Interest Rates on as well negative as positive Cash Balances. A Cooperative Cash Balance is always positive or equal to zero.

6.2.6.1 Loan by Coops (common loan for coops)

If the project type is a Coop, there can be specified loans granted to the Cooperative as collective loan, and not to the individual member of the Coop.

The input form for the loan follows the structure given previous, see input form below.

Edit cooperative loan X

Cooperative loans are obtained by the cooperative

Total investment: 294.975 [1000 US\$].

To be financed as follows:

Type of loan	Share [%]	Amount [1000 US\$]	Term [years]	Terms per year	Annual interest rate [%]
Serial	10	29.498	10	1	5

Cash payment by shareholders 1000 US\$

Value of tax credit is used to reduce debt

6.2.7 O&M (Operation and Maintenance)

The screenshot shows a software window titled "Edit input for economy calculation" with several tabs: Setup, Project, kWh Price, Budget, Loan, O&M, Infl. etc., Taxation, and Description. The O&M tab is active. At the top, it says "All amounts are indicated in net present values and applies for:" with radio buttons for "1 WTG" (selected) and "50 WTGs".

No	O&M costs (type)	Annual O&M expenditures Text	From year	[US\$]/[%]	From year	[US\$]/[%]
1	Annual amount	Insurance	6	20000	0	0
2	cent/kWh	Service and repair	2	1	10	1,5
▶	US\$/kW	Administration and land rent	0	8	0	0

Below this table are buttons: "Add O&M costs", "Delete O&M costs", "Add transfer", and "Delete transfer".

No	Transferences to overhaul	Amount [US\$]	To be used in year	Transference from year
▶	New Gearbox	500000	12	5

On the right side of the window, there are buttons: "Next", "Ok", "Cancel", "Advanced", and "Save template".

There can be specified 2 periods with different O&M costs.

O&M can be specified as several different components, where each and all of the components can be listed as:

- Annual amount
- % of investment (project costs)
- % of Electricity sale (annual income)
- Costs in specified Currency/kWh - e.g. 0.01 US\$ pr. kWh produced electricity
- Costs in specified Currency/kW - as the above item, but pr. installed capacity
- Annual amount, no inflation – as first item, but not inflated

Transferences to overhaul - major investments will have to be expected during the lifetime of the wind turbine - e.g. new Gear box after 12 years, which will be saved during year 5-12 in example above.

6.2.8 Inflation, etc.

The screenshot shows a software window titled "Edit input for economy calculation" with several tabs: Setup, Project, kWh Price, Budget, Loan, Q&M, Infl. etc., Taxation, and Description. The "Infl. etc." tab is selected. The window contains the following input fields and labels:

- Inflation:** A text box containing "2.0" followed by a percentage sign "%".
- Inflation regulation begins : 1. January this year :** A text box containing "1" followed by an equals sign "=" and another text box containing "01-01-2012".
- VAT:** A text box containing "25.0" followed by a percentage sign "%".
- For calculation of the socio-economic electricity price:** A section header.
- Socio-economic calculation interest rate:** A text box containing "5.0" followed by a percentage sign "%".
- For calculation of net present value:** A section header.
- Interest rate:** A text box containing "6.0" followed by a percentage sign "%".
- Interest rate is the expected lending rate + additional charge for the time delay in repayment + risk:** A descriptive text label.

On the right side of the window, there are several buttons: "Next", "Ok", "Cancel", "Advanced", and "Save template".

The VAT taxation amount will not affect the results in this version of WINDBANK - all amounts are assumed to be excl. VAT.

For a socio economic evaluation of project, the price per produced kWh can be calculated. For this a socio-economic calculation interest rate must be used. This is normally given by the government. The value is decided based on a combined evaluation of the interest level and the risk by the type of technology. The Government can based on the cost/kWh seen in a long term perspective tell which technology is cheapest to use for electricity production.

For net present value calculation, similar can be given a interest rate, where it is the investor who decides the interest rate based on expected risk etc.

6.2.9 Taxation

The Tax item can be divided into taxation concerning Operation & Depreciation and Interests. In some countries there will be different ways of treating tax savings on interests and on negative profit – if any.

The item ‘Book Depreciations’ affects the annual ‘balance sheet’, which is different from the ‘annual liquidity’ (cash flow). For the balance sheet, the typical way to handle depreciation is linear over the expected lifetime of the project, telling that the value of the project is decreased with a the same amount every year. But regarding tax, it is often allowed to make a faster depreciation. These regulations are made by the governments to give investors an incentive to investments, to make the county develop faster and be more competitive. That’s why the “Fiscal Depreciation” can be handled separately, but it might not be useful in all countries.

The item ‘Fiscal Depreciation’, affects the ‘annual liquidity’, if the depreciation gives tax savings. The input of the depreciation can be given in several different ways. And there can be defined up to three different sets, which link to the budget lines, where one of the three different sets can be chosen. For the different ways to input, the first two will always work, while the last two only work in combination with the loan type “Cash credit”. These work so the repayment on cash credits is adjusted in combination with the depreciation amount, so the fist years always will give a liquidity of zero. In other words, the project is handled so the repayment is as fast as possible, based on the project profit including tax savings due to depreciation. The four different depreciation input methods:

1. Maximum percentage: Each year the fiscal depreciation amounts to a given percentage of the project value, which is not written off in the balance sheet.
2. Entered annual percentage - the annual depreciation percentage can be entered separately for each year by using the ‘Edit’ bitmap button.

3. Maximum annual depreciation amount - gives you the possibility of letting the software calculate the annual percentage for depreciation based on the investors' capabilities of exploiting the tax allowances.
4. Entered annual income tax payment - as the above item, but where the software calculates the depreciation percentage from the tax allowances and income tax percentage.

Which methods and percentages that can be used depends on the local tax regulations, please confirm with an auditor.

6.2.10 Description

Any comments can be entered and will appear on each printed report page.

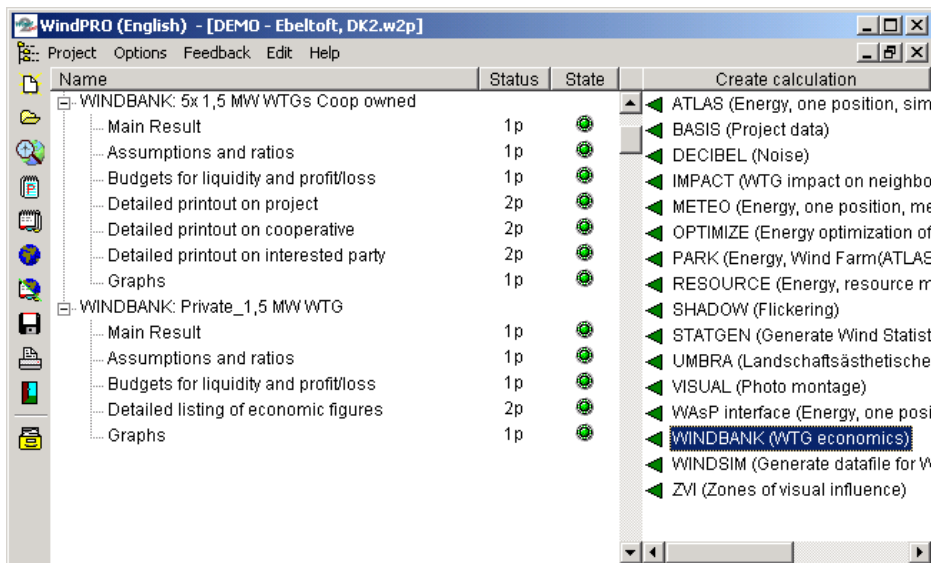
6.3 WINDBANK – Calculation and printouts

6.3.1 Starting calculation

When you activate the bitmap button 'OK' the calculation will start automatically.

After the calculation has been completed the following reports will appear:

Below as well an example of coop's owned as private/company owned WTG project are shown. The Coop's calculation produces 2 more reports than the private/company owned.



The Printouts can be activated for preview purposes by double clicking on the report name. You can also mark a report and click on the printer symbol. For a printout of all the reports, right click on the main heading.

6.3.2 Printouts

The printouts are divided into 5 different report types:

- Main result, with main figures (budget, financing and result).
- Assumptions and Ratios, with more detailed assumptions and some key figures.
- Budgets for liquidity and profit/loss estimates. Time Series with main figures (Cash Flow).
- Detailed financial statement for the "project" - with Time Series of all the calculated values.
- Graphs - graphic presentation of most of the important time series.

For Coop's 2 more printouts will appear:

- Detailed financial statement for the Cooperative including how the economy for the Cooperative will interact with the Coop Members.
- Detailed financial statement for the individual Coop Member (the interested party)

The printouts should be fairly self-explanatory - if not, don't hesitate to call at EMD.

But in order for you to understand the basic concepts of the economic figures, an overview of the main budget is given in part 6.1.

8. WindPRO Optimize

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8.0 OPTIMIZE – Intro, step-by-step guide

8.0.1 Introduction to Optimize

What is the optimal park layout?

The optimal park layout depends very much on the situation.

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

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

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

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

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

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

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

Optimization in WindPRO consists of four elements:

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

The optimization algorithms cover the following four situations:

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

8.0.2 Optimize Step-by-step guide

8.0.2.1 Random pattern (hilly/complex terrain)

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

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

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

8.0.2.3 Noise based on remove/noise reduce visible WTGs

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

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

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

8.1. OPTIMIZE – Energy and noise

8.1.1 Calculation methods

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

Model A. Regular pattern, where strict geometrical requirements is met (straight parallel rows with constant distances between WTGs in rows or arc layout)

Here, the Park-design object is used. Both manual and automatic optimization is possible.

The manual way: With the park-design object the user can graphically move, rotate and change distances while the program keeps track of the number of WTGs or total capacity within the wind farm areas that can be defined with the WTG-area object. Once a reasonable layout has been found that meets the constraints for the project you can establish with the “realize” menu the WTGs that are within the specified WTG areas. New additional layout can be established - each time a layout is realized, a new layer is automatically created holding the realized WTGs. When the different layout alternatives have been created, the alternatives can be easily calculated and compared with regard to energy production, noise, visual impact etc.

The automatic way: After establishing of the Park design object, start the OPTIMIZE program from the main menu. Select “Regular pattern” and set up the calculation. Note you can set a minimum park efficiency (max. array losses) and thereby secure that configurations not fulfilling this minimum is excluded in the optimization. When the optimize window is started you can choose which parameters to vary and step size. Choosing “Full optimize” all combinations will be calculated and the one giving the highest energy production will come out as the result. If minimum park efficiency is set, this criterion will be added in the selection of the optimal layout, ignoring layouts that do not meet the minimum park efficiency.

Model B. Automatic optimization of the layout with regard to energy production within specified areas.

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

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

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

To place the turbines three options are available.

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

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

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

Model C. Noise optimization.

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

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

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

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

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

8.1.2 The objects used in the optimization calculations

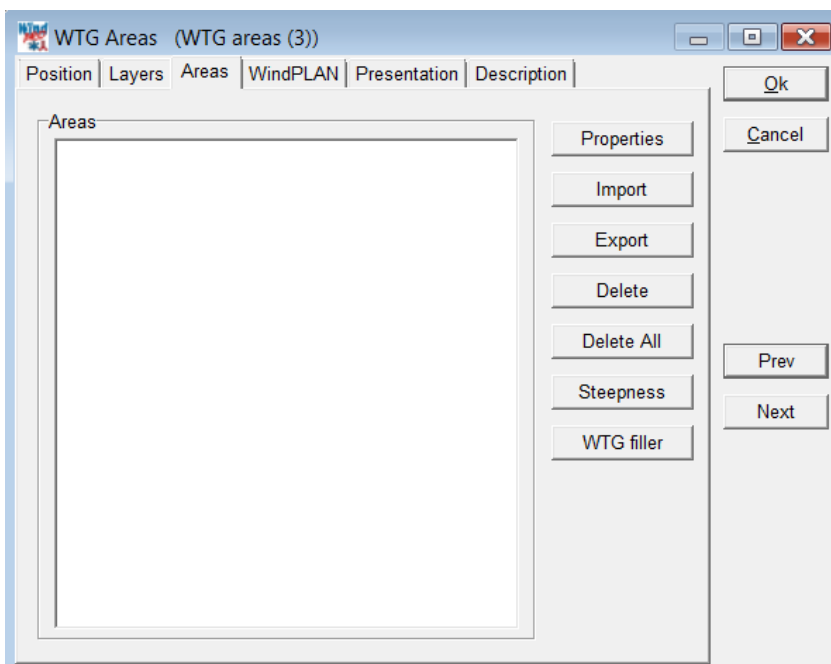
8.1.2.1 The WTG Area Object



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

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

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



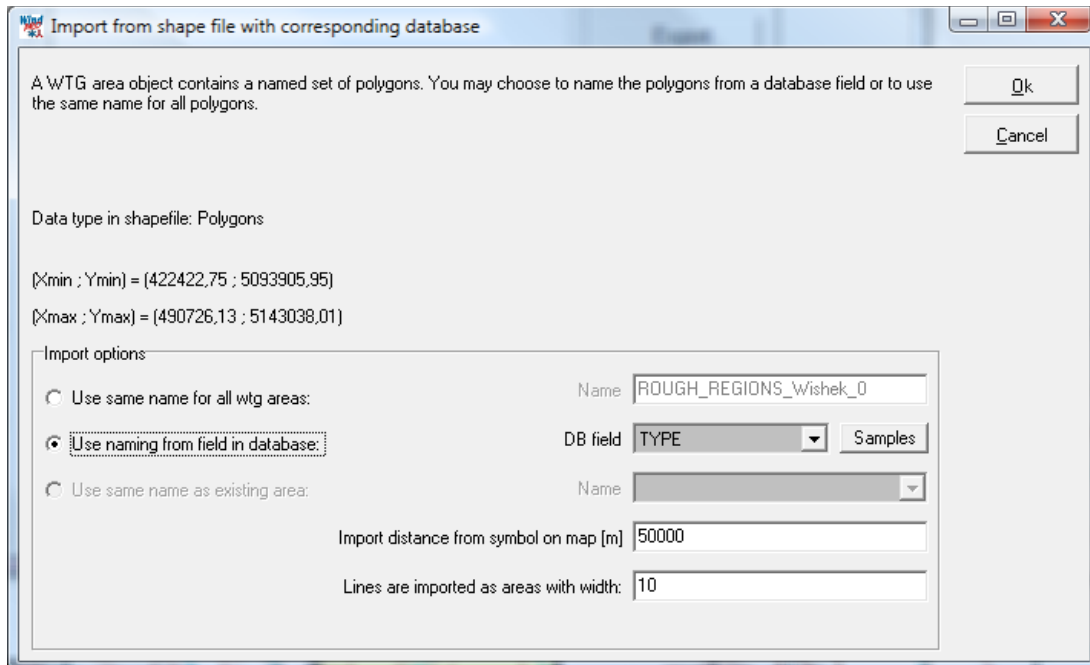
The limits of the areas can be digitized directly using an on-screen map (see below), but it is also possible to import coordinate files defining the limits. At present, files in the formats: **.dxf** (AutoCad/Autodesk) or **.shp** (Shape files from Arc View GIS files) can be imported.

Import of areas from file

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

In the file browser select the appropriate file. Beware that the coordinate system of your file has to be selected accordingly otherwise the areas will not be imported into their correct positions.

If the file is a .dxf file it is simply loaded. If however a shape file is selected an import window appears.



This window allows some options when loading an area file:

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

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

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

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

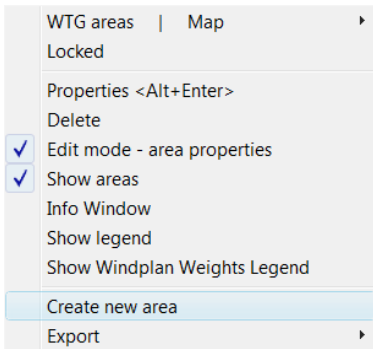
Lines are imported as areas with width: some shape files contain elements not defined as an area but as open lines. The WTG area object cannot operate with lines, but will convert the lines to areas with a width given by the number in meters in this field.

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

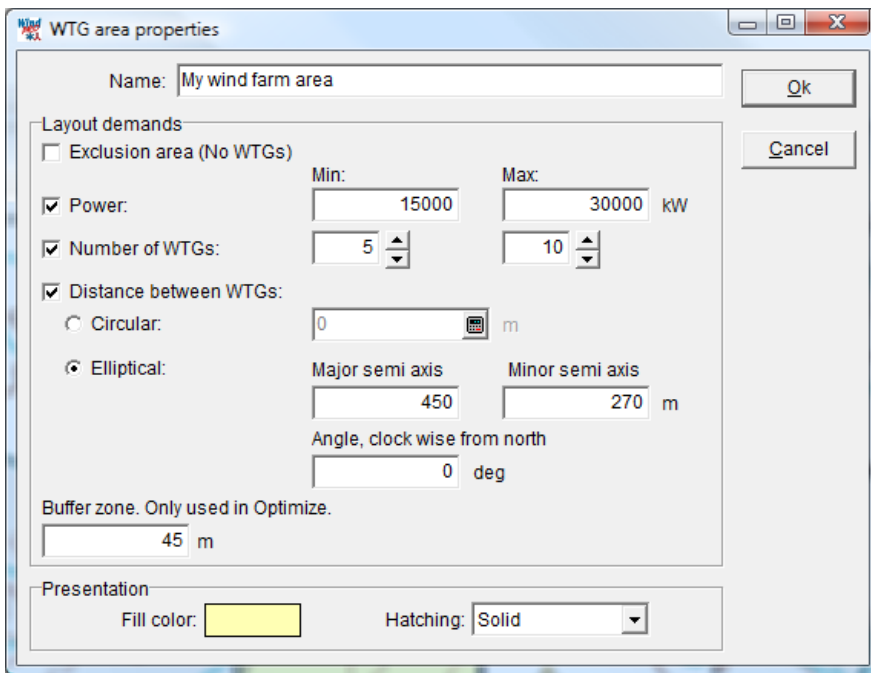
Digitizing your own WTG areas

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

You will notice that the WTG area object is surrounded by a red dashed square. This means that it is in edit mode and you can now start digitizing. Find the boundary of your area and right click in the mouse at the starting position. You now get the following options:



Select “Create new area”. Now appears the properties for this particular area you have started to digitize.



Give the area a name and set appropriate properties for the area.

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

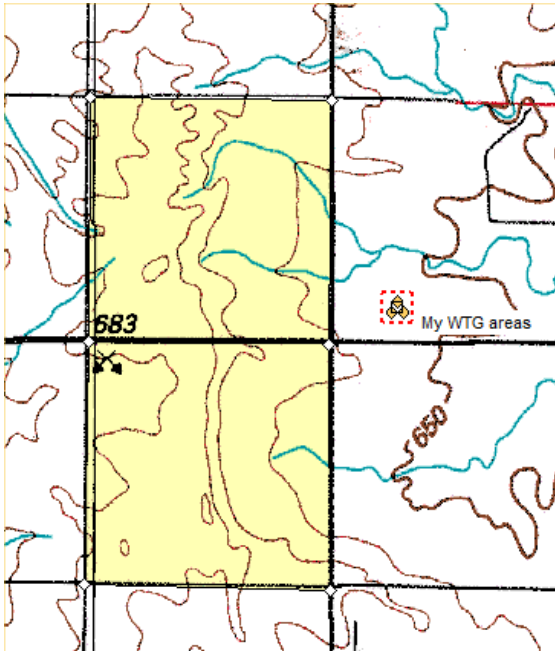
Number of WTGs: Same as for power but by count of wind turbines.

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

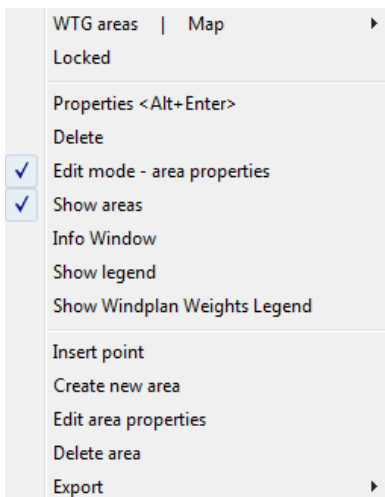
Buffer zone: This creates a setback from the area boundary to keep the turbines away from the edge of the area; this could be used to avoid the blade tips to cross into the neighboring piece of land.

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

Click Ok and start digitizing (see chapter 2 for detail on digitizing areas). Be sure to close the area (right click, End) before proceeding.



If you select the area (by clicking on it) you can see the points it is made of. These white diamonds can be moved manually from the map. If you right-click on the boundary, you have a few more options:



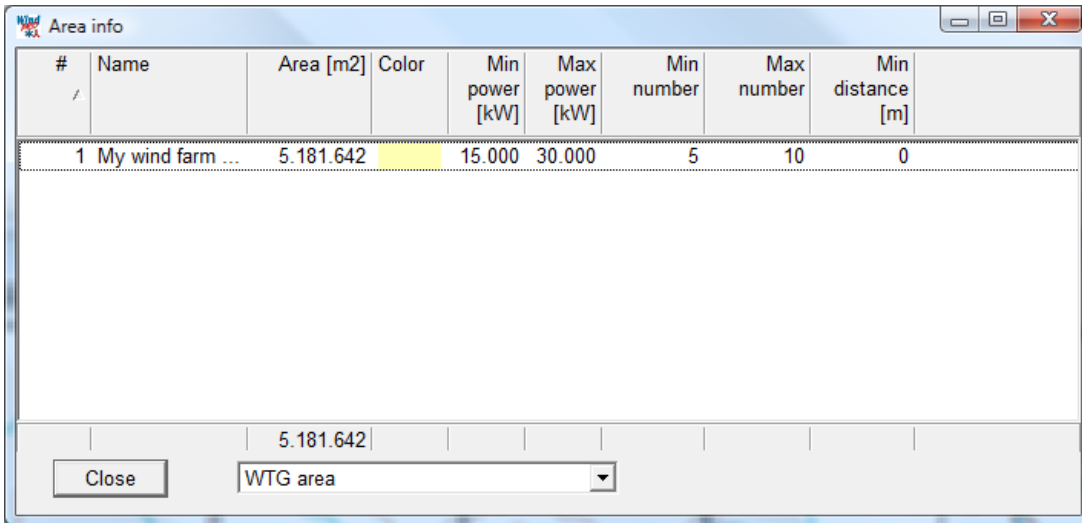
Insert and Remove point will add or remove node points along the sides of the area.

Delete area will simply remove the area. Be careful not to select Delete as this will remove the entire area object.

Edit area properties takes you back to define the properties of this particular area.

Create new area allows you to digitize another area.

Info Window gives information of the individual defined areas like size (m²), color representation and demands see example below:



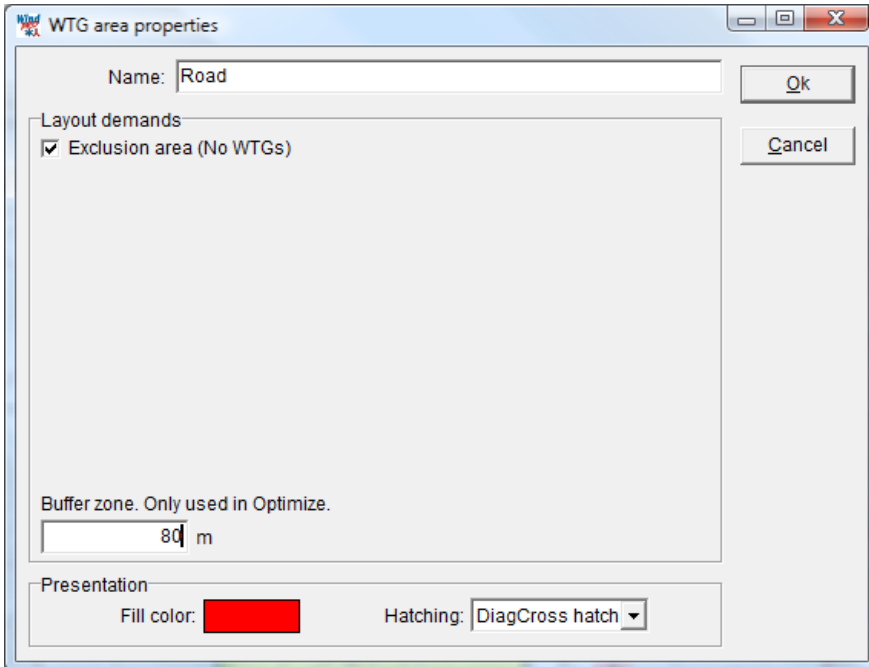
Above only one area is digitized. This is 5,2 mio. square meter, which is 5200 ha or 5,2 km².

Show legend will present a legend in a hanging window.

Creating exclusion zones

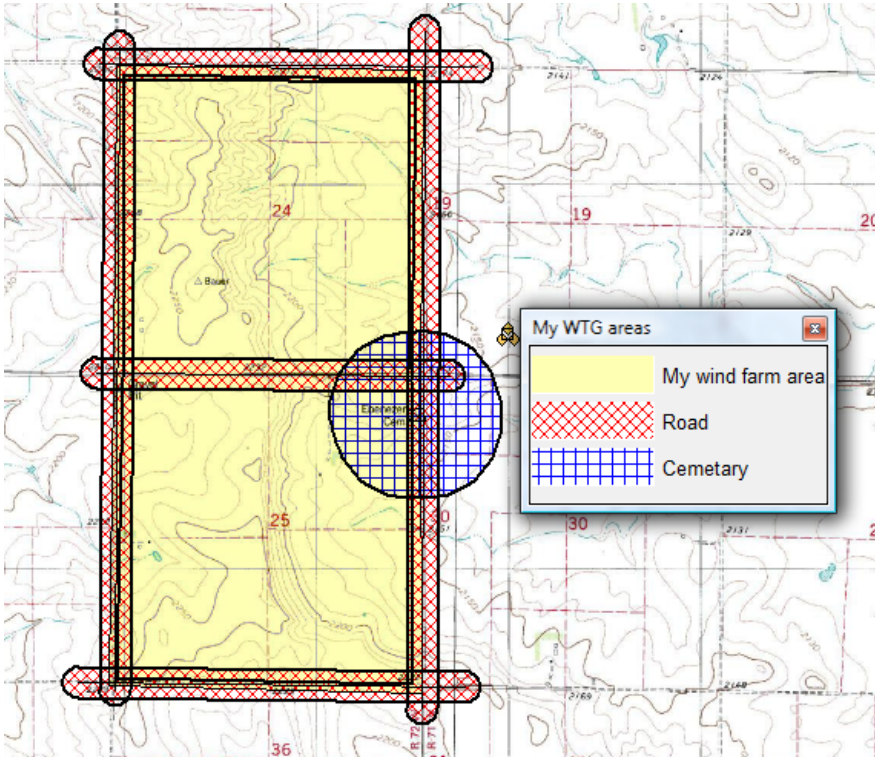
An exclusion area is an area that the optimizer will avoid while designing the wind farm. Exclusion areas can be used for example for forest, roads, power transmission lines, protected areas or unavailable land. Note that the exclusion zone around a neighboring dwelling is rather input as an NSA object with a given distance demand (cf Chapter 4.1.2.2).

The buffer zone of an exclusion area is an extra exclusion band around the defined area. It is meant to respect a certain “security distance” from the exclusion area. For example the buffer zone a road is usually equal to the wind turbine height.



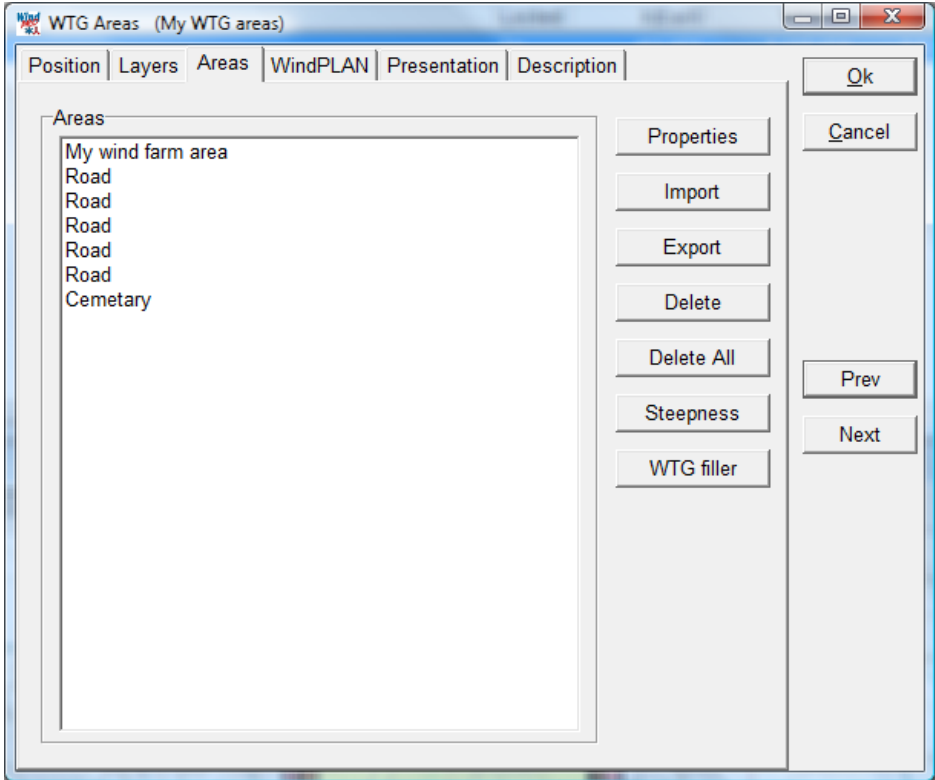
A tip when digitizing roads is to first digitize along the road, then backtrack along the same path and set the setback from the road as an exclusion zone.

When you take the WTG area object out of edit mode all the buffer zones will be shown on the map. The above example looks as shown below.



Properties of the WTG area object

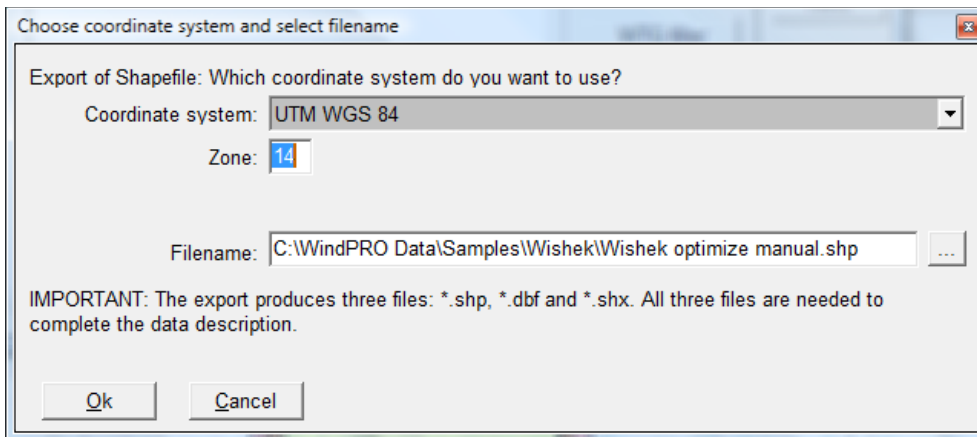
Right click on the WTG area object to assess the properties of the WTG area object. Here the digitized or loaded areas are listed and a number of options are given on the right side of the list. There are a number of tabs, but only the "Areas" is relevant for the Optimize functions.



Properties: Highlight an area and select Properties to access the properties of the particular area. Double clicking on an area will also access the properties of the area.

Import: See above

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

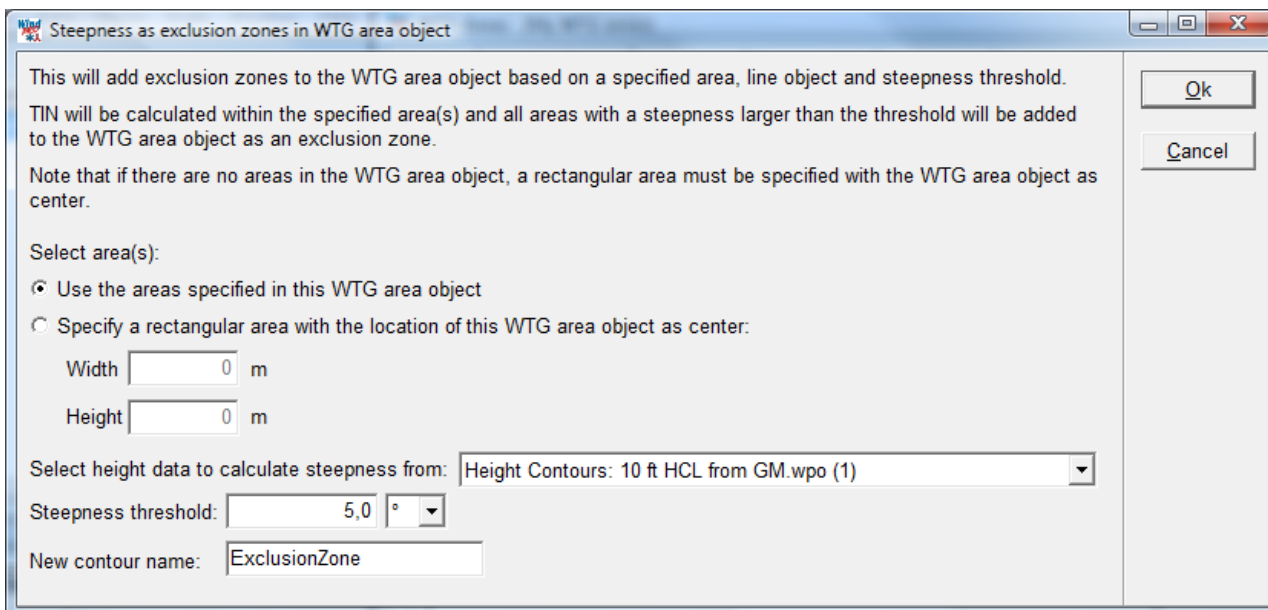


Delete: Highlight an area and press Delete to remove it. WindPRO will first ask if you are sure and then ask if you want to remove all areas with this name. In this way it is possible to easily get rid of for example 50000 imported wetland areas.

Delete All: This removes all areas.

Steepness

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

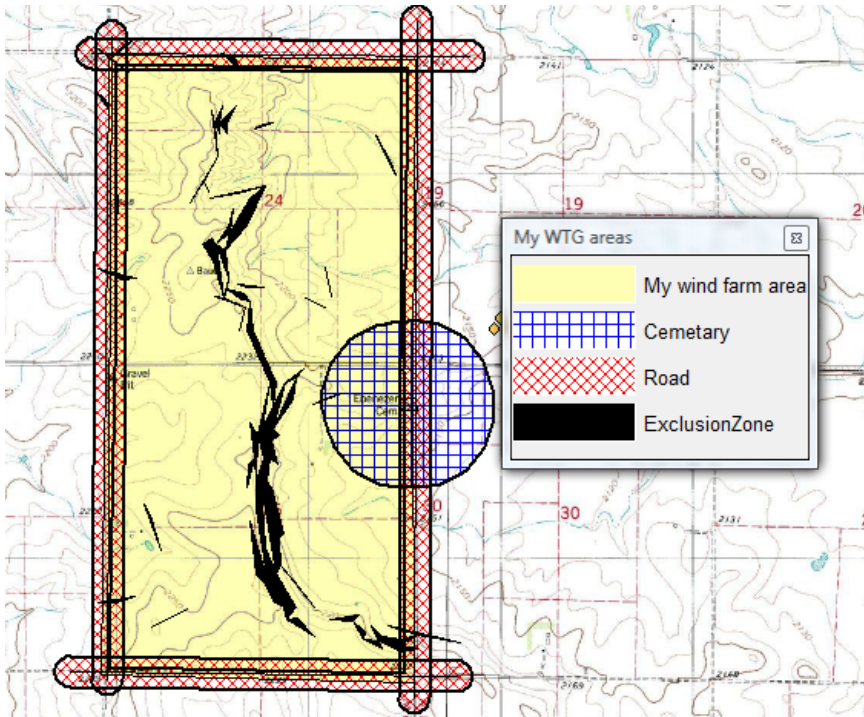


The extent of the steepness analysis can either be given by the WTG areas defined in the WTG area object (recommended) or by giving a width and height of a rectangle centered on the WTG area object.

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

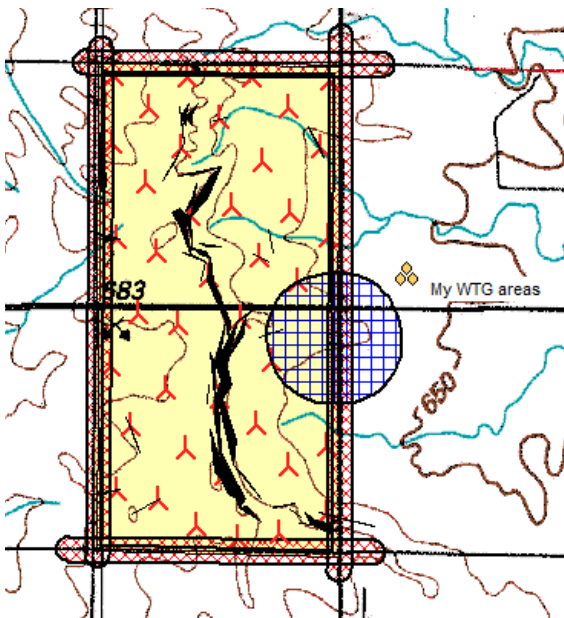
The steepness threshold is the steepness beyond which should be classed as exclusion zone. The steepness can be given in both degrees and percentage.

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



WTG filler

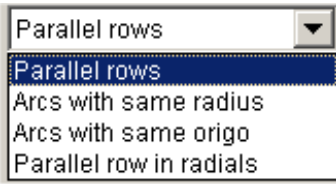
The WTG filler button fills up the available area with turbines. A turbine type and hub height is selected using the usual WTG browser. Then WindPRO fills up the available land defined by the WTG area object, but excluding areas defined as exclusion zone. The filler ignores the minimum and maximum number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



8.1.2.2 The Park Design object



The Park Design object creates regular pattern layouts. Instead of placing individual turbines or rows of turbines on the map, the Park design object can place a geometrical layout consisting of rows and columns on the map. The following regular patterns are available in present version:

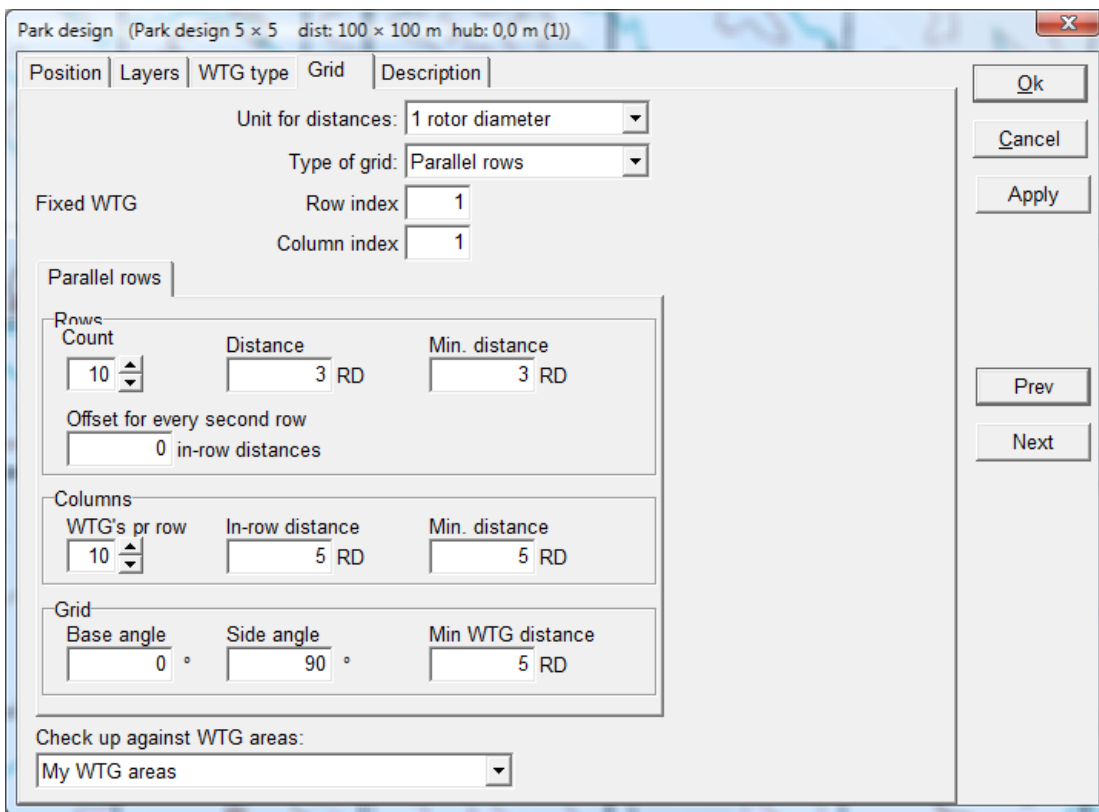


With the park design object it is possible to create a layout template which can be realized within the available land boundaries defined by the WTG area object.

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

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

The grid tab defines the WTG grid:



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

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

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

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

Rows

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

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

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

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

Columns

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

Grid

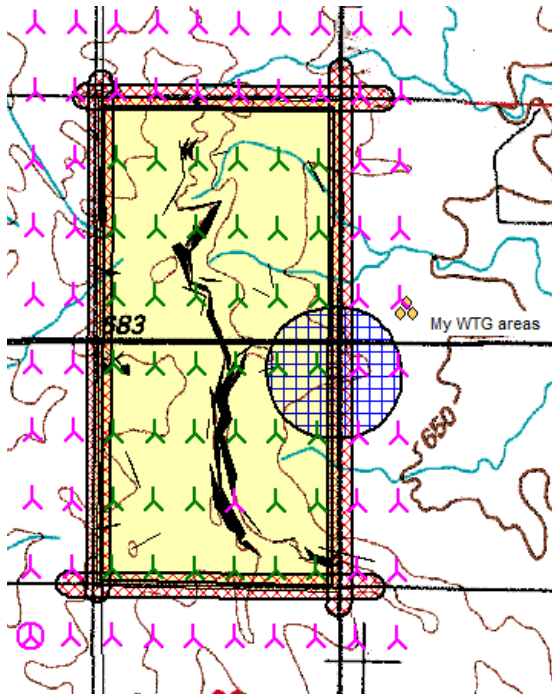
Base angle: The angle (direction) of the base line in the grid.

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

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

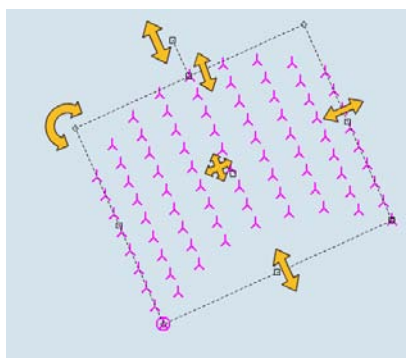
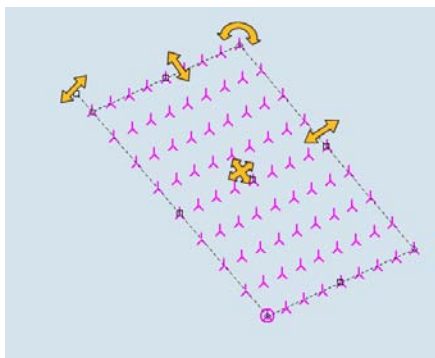
Check up against WTG areas: Here a WTG area object must be selected. The WTG area object will give the boundaries of the wind farm and thus define which turbines in the grid will be allowed to be realized.

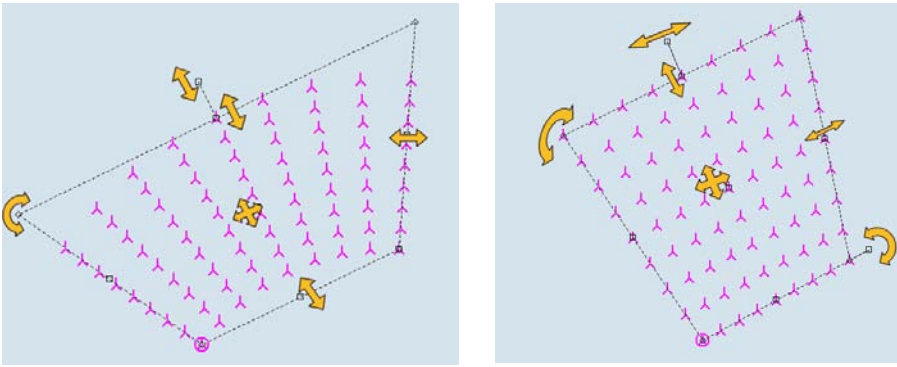
Press OK to close the properties window and the Park design object now appears as a grid of turbines.



Manipulation of the layout with the Park design object.

Below the four different regular patterns (Parallel row, Arcs with same radius, Arcs with same origo and Parallel row in radials) are illustrated:



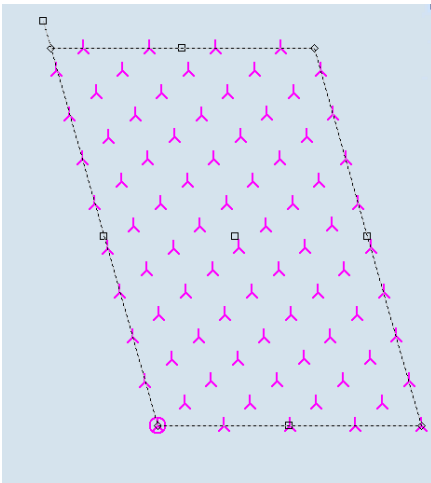


There are handles, which makes it possible with mouse drags to change all figures defining the rotation, distances, position and specific angles/radius depending of type of pattern.



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

The only parameter that cannot be changed graphically is the row offset, illustrated below.



The row offset in the parallel row layout makes it possible to shift every second row from 0 to 1 in row distances. Here illustrated by the value 0.5.

Park design (3)

Position | Layers | WTG type | Grid

Unit for distances: rotor diameter

Type of grid: Parallel rows

Fixed WTG

Row index: 1

Column index: 1

Parallel rows

Rows

Count	Distance	Min. distance
9	11.36 RD	0 RD

Offset for every second row: 0 in-row distances

Columns

WTG's pr row	In-row distance	Min. distance
9	14.56 RD	0 RD

Grid

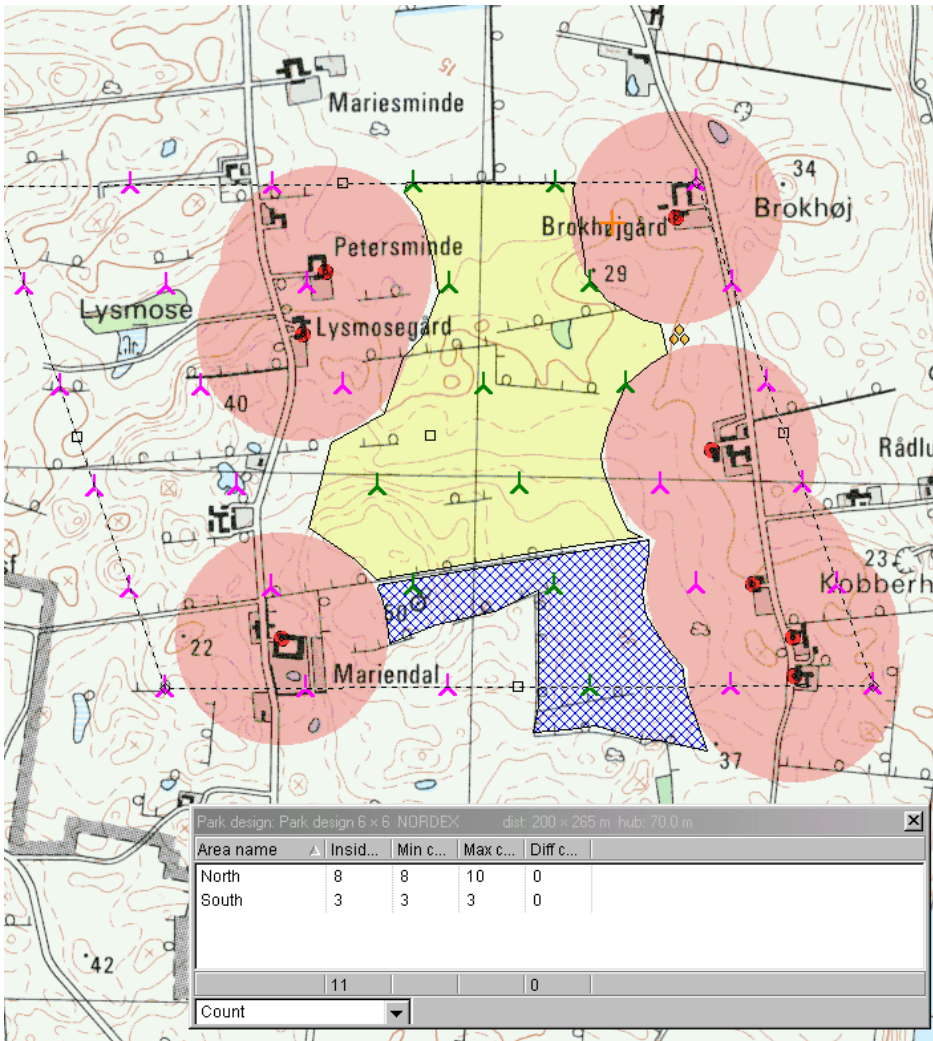
Base angle	Side angle	Min.WTG distance
24.33 °	106.44 °	0 RD

Check up against WTG areas:

WTG areas

Ok
Cancel
Apply

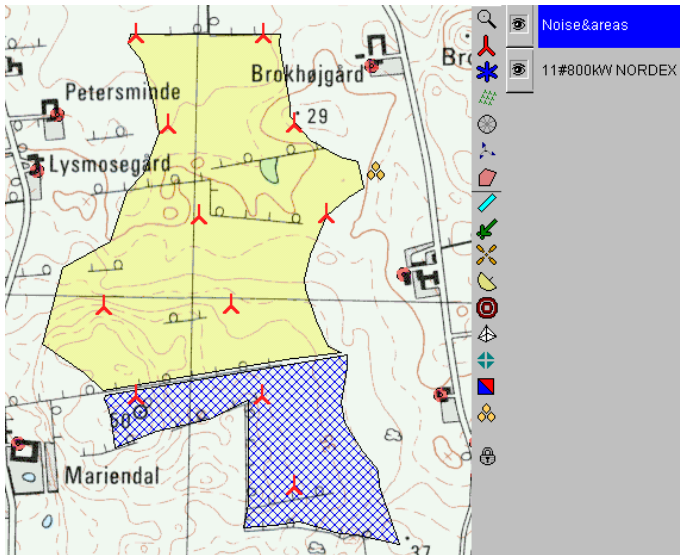
It is possible to keep a continuous control of the number of WTGs or total installed capacity within the area specified by the WTG-area object (see next graphic, right click on the object and select "Info window") when the specific WTG area object is selected in the drop down menu in the bottom.



WTG symbols inside the WTG areas are shown in green while those outside the areas are shown in pink. Note the info window that informs you that there are 8 WTGs in the northern area and 7 in the southern. The deviation between actual and required values is shown in the rightmost column - in this case "0" in both areas indicating that the actual values are within the requirements.

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

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

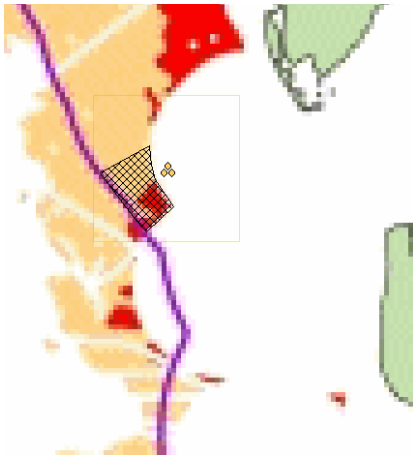


8.1.3 OPTIMIZE – Energy, Regular pattern, model A automatic

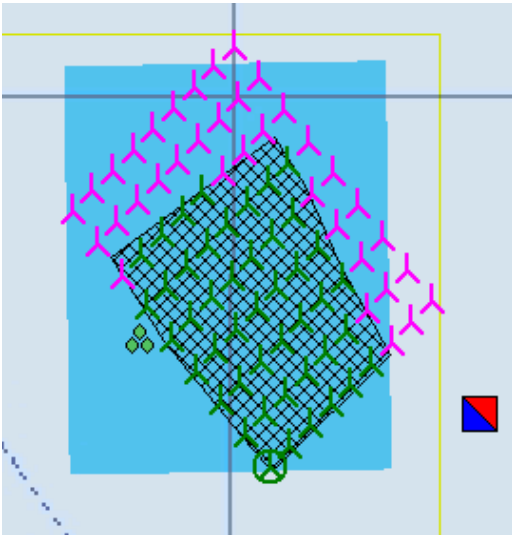
The optimization of a regular pattern layout is simply a calculation of all layout combinations possible with the chosen set of parameters for the project.

This is here illustrated for an off-shore project.

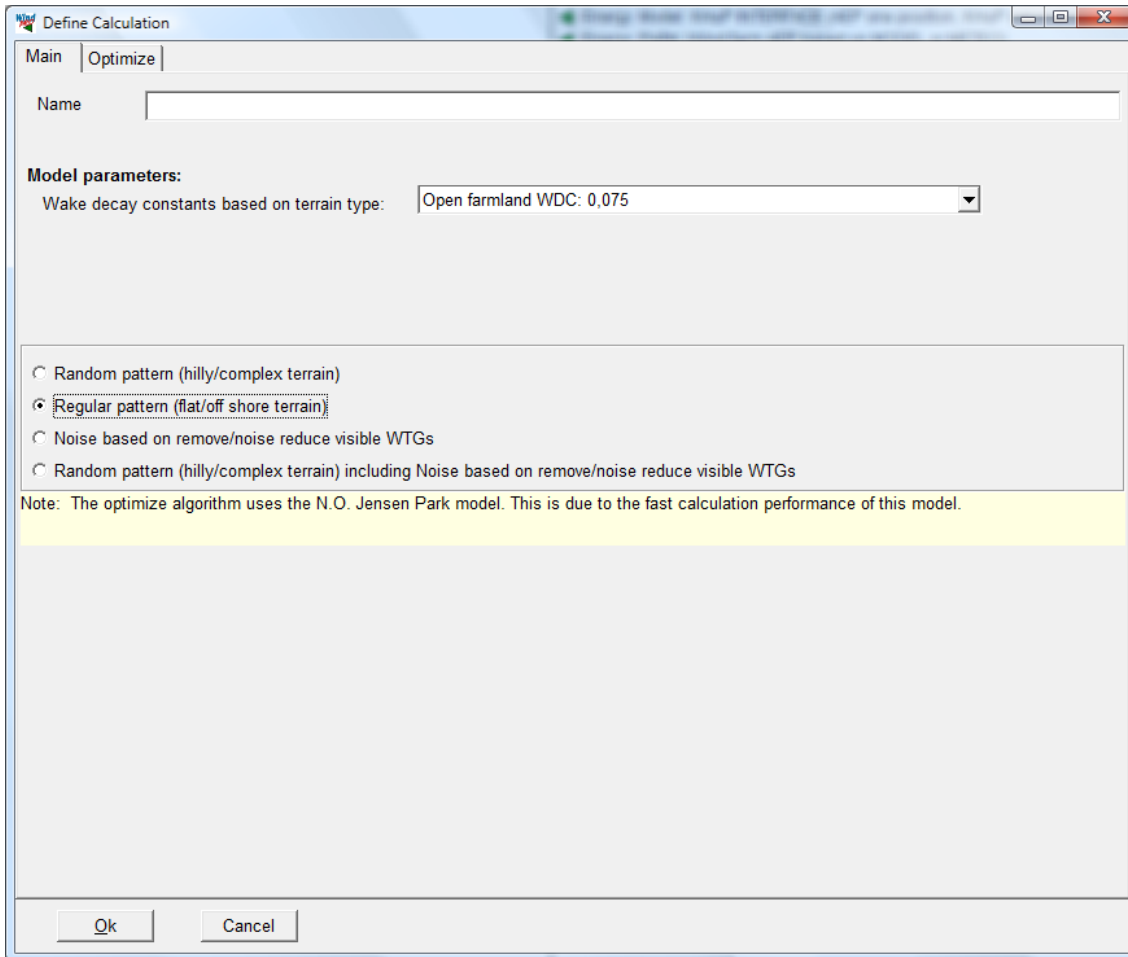
First the area of interest has to be defined. Below a map from UK, DTI report showing “potential areas” give an example of a region that could be chosen.



A WTG area is defined with the WTG area object around the area of interest by digitizing on top of the background map. On below map a wind resource map has been calculated and placed as a background on top of the map (with a Result layer object). As can be seen in the example the wind resource is often uniformly distributed and thus a METEO object can be used as an alternative to the wind resource map. A PARK design object giving the first draft layout is placed on top of the WTG area.



The WTGs inside the area are green, the ones outside are purple. Now it has to be decided which criteria should be met and which parameters to vary. The calculation module OPTIMIZE is started.

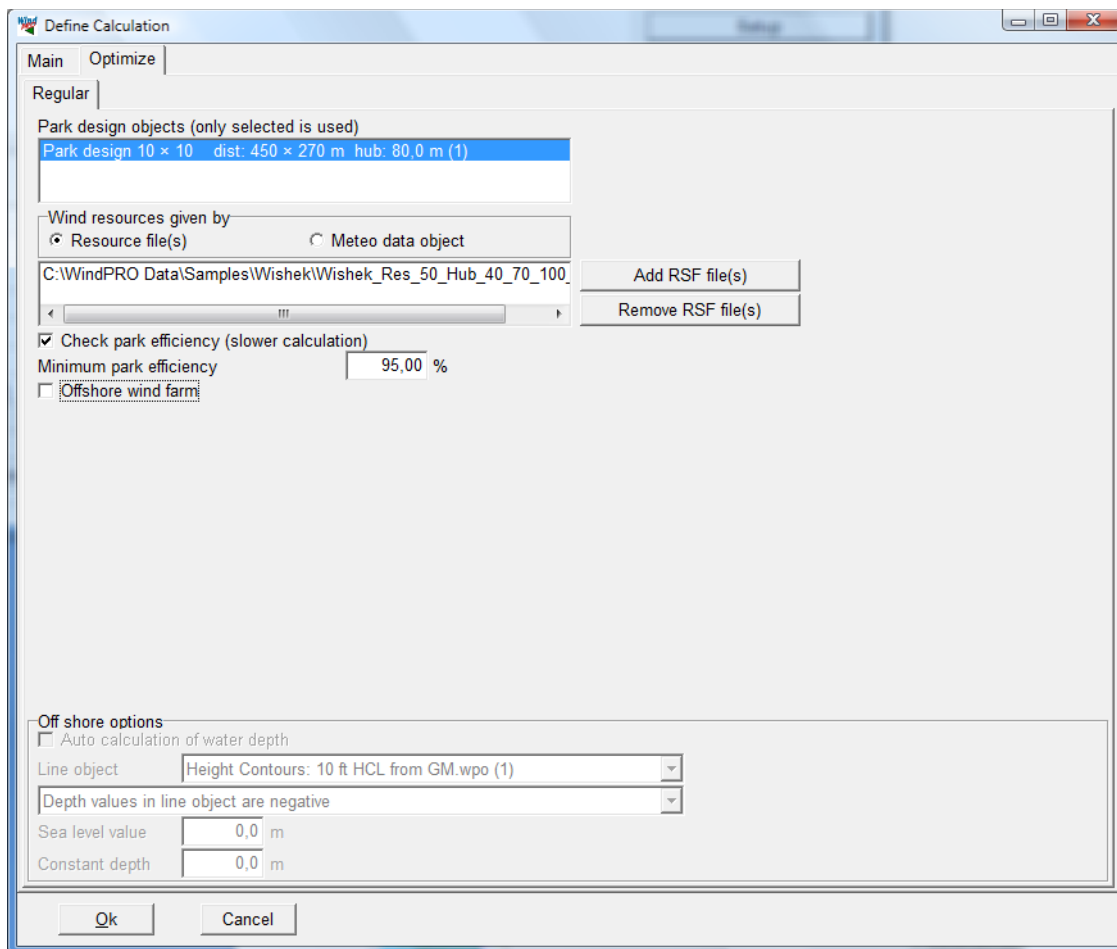


While the general recommendation is to set the Wake decay constant to 0.075, the consensus is that 0.04 is a better choice for off-shore wind farms.

For a regular pattern optimization select the Regular pattern option.

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

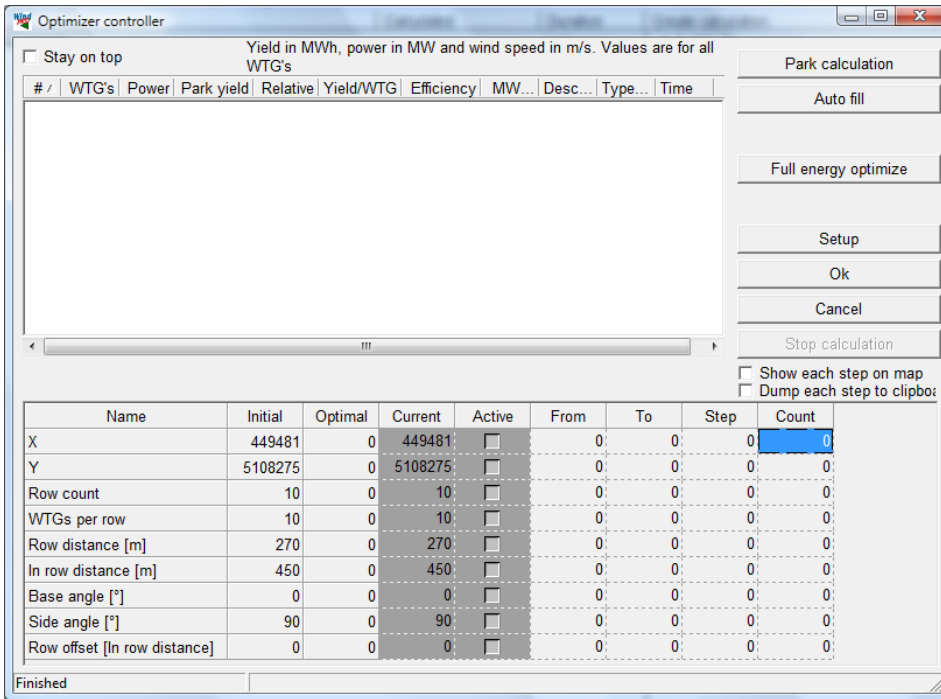
object will then be used for all turbines in the layout. A minimum park efficiency can be set (here 95%). Layouts with a poorer performance than this will be ignored in the optimization.



It is possible to hatch a box called Offshore wind farm. This makes the bottom part active. WindPRO can then use a line object with height contours as water depth (Auto calculation of water depth) or assume a fixed water depth (with Constant depth). These values are used later when dumping results to file (see below).

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

Press OK to start the optimization. This opens the Optimizer controller for regular pattern optimization.



The Optimizer controller is one of the few windows in WindPRO which are allowed to stay open while you work on the map. The box “Stay on top” forces the controller always to remain on top of the map. Unfortunately this may block access to error messages so it should be used with care.

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

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

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

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

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

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

Start the calculation with “Full energy optimize”.

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

Optimizer controller

Stay on top Yield in MWh, power in MW and wind speed in m/s. Values are for all WTG's

#	WTG's	Power	Park yield	Relative	Yield/WTG	Efficiency	Desc...	Type...	Time
1	46	161,000	705,369	100.0	15,334	96.5	Regu...	10-04-2003 ...	
2	64	224,000	965,727	136.9	15,089	95.0	Regu...	10-04-2003 ...	

Park calculation

Full optimize

Setup

Close with save and report

Close without save or report

Abort calculation

Show each step on map

Dump each step to clipboard

Name	Initial	Optimal	Current	Active	From	To	Step	1,944
X	302666	302666	302666	<input type="checkbox"/>	0	0	0	0
Y	447315	447315	447315	<input type="checkbox"/>	0	0	0	0
Row count	9	9	9	<input type="checkbox"/>	0	0	0	0
WTGs per row	9	9	9	<input type="checkbox"/>	0	0	0	0
Row distance	761.7	730	700	<input checked="" type="checkbox"/>	700	750	10	6
In row distance	1065.9	800	800	<input checked="" type="checkbox"/>	800	1000	25	9
Base angle	45.38	46	47	<input checked="" type="checkbox"/>	45	50	1	6
Side angle	82.69	83	83	<input checked="" type="checkbox"/>	80	85	1	0
Row offset	0	0.5	0.5	<input type="checkbox"/>	0	1	0.1	0

Finished

The optimized layout based on first run.

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

Copy initial to current
Copy optimal to current
Copy to clipboard
Paste from clipboard
Calculate with current
Start parameter variation
Update park design object with current values
Realize park design object
Abort parameter variation

A right click in the parameter variation area access the above list of possibilities. They have the following functions:

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

Copy optimal to current: Copies the parameter setting from the so far most optimal layout and pastes it into the “current” column.

Copy to clipboard: Allows for transfer of settings to spreadsheet and other applications.

Paste from clipboard: Allows for transfer of settings from spreadsheet and other applications.

Calculate with current: Performs a PARK calculation with the settings in the “current” column. The result is displayed in the Optimize window as a separate layout result.

Start parameter variation: Starts the optimization run through the parameter intervals searching for the optimal layout.

Update park design object with current values: Modifies the active Park design object to reflect the parameter settings in the “current” column.

Realize park design object: Converts the draft WTG layout (green and purple symbols) to actual WTGs (red symbols) that can be used by other calculations.

Abort the parameter variation: Aborts the optimization run before it is through.

8.1.4 OPTIMIZE – Energy, Random pattern, model B

An automatic calculation of WTG positions requires the following input:

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

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

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

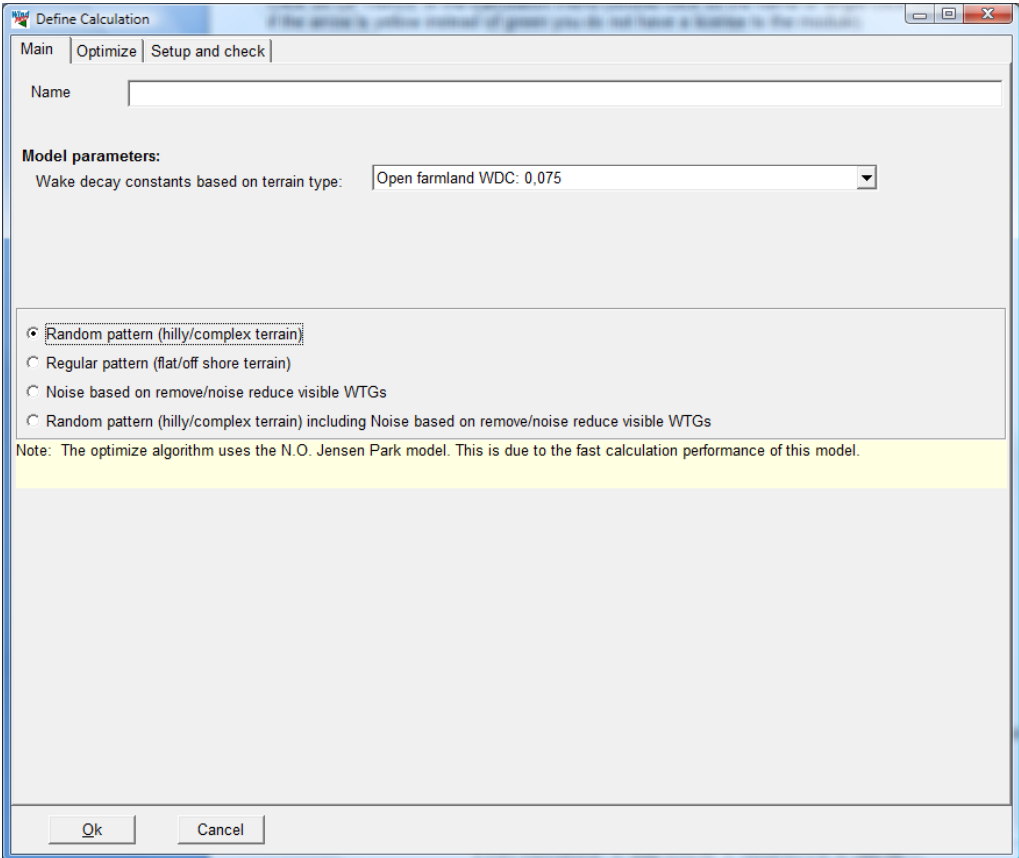


You can with advantage present the calculated .rsf file via the Result layer object before starting OPTIMIZER. The .rsf file will then automatically be transferred to this object where it can be checked that the .rsf file looks plausible.

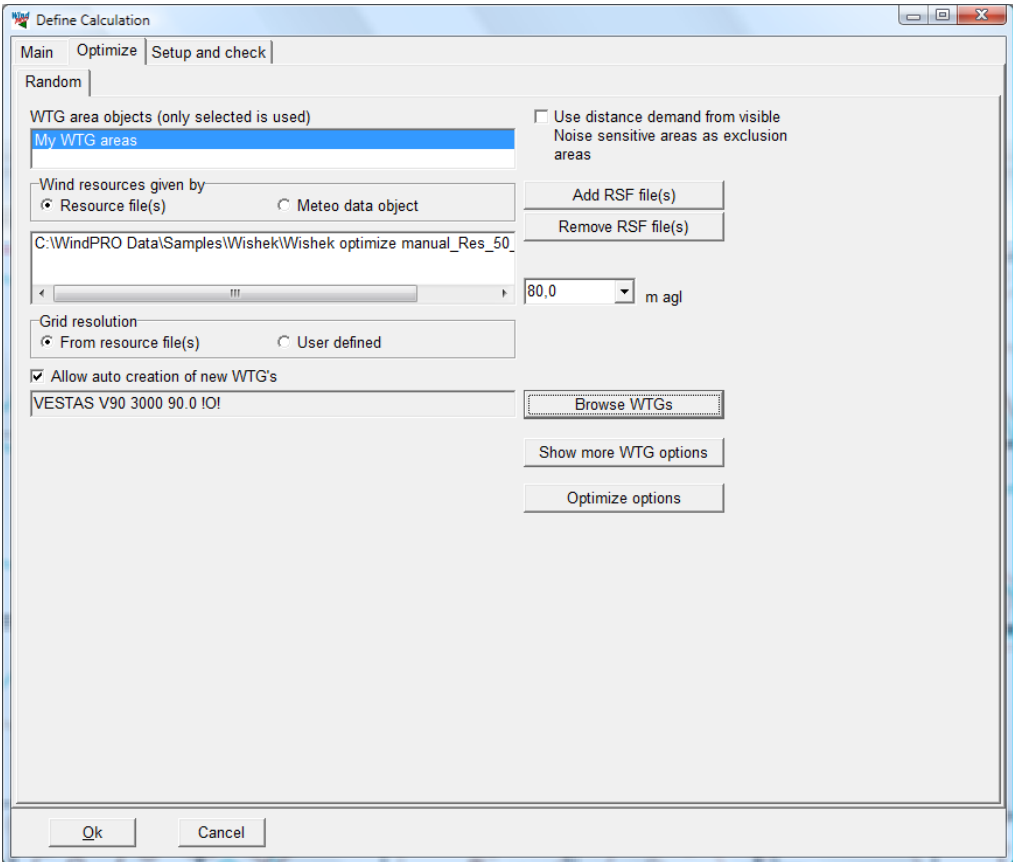
Click on OPTIMIZE in the calculation menu (double-click on the name or single-click the green arrow beside it - if the arrow is yellow instead of green you do not have a license to the module).

8.1.4.1 Optimization properties

On the Main tab select Random pattern and the appropriate wake decay constant. Note that in the optimization a simplified version of the N.O. Jensen method is used.



Continue to the Optimize tab.



The window shown above is used to define the data you want to use and to perform different choices in case the Random pattern method is chosen.

The following settings are available:

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

More WTG options - New WTGs can be created

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

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

More WTG options - No new WTGs can be created

Here you have to create each WTG to be used in the project and the optimization manually. The options for these NEW WTGs you have created or are going to create are:

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

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

Existing WTGs (blue symbols) will always stay at their positions but are only included in the calculation if they are within the .rsf definition area. If they are outside, the program will simply disregard them in the park/optimization calculations. When generating reports you can choose whether or not to include these WTGs in the printout. This choice is made in the properties for existing WTGs (see screen dump below).

WTG data (15)

Position | Layers | **WTG(s)** | Statistics | Animation | Miscellaneous

Annual production all WTGs in this row: *) MWh/yr

Annual production per WTG: MWh/yr

No. of months in calculation: months

Production source:

Imported coordinate precision:

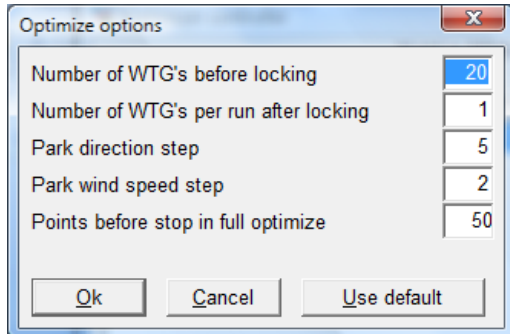
Treat as Park WTG (influences how it appears in printouts)

*) Notice: production should be corrected to normal wind year.

Ok Cancel

If the bottom check box is marked, the WTG will be included in the energy production calculation and in the report as a member of the wind farm. Otherwise it will only contribute to the array loss calculation while the energy production will not be included.

Optimize options



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

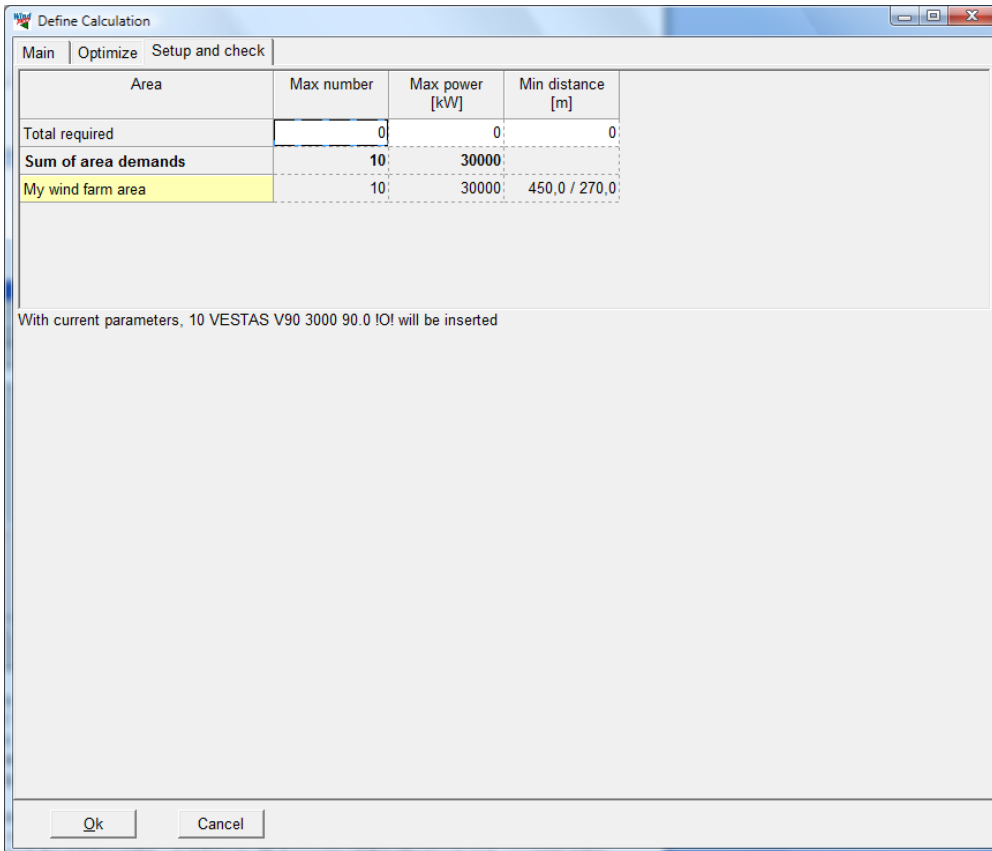
Number of WTGs per run after locking the first ones. After locking, WTG no. 21 will be inserted on the best remaining position with regard to the total wind farm production. You can also increase the number of WTGs per run after locking, e.g. to 5 WTGs - this speeds up the calculation but at the possible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

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

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

8.1.4.2 The Setup and check sheet

Here you can view the various optimization parameters entered into the program. The program checks the requirements from the WTG-area object and the optimize sheet. It informs you about the optimization to be started so that changes can be made before a time consuming calculation is performed.

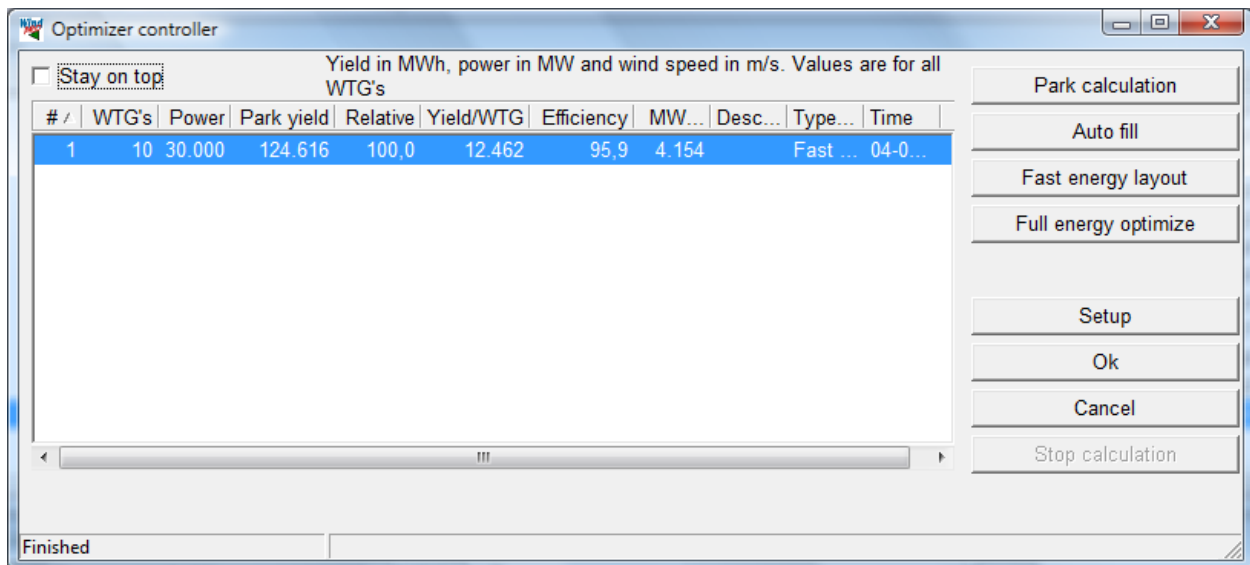


In the above example there is one area in the WTG-area object with a total maximum of 10 WTGs and 30000 kW. Since a 3 MW WTG has been chosen, the requirements will lead to a maximum of 10 WTGs. NOTE: Only the requirements to the total will be checked - not the requirements for the individual areas. Therefore the check will not necessarily give the precise prognosis. Furthermore, it might not be possible to include all the WTGs due to requirements to minimum distances and project area limitations.

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

8.1.4.3 Start and use of the OPTIMIZE window

By clicking the OK button for "Define calculation" the Optimizer controller window appears.



You can now click on the map and have both the map + the object list + the optimize window opened at the same time. The Optimizer controller is one of the few windows in WindPRO which are allowed to stay open while you work on the map. The box “Stay on top” forces the controller always to remain on top of the map. Unfortunately this may block access to error messages so it should be used with care.

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

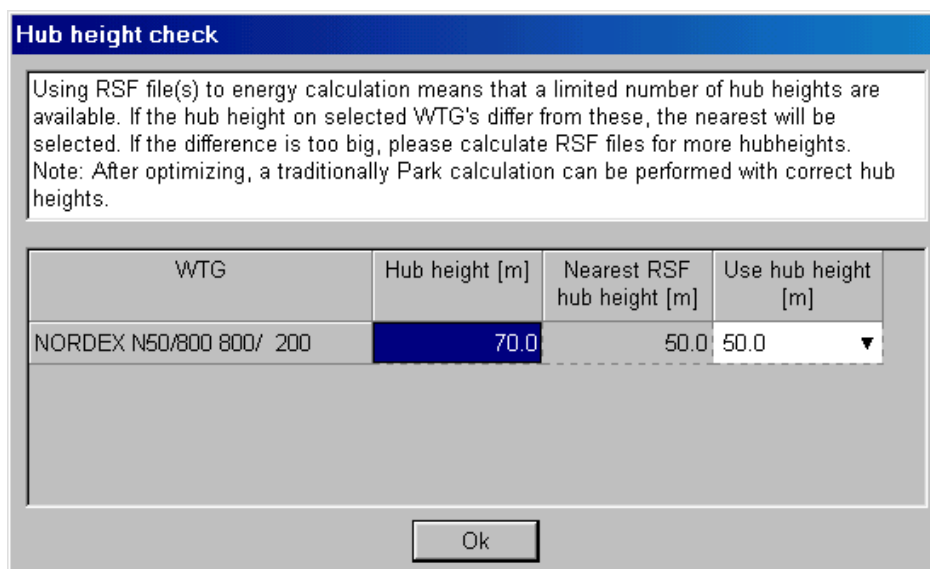
Here are four options:

Park calculation

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

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

If a calculation is started based on WTGs with other hub heights than those included in the .rsf file, the window below will appear:



Here, you select which hub heights to use from the .rsf file. Of course using the wind speed from the wrong height results in the wrong wind speed and thus wrong production. However the relative differences will usually be correct if the height difference is small.

Auto fill

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

Fast energy layout

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

Full energy optimization

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

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

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

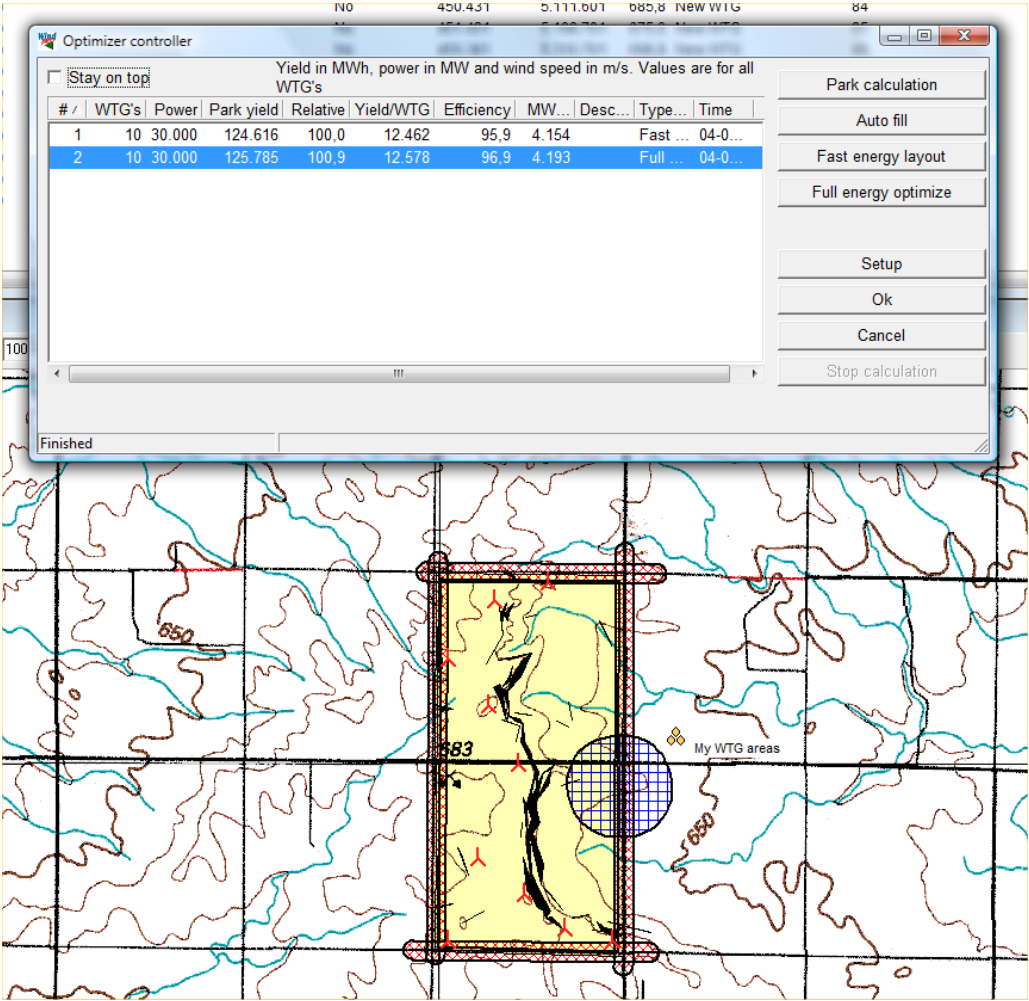
8.1.4.4 An example of an optimization process

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

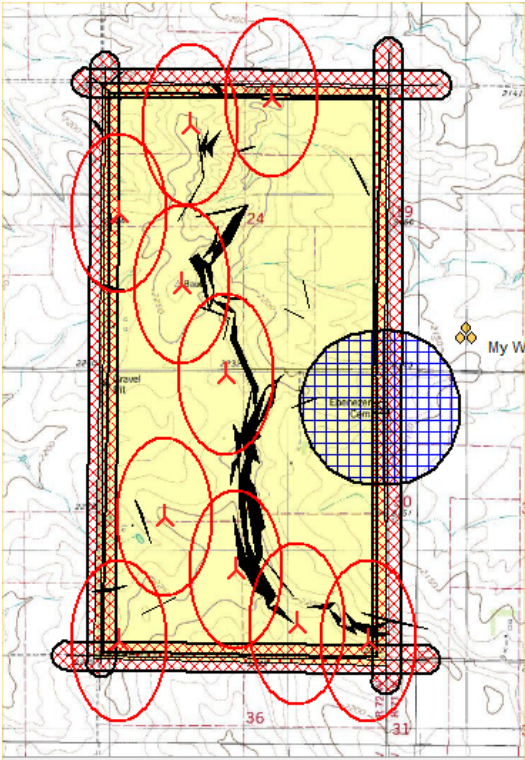
- First, a fast optimization is run
- Then a full optimization
- A couple of WTGs are moved to improve the visual layout and a park calculation is run
- This step is repeated

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

The gain from the fast optimization to the full optimization is 0.9% or 1.2 MWh/yr.

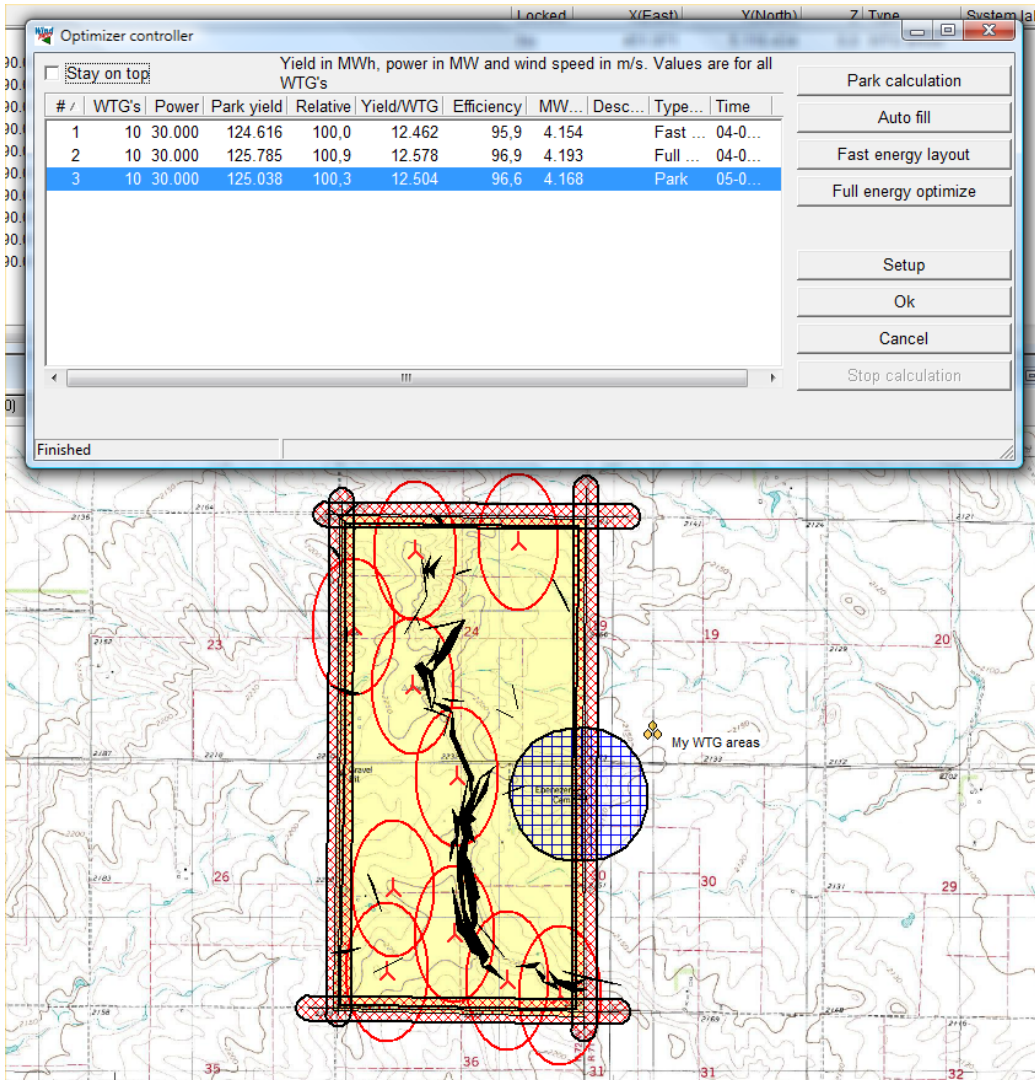


Right click on a turbine and select "Show distance circle". Distance circles or ellipses now become visible. The spacing is defined in the WTG area object and in this case it is defined as an ellipse with 5 times rotor diameter in the main (north) direction and 3 times rotor diameter across the main direction.



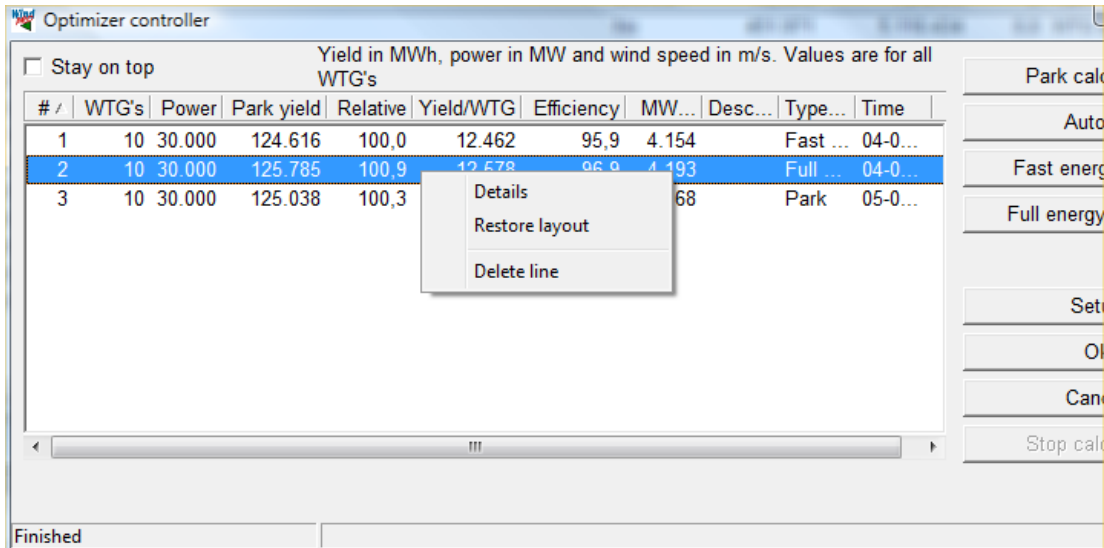
We try to move a few of the turbines that may be located inconveniently to more appropriate positions. In this way it may be possible to outsmart the optimizer and get a slightly better production. Remember that the optimizer only test locations defined by the grid size.

Press the “Park calculation” button to update the calculation result.



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

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



Delete line removes an unwanted layout from the list.

Under "Details" you get the following window:

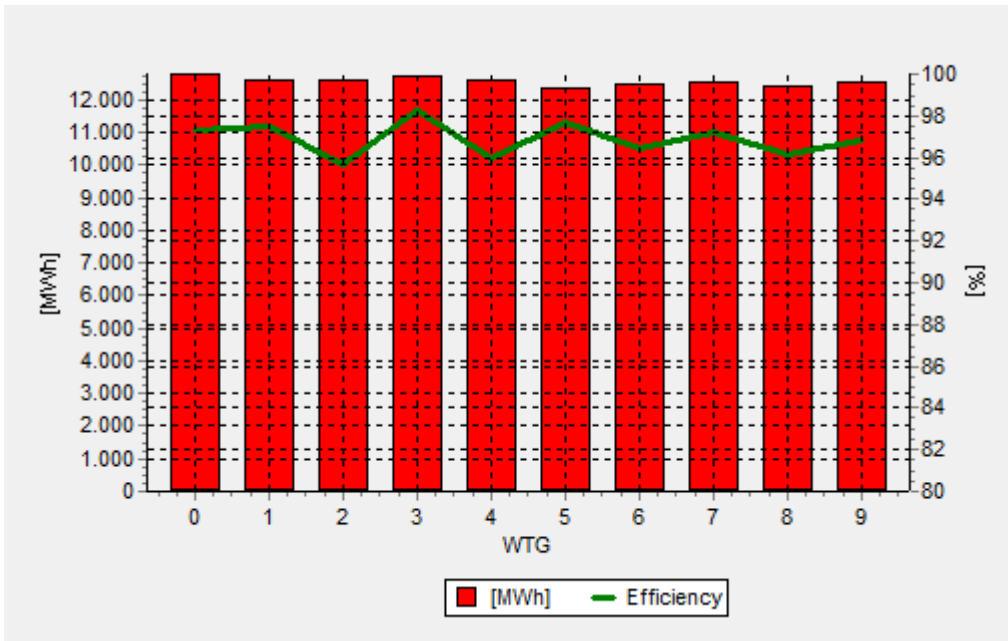
Description: Calculation time: 04-08-2010 16:52:50
Calculation type: Full optimize

Name	Noise level	Yield [MWh]	Efficiency [%]	MWh/MW [h]	X	Y
VESTAS V90 3000 90.0 IO! hub: 8...	Setting 0	12.798	97,3	4.266	450.431	5.111.601
VESTAS V90 3000 90.0 IO! hub: 8...	Setting 0	12.636	97,5	4.212	451.431	5.108.701
VESTAS V90 3000 90.0 IO! hub: 8...	Setting 0	12.592	95,7	4.197	450.381	5.110.701
VESTAS V90 3000 90.0 IO! hub: 8...	Setting 0	12.758	98,3	4.253	450.031	5.108.701
VESTAS V90 3000 90.0 IO! hub: 8...	Setting 0	12.600	96,0	4.200	450.681	5.109.101
VESTAS V90 3000 90.0 IO! hub: 8...	Setting 0	12.397	97,7	4.132	450.881	5.111.751
VESTAS V90 3000 90.0 IO! hub: 8...	Setting 0	12.484	96,4	4.161	451.031	5.108.801
VESTAS V90 3000 90.0 IO! hub: 8...	Setting 0	12.559	97,2	4.186	450.031	5.111.101
VESTAS V90 3000 90.0 IO! hub: 8...	Setting 0	12.420	96,1	4.140	450.631	5.110.201
VESTAS V90 3000 90.0 IO! hub: 8...	Setting 0	12.541	96,8	4.180	450.281	5.109.401

Close Copy Graphs

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

The results can be viewed graphically:



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

8.1.4.5 Calculation report

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

The report can now be printed.

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

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

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

8.1.5 OPTIMIZE - Noise, model C

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

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

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

Instead a number of partial solutions are made in WindPRO.

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

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

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

8.1.5.1 Noise reduced WTG's

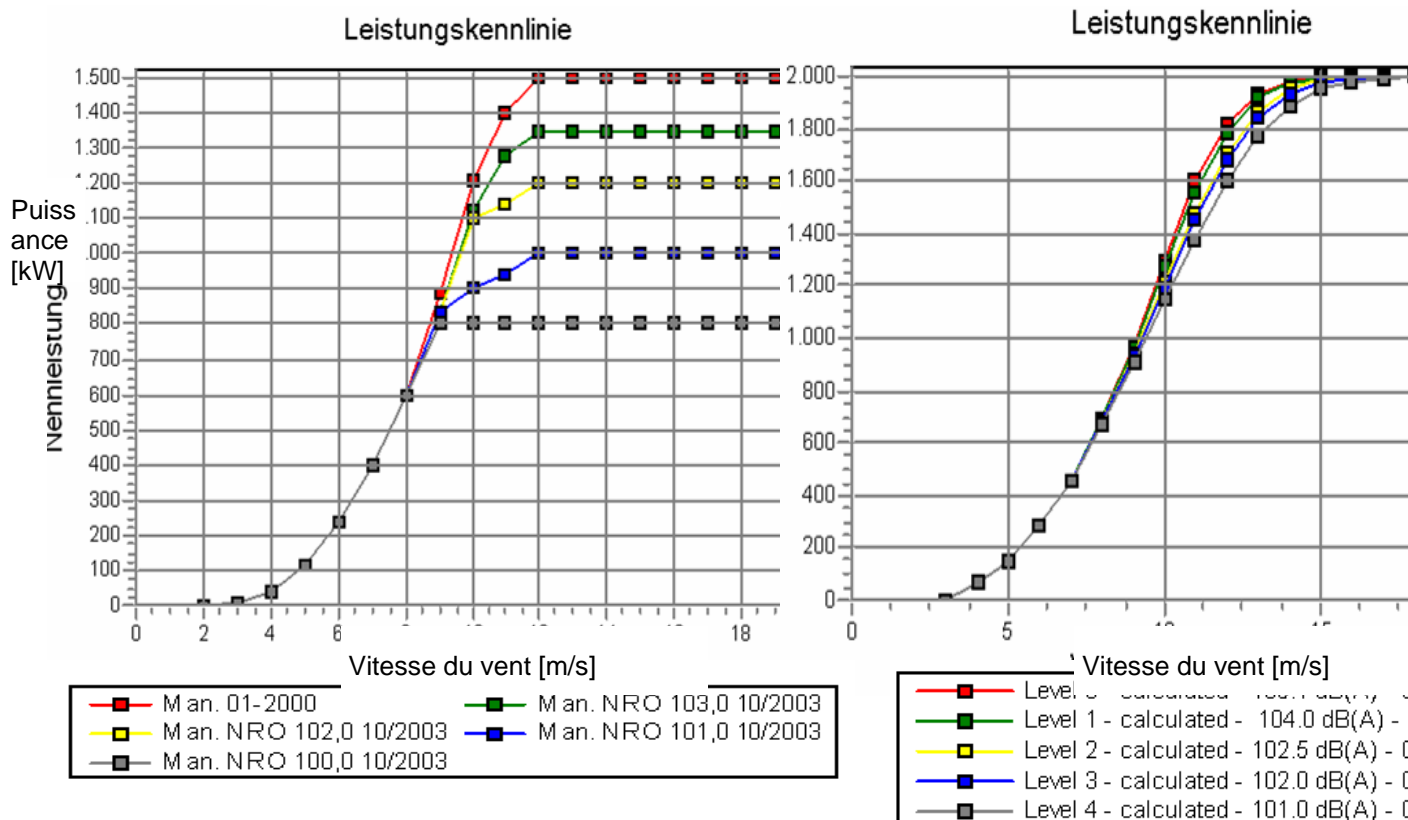
WTG's can often be reduced in noise at the expense of production output. These reduced states are referred to as operation modes. The standard operation mode is labeled Level 0 and will usually be the default setting for the turbine type in WindPRO.

There are two typical strategies for reducing noise.

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

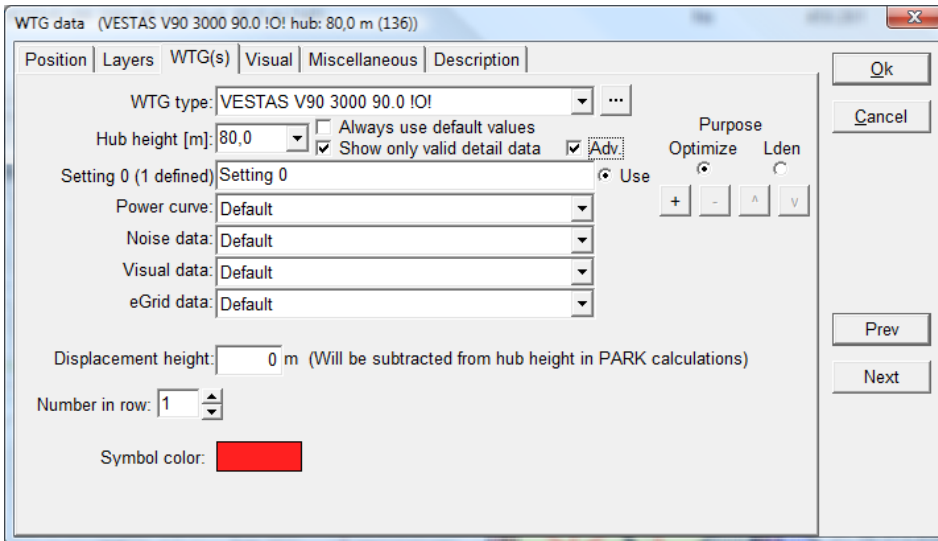
Another method is to cap the production output and thus reduce the noise. This is sometimes referred to as the German model and is used when the noise codes require noise to be calculated for the maximum noise level.

The two strategies are illustrated below.



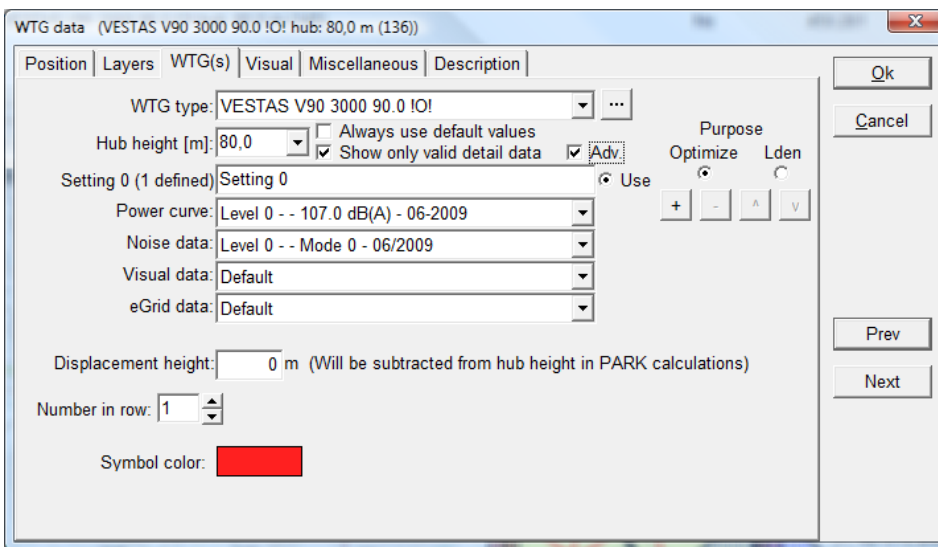
In the Basis section of the manual it is described how to select specific noise data and power curves for the WTG object. For the Optimize functions this feature is expanded.

If the hatch is removed from the "Always use default values" box on the WTG(s) tab in WTG properties the individual settings becomes available. Hatch the "Adv." box to enter the advanced mode.



There are two purposes for the advanced mode. Optimize and Lden. The Lden purpose is covered in the Decibel section of the manual. Unfortunately it is not possible to use the optimize functions if the turbine is setup with Lden definitions.

Select the Optimize purpose. Setting 0 is automatically defined with default power curve and noise data. Select a level 0 power curve and a level 0 noise record for the turbine. Be sure the same level is chosen for both power curve and noise record.



Press the “+” button to create the next setting and fill in level 1 power curve and noise data. The three other buttons now become active. The “-” button remove a setting, while the arrow up and down buttons move between the different settings.

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

Press OK to leave the turbine.

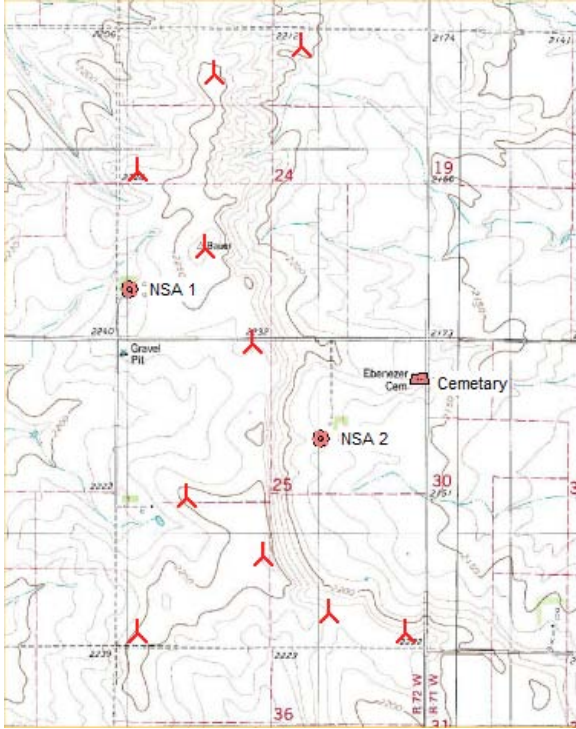
If there are many turbines in the project it is useful to highlight objects in the object list and choose “Edit selected objects” and there set the advanced settings.

8.1.5.2 Noise sensitive areas.

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

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

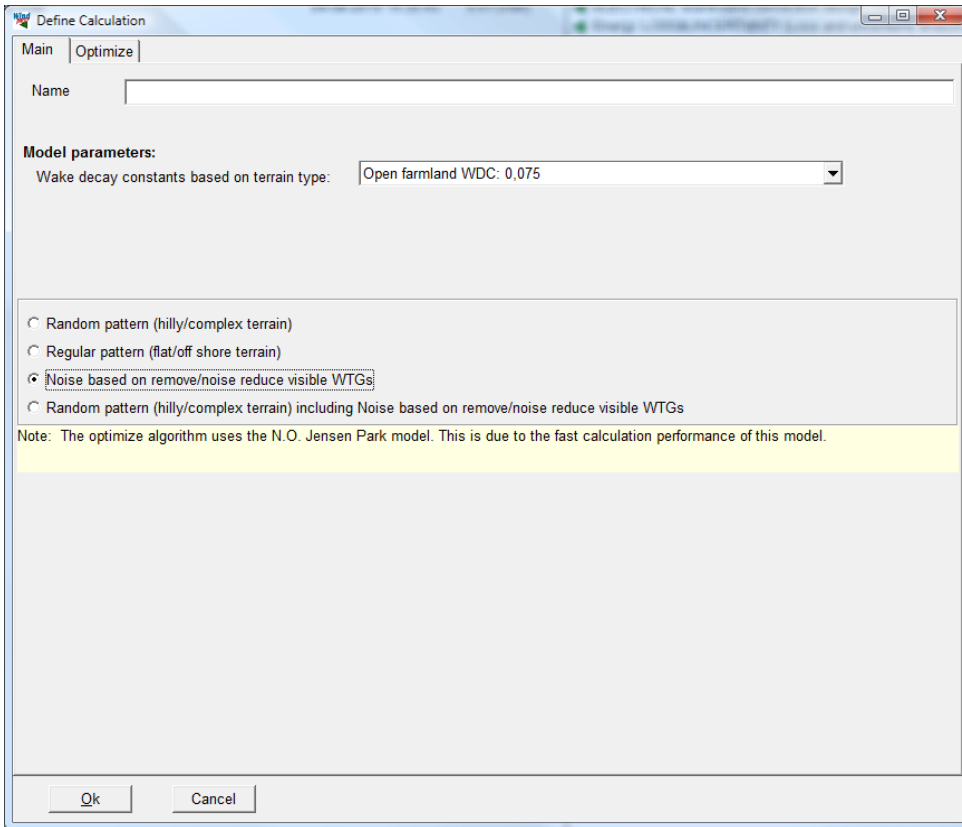
In the below example three NSA are created at two dwellings and a cemetery. The given layout is the optimized layout from the full optimization. Note that this layout was created without setbacks from dwellings so the layout is at a disadvantage from the outset.



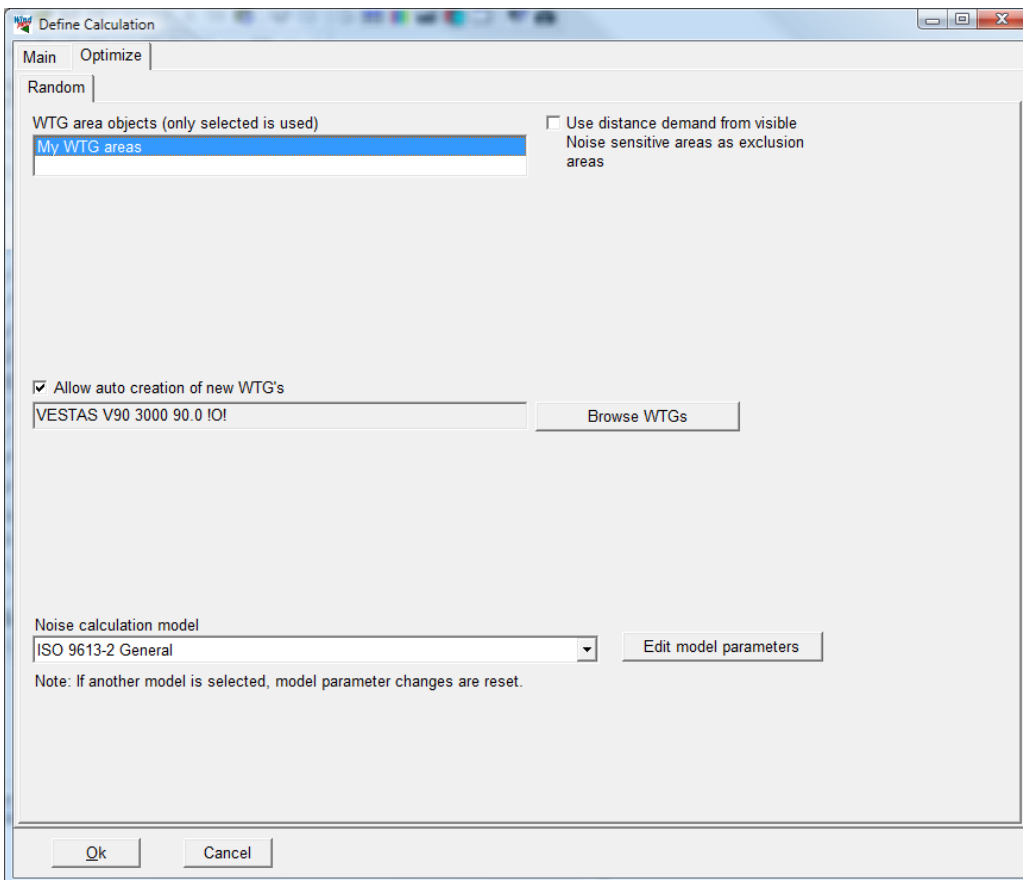
8.1.5.3 Noise optimization setup

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

Select as optimization type “Noise based on remove/noise reduce visible WTGs”.



Go to the Optimize tab.

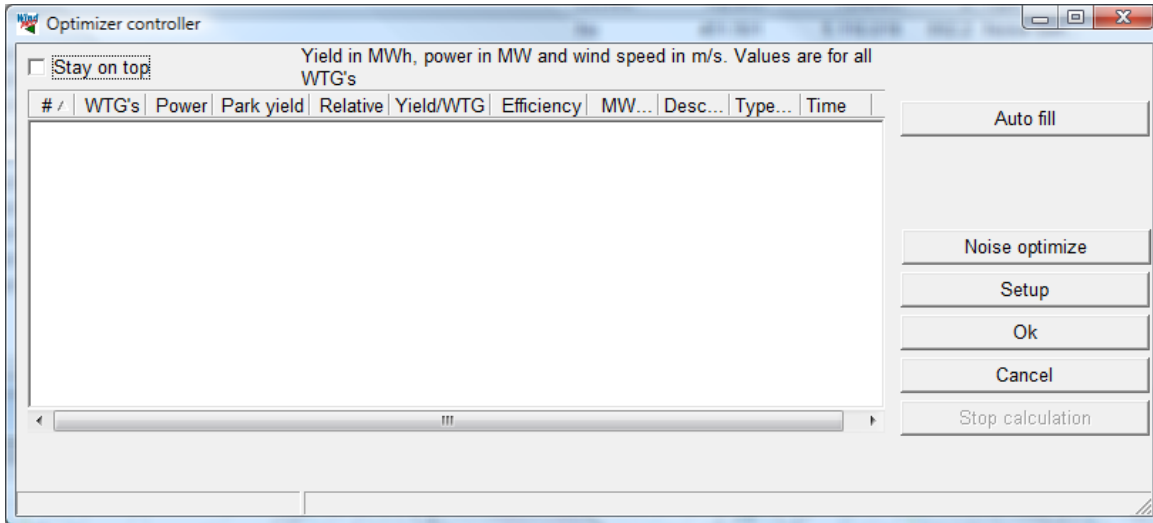


Select the WTG area object for the area definition.

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

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

Press OK to start the Optimize controller.



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

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

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

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

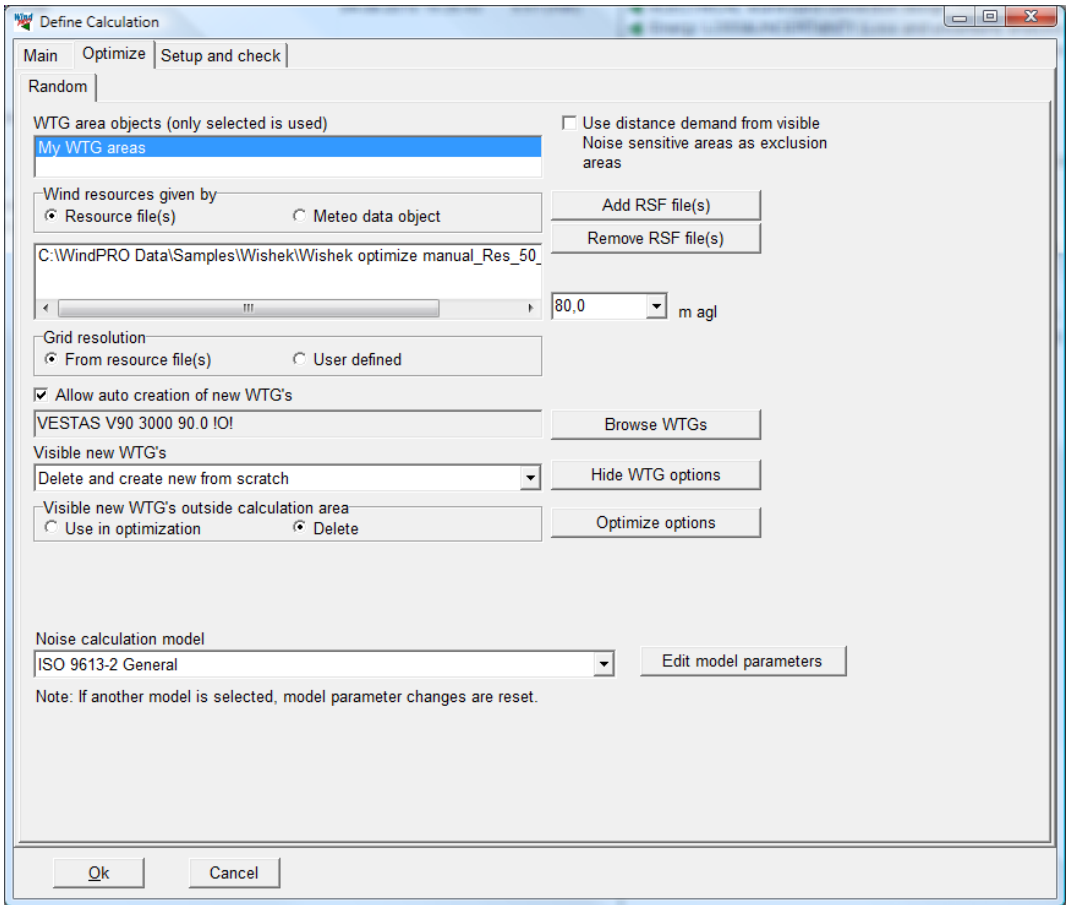
A line with a result appears in the Optimizer controller, but this will only inform about the resulting number of turbines.

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

8.1.6 OPTIMIZE, Noise and energy

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

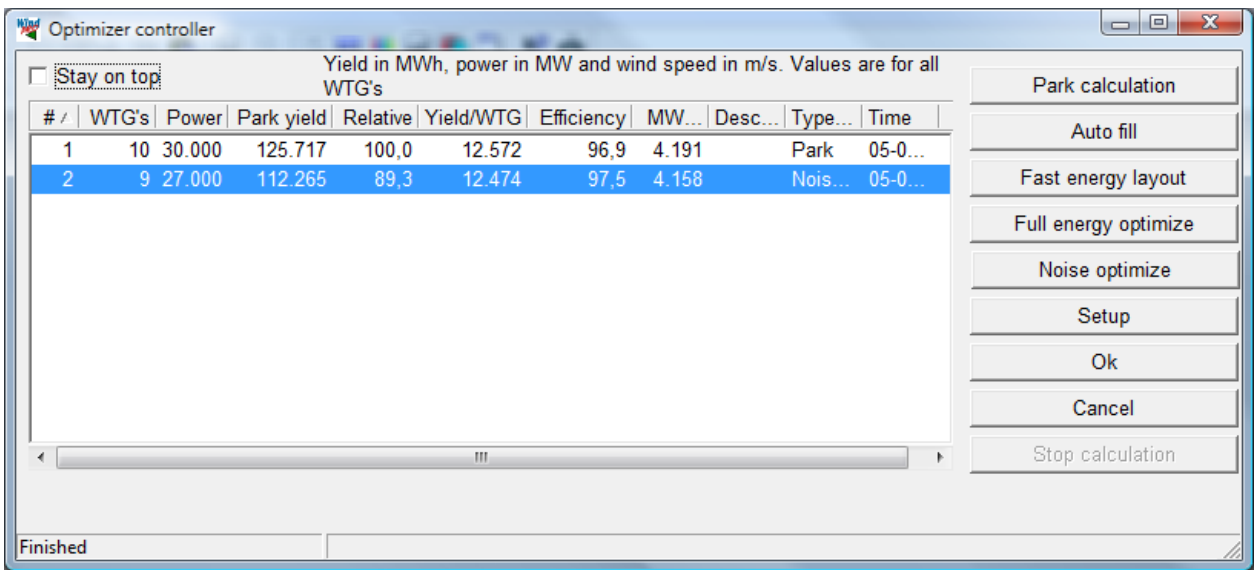
The setup is a combination of the two.



All the parameters are described in previous sections.

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

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



9 ENERGY, Model - CFD interface

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9.1 CFD interface – Introduction and step-by-step guide

9.1.1 Introduction to CFD interface

The application of wind energy in very complex terrain requires new procedures for deriving better estimates of the wind resource. This is the case, as the traditional calculation models may prove erroneous in some of these situations. A straightforward idea would be to try and implement a state-of-the-art computational fluid dynamics (CFD) code in the analysis procedures. Several commercial products utilizing CFD for wind energy purposes are on the market. The present CFD interface in WindPRO makes it convenient to interact between these CFD tools and WindPRO. The CFD interface consists of two parts:

PREPROCESSING: Generates the data files to CFD software based on already established data in WindPRO.

POSTPROCESSING: Import CFD results for comparison with WindPRO (WAsP) results.

In addition wind resource maps generated from CFD products can be utilized in PARK calculations so the CFD Wind distribution calculations can be used as input for PARK calculations.

9.1.2 CFD interface Step-by step-guide

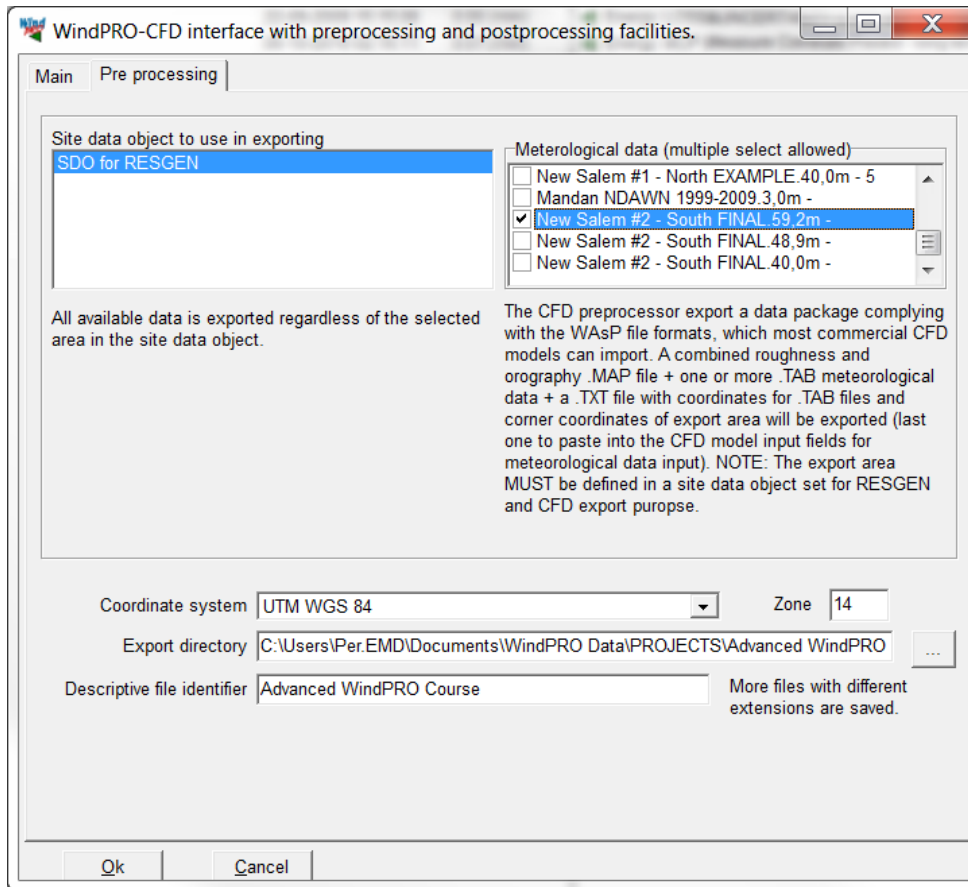
- Establish elevation data and roughness data in WindPRO line objects (see BASIS)
- Establish a Site data object with links to the line objects (or files)
- Eventually load wind data in METEO objects (See Energy, METEO)
- Start CFD interface, choose the data to be used for CFD model calculation, choose coordinate system and export directory (folder).
- Click OK and the data will be exported to the chosen folder in standard WAsP file formats, which most CFD tools can import.
- Run the CFD model, calculate a Wind resource map (must have a .rsf or .wrg (WAsP) output file format)
- Start the CFD interface, choose post processing
- Load the CFD resource file along with a similar WAsP calculation result
- Compare the calculations with the different compare tools

Calculate AEP for wind farm:

- From PARK, the wind distribution tab, select “use resource file(s)”, point out the CFD result
- Run the PARK calculation based on the CFD results /(See ENERGY PARK for further details)

9.2 Preprocessing

9.2.1 Generate data for CFD calculations



The screen above shows the needed information for setting up a data export.

A site data object holds all the links to elevation and roughness data, that will be exported as a .MAP file holding as well elevation as roughness (WASP format). These data can be imported by most CFD tools for wind engineering. In addition a .txt file with coordinate info that might be useful for setting up the CFD model is generated.

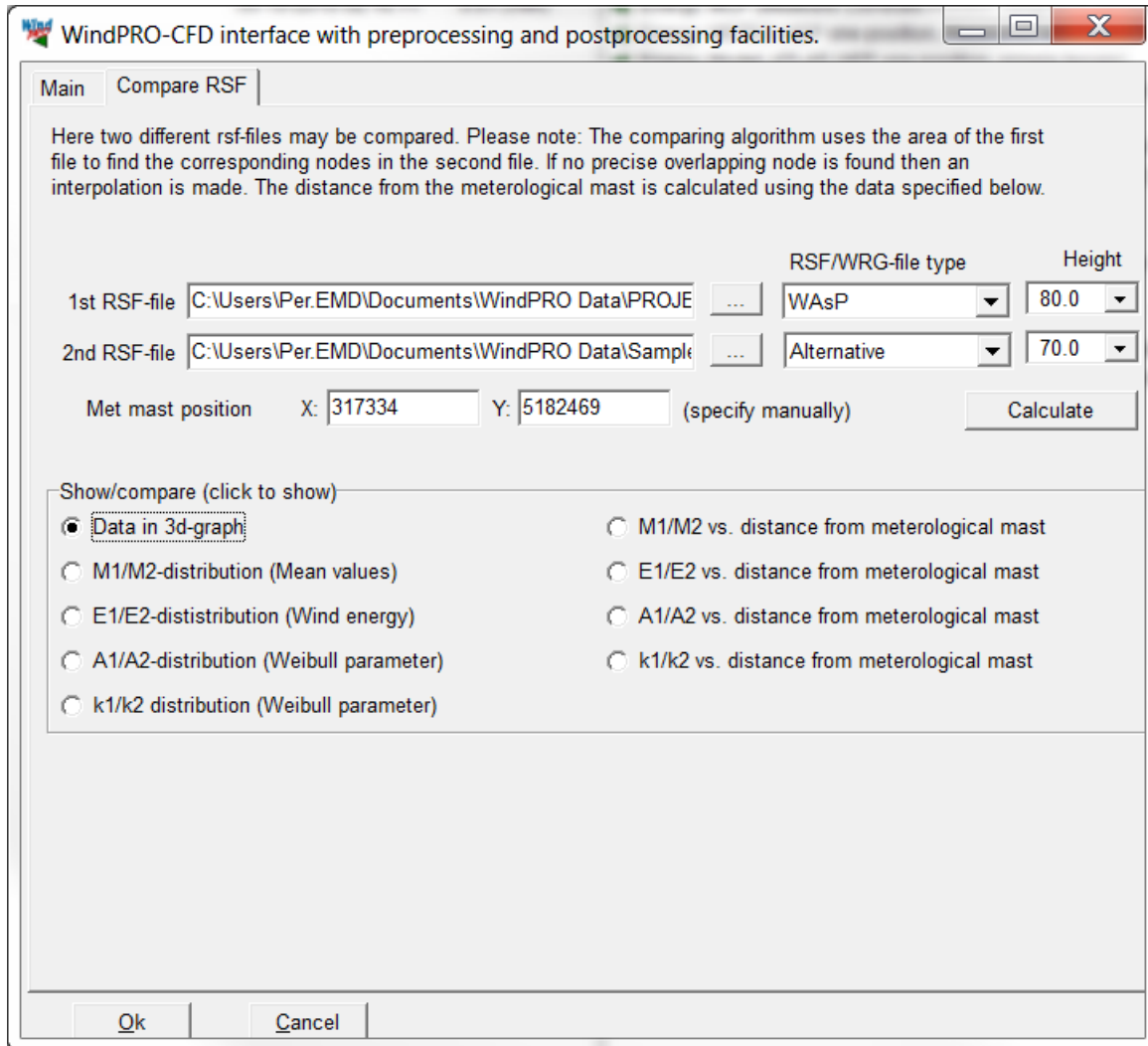
A METEO object holds the wind data and the position of the measurements. These data will be exported as a .TAB file along with a text file with coordinates and measurement height.

The “data package” can be sent to the operator of the CFD model.

9.3 Post processing

The post processing facility requires a resource file in .rsf or .wrg format is available from the CFD model. The following facilities are available:

1. Load two different resource files (typically CFD and WASP, but could be two different CFD models)
2. Calculate “compare nodes”, the software “synchronise” if different resolution or offset in the files by interpolation.
3. Compare the results (a number of graphic compare options available, see below)



9.3.1 More about comparing rsf-files

The WAsP and CFD results are taken from the resource file where the Weibull A and k parameters are saved. The mean wind speeds are calculated from the A and k parameters, using the following relationship:

$$\mu = A \cdot \Gamma(1 + 1/k)$$

Where Γ is the gamma function

A, k is the Weibull distribution parameters (normally denoted scale and form parameters)

It should be noted that the Weibull parameters are fitted to the measured distribution using the requirement that:

- The total wind energy in the fitted Weibull distribution and the observed distribution are equal.
- The frequencies of occurrence of the wind speeds higher than the observed average speeds are the same for the two distributions.

These two requirements show that the WAsP fitting routine does not assure that the calculated mean wind speed is not necessarily close to the observed value. Thus, it would be preferable to compare the energy content in the wind from the two methods. The parameter chosen for comparison is now the ratio between the mean wind speed calculated from your CFD software and WAsP: This parameter, R, is calculated as follows:

$$R = \frac{\mu[U_{10, \text{WindSIM}}]}{\mu[U_{10, \text{WASP}}]} = \frac{A_{\text{WindSIM}} \cdot \Gamma(1 + 1/k_{\text{WindSIM}})}{A_{\text{WASP}} \cdot \Gamma(1 + 1/k_{\text{WASP}})}$$

Where A_{WASP} , k_{WASP} are Weibull distribution parameters (WASP calculation)
 $A_{WindSIM}$, ($k_{WindSIM}=2$) are Weibull distribution parameters (WindSim)

In extend to comparing the mean wind speed it is also possible to compare the following parameters:

- Weibull A-parameter (total distribution)
- Weibull k-parameter (total distribution)
- Energy level (total distribution)

The plotting of the parameters may be done as a simple distribution, as a function of the distance from the meteorological mast or mapped onto a 3d graph showing the height contours.

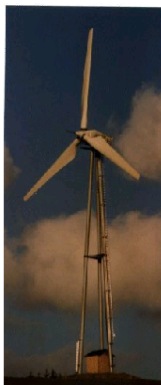
9.4 Example of the Methodology – Case Study Torrild

9.4.1 Site and Analysis Conditions

A total of 15 Bonus 150/30 kW MK II turbines are situated on site. The power production from these turbines is used for verification purposes. The hub height is 30 meters.

Two models were run. The 'Meso'-model was run with a grid resolution of 200 meters resulting in 10000 nodes. The micro model has been nested within the Meso model. In the 'Micro' model test case, the grid resolution was chosen to be 20 meter, also resulting in 10000 nodes. Here, only results from the micro model will be presented. The main characteristics of the area are shown below:

Company	BONUS
Type/Version	MK II
Rated power	150.0 kW
Secondary generator	30.0 kW
Rotor diameter	23.8 kW
Tower	Tripod
Origin country	DK
Blade type	LM 11
Generator type	Two generator
Rpm, rated power	40.4 rpm
Rpm, initial	30.3 rpm
Default hub height	30.0 m
Alternativ hub heights	0.0 m
Valid	No
Creator	EMD
Created	07-10-1998 00:00
Edited	07-10-1998 00:00



Calculation area	4 km ²
Coordinate system	UTM zone 32 – datum ED50
Geographical limits	(y _{min} , y _{max})=(6203500, 6205500) (x _{min} , x _{max})=(563700, 565700)
Grid size	20 meters
Number of cells	10000
Wind data	Station 5 – Feb to Oct 2000 Station 36 – Feb to Oct 2000 (St 36: data acquisition very low)

A through description of the site with an analysis of the wind climate and the production from the turbines using traditional methods, see [i]. The orography and roughness for the calculation area are shown in Figure 8. These figures represent the initial extraction area, which was 4 x 4 km². This was later reduced into a 2 x 2 km² area. The approximate position of the final calculation area is shown by the black square in the figures.

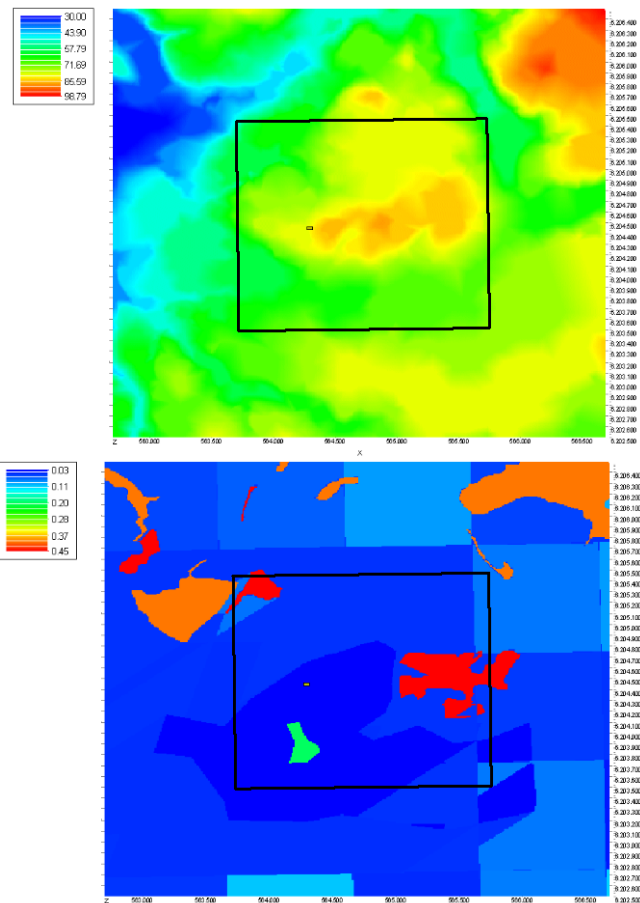


Figure 1 Orography and roughness from the initial extraction (orography in [m], roughness in [m]).

9.4.2 Comparing WAsP and WindSim CFD Results

The main statistics of the ratio between the WindSim and WAsP results are shown in Table 1. The mean value of the ration is 97.2%, which mean that the WindSim calculations in general seem to underestimate the mean value of the wind speed distribution. However, this difference may also be due to differences in fitting techniques when fitting the Weibull parameters. The coefficient of variation is 2.4%, which is judged acceptable. When looking at the energy level, the WindSim calculation underestimates approximately – in mean - 9 % as compared to WAsP.

Mean wind speed			Energy level		
μ	σ	$COV=\sigma / \mu$	μ	σ	$COV=\sigma / \mu$
0.972	0.023	0.024	0.907	0.069	0.076

Table 1: Statistics on the ratio, R, between the mean wind speed or energy level calculated from WindSIM and WAsP.

The dependency on the distance from the meteorological mast and the height above ground is shown in Figure 9. It is obvious, that the WindSim model seems to underestimate increasingly as the distance from the meteorological mast increases. A larger variation is seen as in a distance approximately 1000 meters from the mast. Inspecting the Figure 10 and comparing with the roughness map in Figure 8 find the reason for this larger variation. Here it is seen, that the large ratio comes where the roughness is high (a small city is situated). Near the site, the two models predict quite similar, and the difference in mean wind speed is within a few per cent.

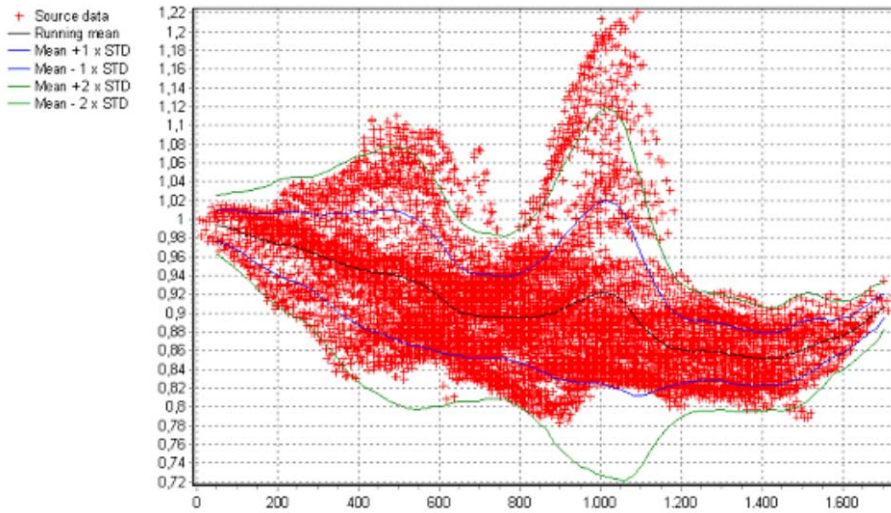


Figure 2 WindSim/ WASP mean wind speed ratio conditioned on the distance from the met mast.

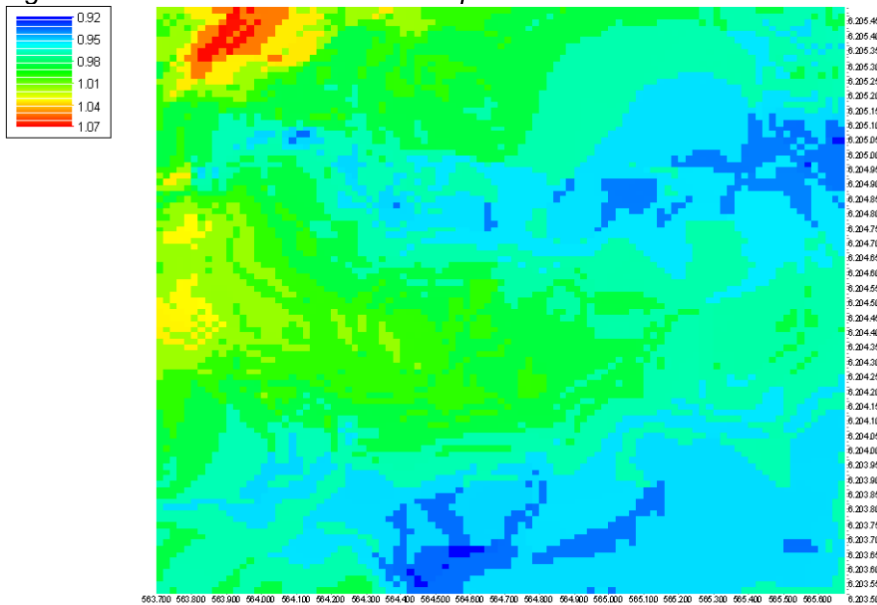


Figure 3 Comparing WindSim/WASP mean wind speed ratio distributed over the calculation area.

9.4.3 Comparing Results at the Meteorological Mast

In order to compare how the different models perform, it is sought to estimate the wind climate at the position of the meteorological mast. I.e. it is possible to compare the model predictions with the original measured data. WASP v. 5.1 is used to fit the Weibull parameters in all models in order to overcome the known problems of using different Weibull fitting algorithms (see Fitting Weibull Parameters for Wind Energy Applications).

9.4.3.1 Calculated Weibull A-parameters [m/s]

Model	Height	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
Measured	30 m	4.70	4.50	5.10	6.60	6.70	6.00	6.60	6.80	7.50	6.30	4.10	5.10	6.30
WASP	30 m	4.73	4.67	5.15	6.59	6.73	6.03	6.57	6.90	7.42	6.35	4.59	5.11	6.34
	70 m	5.59	5.45	6.25	8.26	8.19	7.10	7.78	8.07	8.81	7.79	5.62	6.26	7.65
	100 m	6.08	5.93	6.82	8.95	8.79	7.70	8.48	8.72	9.52	8.43	6.08	6.79	8.28
WindSim	30 m	4.60	4.50	5.10	6.60	6.70	6.00	6.50	6.80	7.50	6.30	4.10	5.10	6.30
	70 m	5.30	5.20	6.00	7.60	7.60	6.60	7.30	7.50	8.30	7.10	4.90	5.90	7.10
	100 m	5.60	5.50	6.20	8.00	8.00	7.00	7.60	7.90	8.60	7.40	5.20	6.20	7.50

9.4.3.2 Calculated Weibull k-parameters

Model	Height	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
Measured	30 m	1.64	2.04	2.20	2.42	2.53	2.19	1.80	2.19	2.27	2.00	1.54	1.62	2.04
WAsP	30 m	1.72	2.08	2.19	2.44	2.53	2.19	1.87	2.21	2.28	2.04	1.63	1.65	2.06
	70 m	1.94	2.33	2.47	2.72	2.83	2.42	2.06	2.49	2.55	2.31	1.82	1.86	2.30
	100 m	2.02	2.42	2.54	2.80	2.92	2.50	2.15	2.59	2.67	2.42	1.89	1.94	2.30
WindSim	30 m	1.63	2.03	2.19	2.42	2.54	2.17	1.79	2.20	2.28	2.00	1.53	1.61	2.05
	70 m	1.63	2.06	2.24	2.44	2.57	2.14	1.81	2.19	2.30	2.02	1.59	1.63	2.07
	100 m	1.65	2.09	2.18	2.35	2.46	2.19	1.81	2.20	2.21	2.00	1.59	1.61	2.05

9.4.3.3 Calculated direction probability [%]

Model	Height	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
Measured	30 m	2.00	3.50	8.10	10.6	9.60	8.20	8.40	12.3	15.6	14.9	4.20	2.70	100
WAsP	30 m	2.10	3.80	7.80	10.5	9.70	8.30	8.60	12.4	15.5	14.4	4.60	2.70	100
	70 m	2.00	3.50	7.90	10.8	10.0	8.20	8.20	12.0	15.7	14.7	4.60	2.60	100
	100 m	2.00	3.50	7.90	10.9	9.90	8.10	8.20	12.0	15.7	14.7	4.50	2.60	100
WindSim	30 m	2.00	3.50	8.10	10.6	9.60	8.20	8.40	12.3	15.6	14.9	4.20	2.70	100
	70 m	2.00	3.50	7.90	10.8	9.70	8.00	8.40	12.2	15.5	15.1	4.20	2.60	100
	100 m	2.00	3.50	7.90	10.9	9.70	8.00	8.40	12.1	15.5	15.2	4.20	2.60	100

When comparing the measured and modelled Weibull A-parameters, it seems like the WAsP model has a tendency to slightly over predict the A parameter at the 30 meters height. The WindSim model gives a result that is very close to the measured data (as it is supposed to as the speedups and direction changes are 0). When looking at the A-parameter at 70 meters and 100 meters, then the WindSim model predicts a lower A-parameter than the WAsP model. There are actual plans on substituting the 15 x 150 kW WTGs with a few 2 MW WTGs – if this happen, we will get the chance to see which model that perform best in this matter.

In this test case, the modelled directional probabilities are not very different from the measured ones.

9.4.3.4 Estimating Meteorological Station 5 with Meteorological Station 36 data and vice versa

The measured data from station 5 and station 36 has been compared with WindSim modelled data at the same positions but using wind data from the other station. Unfortunately, the data from station 36 is erroneous in long periods, leaving us with only 17 days of good data from February 2000. The analysis of these remaining data is shown below. A WAsP analysis has been made for comparison.

In the Figure 11 the speedup data from the two stations are shown. The actual WindSim data are calculated at one wind speed only (approx. 7-8 m/s), and the data is assumed to have a linear development as shown on the figures – passing through 0.0. A speedup-development is assumed to be stepwise linear if more calculation wind speeds are added. Examining the two figures it is easy to see, that at 10 m/s the maximum speed-up is approximately 0.3 m/s, i.e. a change no more than 3%. This means that we should expect only small changes in the modified wind distributions.

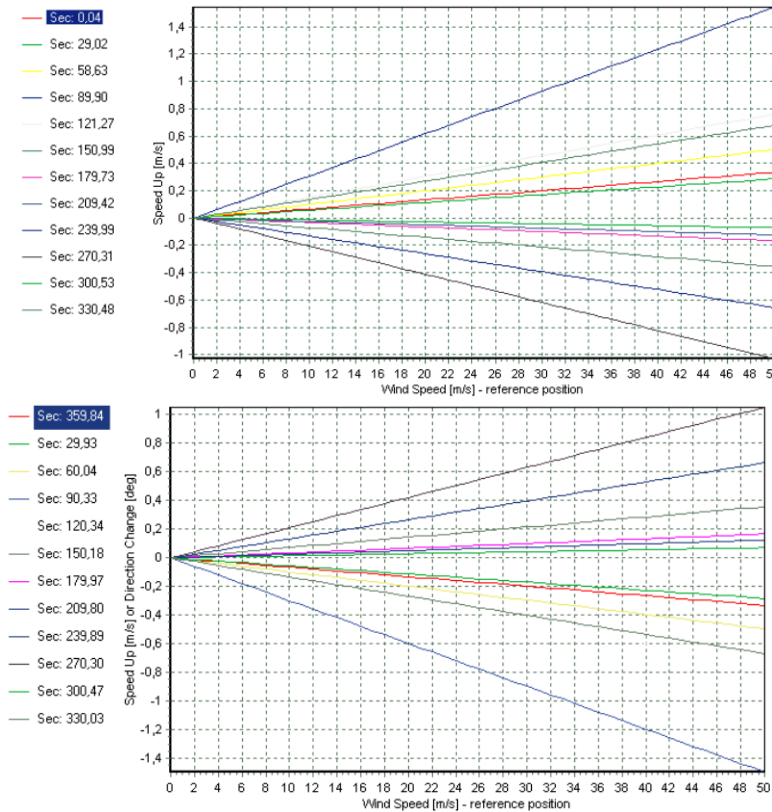


Figure 4 Speedup data from calculated sectors (left=St 36 using St 5, right = St 5 using data from St 36)

WindSim results

The measured distributions for the 17-day period and the estimates of the new wind and directional distributions are shown in Figure 12 and Figure 13. It is obvious that the predicted distributions at the other position looks very much like the one that they are derived from. This is due to the very small modification factors for all dominating sectors (SSW to NNW). It seems that our model has not been able to capture the large differences in the two measured distributions. However, when over viewing the site, then it is obvious that both of the meteorological masts are operating in wind turbine wakes for long periods. The meteorological mast number 36 is placed only 70 meters from the near most turbine. Making a park analysis in WindPRO the ‘park efficiency’ is found to 92.2% for station 5 and station 36 is at 87.7% (park efficiency is calculated relative to energy levels). Interpreting the park efficiency in terms of wind speeds, approximate calculations shows that the omni directional mean wind speed at the sites is lowered with 0.19 m/s (station 5) and 0.30 m/s (station 36) relative to the free wind speed. Thus, it is concluded, that the WindSim model performs as expected and the main difference in measured wind statistics is due to wind farm wake effects. In addition, differences in anemometer calibration and/or type may cause differences in wind statistics, but this issue is not investigated further here.

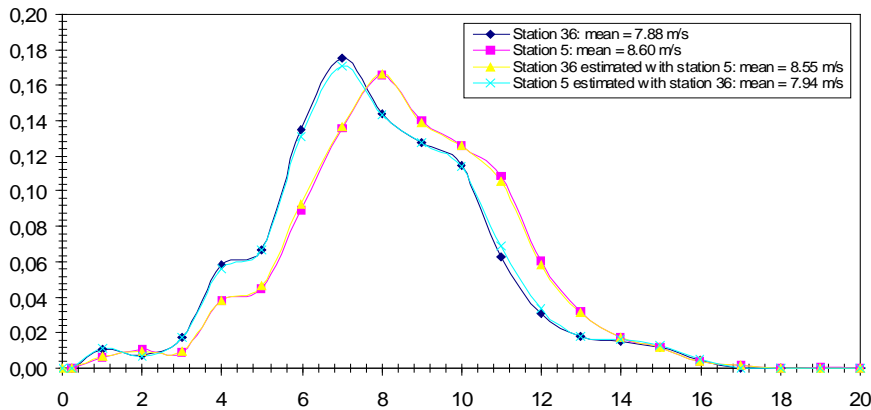


Figure 5 Sample and modified distributions for Stations 5 and 36.

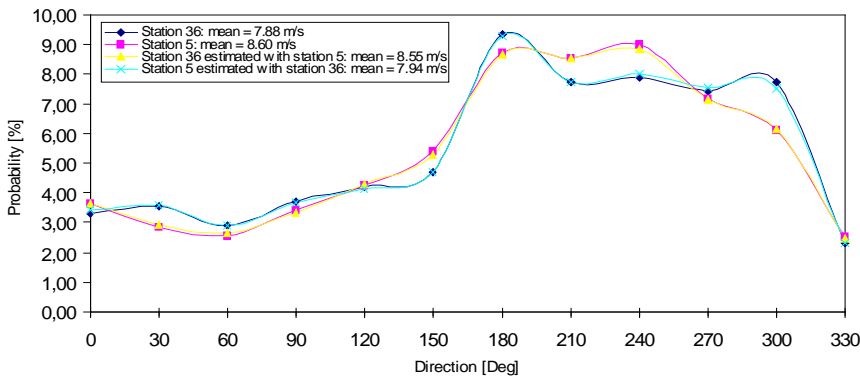


Figure 6. Directional distributions for stations 5 and 36 and the model data.

WAsP results

In order to support the conclusions regarding the main differences in measured wind distributions a WAsP analysis has been performed, analysing differences in the two meteorological stations by using the ‘long term’ data from station 5. Only the Weibull A-parameter is reported below in Table 2. It is seen, that the differences at the two sites are almost negligible, supporting the conclusion that the main differences in the measured wind statistics comes from the wake effects.

Station	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
St 5 measured (long)	4.70	4.50	5.10	6.60	6.70	6.00	6.60	6.80	7.50	6.30	4.10	5.10	6.30
St 5 with 5 long term	4.73	4.67	5.15	6.59	6.73	6.03	6.57	6.90	7.42	6.35	4.59	5.11	6.34
St 36 with 5 long term	4.68	4.53	5.10	6.75	6.84	5.98	6.50	6.83	7.67	6.74	4.68	5.17	6.45

Table 2: Weibull A-parameters for estimated with different meteorological stations (5 and 36).

9.4.4 Comparing with production data

The production data from the turbines have been analysed in [1], and the results from this reference is used here. The WindSim results have been save in a rsf-file and processed using the PARK module in WindPRO in order to include wake effects. The results from the analysis are shown in the Figure 14 where data from the ‘Goodness’ indexes for all turbines on site is plotted. The ‘Goodness’ is defined as the ratio between the actual measured production and the calculated (modelled) production, i.e. a ‘Goodness’ larger than 1.0 is an underestimation of the actual measured production.

When inspecting the Figure 14 it is obvious that both models seem to underestimate the actual measured production. As stated before in 3.3, the WAsP model over-estimates the wind climate even if the same position is estimated. This may account for some of the difference between the two models. Also, results from the WAsP model seems to somewhat correlate to the height (green line in graph below), i.e. ‘high’ altitudes may also be followed by a relative large ‘Goodness’. The WindSim model does not have the same trend, but seems to increase in ‘Goodness’ as the distance from the meteorological mast increases.

So a promising thing about WindSim is that is seem to “catch” the lower sited WTGs much better (WTG 5 and 9), which indeed is a positive trend. Thus, this may invoke much improvement at sites with more complex terrain. WindSim predicts the WTGs farther away from met mast worse. This may be caused by the fact that a WindSim micro siting analysis does not take roughness at longer distance into the calculation (except in cases where the analysis has been run as a nested analysis). In general, it seems that the ‘physical’ roughness description used in WindSim does not capture the effect of the complex roughness as well as the more refined (but experience based) treatment of roughness in WAsP. This lead to conclusion, that WindSim performs its optimum at sites with more simple roughness and complex orography.

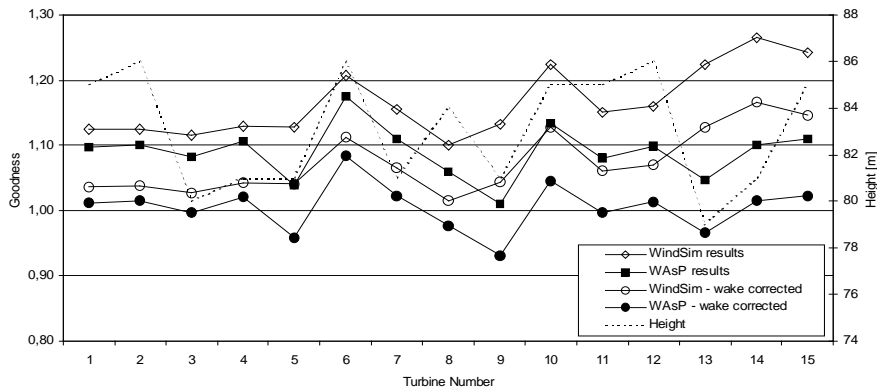


Figure 7 Comparing energy production calculated from WindSim with those calculated with WAsP.

When finding that both initial WindSim and WAsP calculation as well underestimate the actual measured production, then we may look for other sources of error than pure model errors. This may be a too conservative power curve, however the power curve seems fine when compared to the HP generic power curves, see [i]. Another obvious source of error could be wind speeds measured too low. This may be initiated by:

- Boom effects
- Wake effects from the nearby turbines (which may be the most probable cause)
- Anemometer errors (e.g. from wear and tear) – calibration required
- False positioning of met mast relative to height contours (or ‘disturbances’ in the actual wind profile – e.g. a zero displacement height)

As stated in Section 3.3.4, the wakes from nearby turbines influences the measured wind speeds significantly. When making a rough correction of the wake influence (simply by adjusting the calculated wind energy with the ‘park efficiency’ factors as stated in Section 3.3.4), then the WAsP results are now within ±9%. The WindSim calculations still – in mean - underestimate the actual production, but within a reasonable margin, see Figure 14 and Table 3. One main reason for the underestimation of the energy is believed to rise from lack of a good/validated free wind distribution. In new wind farm projects, this issue does not occur, but in validation cases, it is of outmost importance to have tools for analysing and ‘cleaning’ the data from wakes. This feature is currently being implemented in an upcoming version of WindPRO.

Statistic	Goodness from	
	WindSim	WAsP
Max	1.167	1.083
Min	1.014	0.931
Mean	1.075	1.005
Standard deviation	0.048	0.037

Table 3: Goodness - Wake Corrected.

9.4.5 Discussion/Conclusion of case study

The case study has demonstrated the application of the new tools available in WindPRO for linking existing data into a WindSim/WindPRO joint analysis. The ease of extracting the WindSim input files enables the user to gain the benefit of a second opinion analysis.

The actual case study from Torrild shows, that the site fits the WASP model best – it is a typical Danish site – even if the orography is some of the ‘roughest’ that we may find in Denmark. The WindSim model seems to have problems with taking complex roughness into account, but it also seem to improve handling of the orography. In addition, it must be noted that the WindSim model has its strengths in sites with complex orography and not sites with complex roughness - as the current site.

9.5 Appendix. Making Joint Wind Distribution Modifications

9.5.1 On-Site Wind Distributions

Traditionally in wind resource assessment, the on-site (subscript: site) and reference-site (subscript: ref) wind speed distribution are given as discrete distributions, showing the distribution of 10-minute averaged wind speed conditioned on the different wind sectors. In addition, the distributions of the wind directions (sectors) are given:

$$P(\theta_{ref}) \text{ and } P(U_{ref} | \theta_{ref})$$

These two distributions are enough for establishing the joint distribution for the reference site:

$$P(U_{ref}, \theta_{ref}) = P(U_{ref} | \theta_{ref}) \cdot P(\theta_{ref})$$

The joint distribution of (U_{ref}, θ_{ref}) is easily extracted from the *.tab file as shown in the **Error! Reference source not found.**

9.5.2 New wind distribution using a JPC-method (JPC=Joint Probability Change)

The distribution of wind speeds and wind directions are given as a discrete joint distribution, e.g. specified by a *.TAB file. The results from WindSim are assumed to be given as node specific speed up addenda, S , and direction change addenda, D , which both are – in the general case – functions of the wind speed and direction on the reference site $S=f(U_{ref}, \theta_{ref})$, $D=g(U_{ref}, \theta_{ref})$. It is now assumed, that the speed up factors and directions are reported in a table with the results is extracted for each calculation node. The reference site samples are - within one bin of wind speed and direction - assumed to follow a joint uniform distribution. The density function is given by:

$$f(u, \theta) = \begin{cases} \frac{1}{\beta - \alpha} \cdot \frac{1}{\delta - \gamma} & \text{if } (\alpha \leq u \leq \beta) \wedge (\gamma \leq \theta \leq \delta) \\ 0 & \text{otherwise} \end{cases}$$

where u is the wind speed at the reference site in the bin considered
 θ is the wind direction at the reference site in the bin considered
 α and β are the lower and upper limits for the wind speed interval
 γ and δ are the lower and upper limits for the wind direction interval

The probability that (u, θ) lies in a interval between $[a, b]$ and $[g, d]$ is found by:

$$P(a < u < b, g < \theta < d) = \frac{b - a}{\beta - \alpha} \cdot \frac{d - g}{\delta - \gamma} \quad \text{where} \quad \begin{cases} a = \alpha & \text{if } a < \alpha \\ a = \beta & \text{if } a > \beta \\ b = \alpha & \text{if } b < \alpha \\ b = \beta & \text{if } b > \beta \\ g = \gamma & \text{if } g < \gamma \\ g = \delta & \text{if } g > \delta \\ d = \gamma & \text{if } d < \gamma \\ d = \delta & \text{if } d > \delta \end{cases}$$

Now the wind speed from the reference site, u_{br} , is added with the speed up addendum, S , and the wind direction from the reference site, θ_{br} , are added with the direction change, D . This yields two new random variables, describing the wind climate at the site.

$$u_{bs} = u_{br} + S$$

$$\theta_{bs} = \theta_{br} + D$$

Now it is possible to evaluate the new 'bin density function' from the old one by adding the (S, D) to the limits of the original bin joint distribution. Now the probability of being within the bin-limits of the new joint distribution is easily evaluated, i.e. creating a new wind and direction joint distribution by moving the probability mass by (S, D).

Example Torrild – Cell 3569

The probability of being in the east-sector is $P[\theta_{br} = 75^\circ - 105^\circ] = 0.106$. The probability of being in the bin between 7 m/s and 8 m/s given that the wind is coming from the east sector is $P[u_{br} = 7 - 8 \text{ m/s} | \theta_{br} = 75^\circ - 105^\circ] = 0.147$. Now, the joint probability of being in the bin 7-8 m/s and having wind from east is:

$$P[u_{br} = 7 - 8 \text{ m/s}, \theta_{br} = 75^\circ - 105^\circ] = P[u_{br} = 7 - 8 \text{ m/s} | \theta_{br} = 75^\circ - 105^\circ] \cdot P[\theta_{br} = 75^\circ - 105^\circ] = 0.015582$$

i.e. approximately 1.5% chance of being in that particular bin at the reference position.

Inspecting the equation above describing the joint uniform distribution, then $\alpha = 7 \text{ m/s}$, $\beta = 8 \text{ m/s}$, $\delta = 75^\circ$ and $\gamma = 105^\circ$. Taking cell number 3569 at position E:568400, N: 6201600 from the WindSIM result files, then the speedup may be found for the particular bin to $S = -0.704 \text{ m/s}$ and the direction change is $D = 0.118^\circ$, making it possible to calculate the new limits for the old 'bin' probability mass, $\alpha_{new} = 6.296 \text{ m/s}$, $\beta_{new} = 7.296 \text{ m/s}$, $\delta_{new} = 75.118^\circ$ and $\gamma_{new} = 105.118^\circ$.

Evaluating the above equation (considering all proper limitations) for the nearby bins, one obtains the results reported in the table below. The table is showing how much of the bin-probability (0.015582) that moves into other (nearby bins). It is seen, that the main change is within the sector as the direction change is very small. Only 29% of the winds remains in the same bin. This procedure is repeated for all bins, calculating a new joint distribution for the site-position.

	$\theta_{bs} = 45^\circ - 75^\circ$	$\theta_{bs} = 75^\circ - 105^\circ$	$\theta_{bs} = 105^\circ - 135^\circ$	$\theta_{bs} = 135^\circ - 165^\circ$
$u_{bs} = 5 - 6 \text{ m/s}$	0.00000	0.00000	0.00000	0.00000
$u_{bs} = 6 - 7 \text{ m/s}$	0.00000	0.70123	0.00277	0.00000
$u_{bs} = 7 - 8 \text{ m/s}$	0.00000	0.29484	0.00116	0.00000
$u_{bs} = 8 - 9 \text{ m/s}$	0.00000	0.00000	0.00000	0.00000

Table 4: Example Torrild: Probability Mass Moved Into Nearby Bins.

The original joint wind and direction distribution are given in Figure 15, while Figure 16 and Figure 17 show the speedup and direction changes respectively. Speedups are interpolated and extrapolated linearly while the direction changes are linearly interpolated but constant when extrapolated (or only one calculation wind speed).

Torrild Meteorological Site Data (Sample)
 55.979786111 10.03035 30.00
 12 1 0

	0.02	0.035	0.081	0.106	0.096	0.082	0.084	0.123	0.156	0.149	0.042	0.027
1	48	20	10	8	12	6	4	12	7	10	23	59
2	97	71	59	74	30	29	20	29	24	61	85	153
3	168	170	111	115	82	125	63	34	29	111	218	165
4	175	234	179	142	121	139	88	50	60	138	170	216
5	133	163	187	151	235	156	93	97	87	122	96	89
6	92	123	146	143	176	107	117	106	91	109	95	122
7	46	78	136	142	175	86	124	117	118	77	79	41
8	30	51	94	147	116	98	92	136	137	99	94	31
9	97	43	57	61	32	64	84	109	94	94	60	38
10	76	36	14	15	17	48	68	89	83	74	44	46
11	37	10	4	3	3	42	56	101	70	49	18	36
12	2	1	1	0	0	42	39	66	67	21	6	5
13	0	0	0	0	0	34	50	27	56	15	1	0
14	0	0	0	0	0	17	58	17	28	11	6	0
15	0	0	0	0	0	5	30	5	16	4	4	0
16	0	0	0	0	0	1	12	2	12	3	1	0
17	0	0	0	0	0	0	2	2	12	2	0	0
18	0	0	0	0	0	0	1	6	0	0	0	0
19	0	0	0	0	0	0	0	1	2	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8 Original Torrild Joint Wind and Direction Distribution (reference position).

	Sec: 0	Sec: 30	Sec: 60	Sec: 90	Sec:120	Sec:150	Sec:180	Sec:210	Sec:240	Sec:270	Sec:300	Sec:330
0	0	0	0	0	0	0	0	0	0	0	0	0
20	-1.141	-1.183	-1.801	-1.76	-1.991	-2.276	-1.946	-1.528	-1.126	-1.414	-1.417	-1.279

Figure 9 Direction Change Data for Torrild Cell 3569 (the direction change is assumed fixed for all bins)

	Sec: 0	Sec: 30	Sec: 60	Sec: 90	Sec:120	Sec:150	Sec:180	Sec:210	Sec:240	Sec:270	Sec:300	Sec:330
20	-0.299	-0.074	0.074	0.118	0.133	0.327	-0.322	-0.37	-0.026	0.341	0.301	0.037

Figure 10 Speedup-data for Torrild Cell 3569 (the data is linear- interpolated for bins between 0-20 m/s)

References

[i] Per Nielsen et al.: *Case Studies: Wind Energy Calculation Methods and Verification (preliminary title)*, Energi- og Miljødata, 2002.

10 ELECTRICAL eGRID

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10.0 eGRID – Introduction

10.0.1 Introduction to eGRID

The influences of WTGs on the electric grid of the utility as well as an optimised design of grid connection due to economic aspects play a more and more important role.

By using the module eGRID, the essential influences of WTG projects on the electric grid can be calculated and documented for unmeshed wind farm and grid cabling by load-flow and short-circuit calculations. Specifically, it is possible to calculate

- Annual losses in cables, lines and transformers based on local wind climate,
- voltages at the grid nodes and utilization check of the components (design check)
- voltage variations at the grid nodes,
- increase of short-circuit current,
- long term flicker,
- voltage variations due to switching effects.

Furthermore, the calculation results are checked against compliance of norms / standards or free-definable guidelines. Everyone, dealing with the electric grid connection of WTGs like planners, manufacturer, grid as well as wind farm operators get with WindPRO and the module eGRID an useful tool, which can be used to determine and to check the influences of planned WTG projects on the one hand and on the other hand to optimise grid connection of a wind farm in relation to energetic and economic terms.

10.0.2 Background of eGRID

The module eGRID have been developed within the frame of the EU-Project „DISPOWER“ (www.dispower.org) in collaboration with University Kassel (Institut für Elektrische Energietechnik/Elektrische Energieversorgungssysteme, Kassel) and ISET (Institut für Solare Energieversorgungstechnik, Kassel).

In order to work with eGRID, the WindPRO module BASIS is required. In BASIS, the project-, object- and map management is being arranged. Please read the corresponding chapter in the documentation for the BASIS module to get further information.

eGRID is used for the calculation and estimation of electric influences of single WTGs or wind farms to the electric grid based on load-flow and short-circuit calculations of radial grids. Hereby, a symmetric three-phase grid structure represents the basis of the load-flow calculations. The German norm VDE 0102 respectively the international norm IEC 60909 is the basis for the short-circuit calculations.

Further, the module provides you with the possibility to perform a calculation of the annual losses within the wind farm cabling based on given wind conditions. By using the results of this calculation, an optimised grid layout based on economic parameters can be designed.

Additionally, within the grid topology the used objects like transformers, WTGs as well as total cable lengths are documented and displayed in order to facilitate the generation of specification sheets. For these calculations, the digital contour lines, which have been created for other calculation purposes within WindPRO, are used to calculate the lengths of cables and overhead lines automatically.

10.0.3 Step by Step guide to the Electrical Calculations

- Establish the maps (if you want a graphical input on the maps) and the relevant project properties (please refer to chapter BASIS)
- To take advantage of the advanced calculation of cable/line lengths, taking the elevation into account, height contour data should be established in a line object. See chapter 2.8 BASIS for details.

Establish the relevant objects;

- WTGs – these can in WTG catalogue be extended with electric properties, e.g. build in transformer and cables for advanced calculations, but for most “traditional” analyses, the WTG can just be connected and handled based on the given Power. Cos(phi) can be added at calculation start.
- External Grid, for defining voltage levels and short circuit power at the grid connection point.
- Electrical cable/line object, which holds all grid line information's. The object work as a special variant of the WindPRO line object, which mean that it must be in edit mode to add/edit lines. Lines can be digitized on map background and “snapped” to objects, like WTGs or transformers, which mean that moving a WTG or transformer automatically moves the line. At right click when digitizing a line, an object, like a transformer can be created and “dropped” at the end of the line current being digitized. The dimensions and electric properties of the lines can be given as “generic” which means that the software automatically calculates the dimensions based on voltage, load etc. This is recommended to use in the preface of the grid design.
- Transformers, bus bars (for splitting a cable/line to go to more destinations), loads and WTGs can be inserted as “free objects”, but must then be connected via the Electrical cable/line object later on to take part in the calculation.

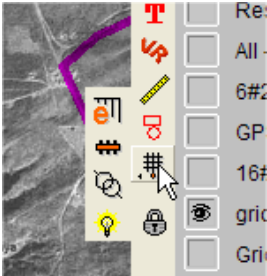
Perform calculations;

- Start the calculation using the project manager and choose the desired calculations
- Especially for the loss calculation, the expected annual wind farm production must be entered OR the expected wind distribution, which then gives the rough energy calculation for use in the loss calculation. Note the loss calculation is based on a simulation of different feed-in situations of the WTGs.
- Preview/Print the results

10.1 Input of data for Electrical Calculation

10.1.1 The eGRID Objects

Please read chapter 2 “BASIS” for general information about the work with maps and objects in WindPRO.



In the object bar to the right of the map, the eGRID objects are “collected” into one expandable object button. The External grid object, which always is the first to establish for designing an electrical grid system, is the “main object” – holding the cursor at this will show the other eGRID objects, from top: Electrical grid (for drawing the grid lines), the bus bar (for connecting more different cable/lines), the transformer and finally the load object.

10.1.1 Input of an External Grid (Grid connection point)



With the symbol *External Grid*, a new grid connection point is being placed on the map. The user interface for the entry of the relevant data (figure 1) appears.

External grid (PCC)

Position | Layers | Data | Description

Infinite Short Circuit Power
 Short Circuit Power Sk [MVA]
 Subtransient Short Circuit Power Sk* [MVA]
 Short Circuit Current Ik [kA]
 Subtransient Short Circuit Current Ik* [kA]

Psi [deg.]
 R/X - Ratio
 X/R - Ratio

Other data
 Values used to calculate necessary cable capacity based on the power feed-in of WTGs

Default CosPhi used for WTGs with no eGrid data

Increase factor
 none
 power curve maximum
 10 min maximum
 1 min maximum
 instant maximum

Default Increase factor used for WTGs with no eGrid data

Voltage level name:
 Frequency (Hz):

Voltage levels that can be used in current grid (when inserting transformer objects):

Level Name	Nominal voltage (kV)	+ %	- %	Line Style
High Voltage	110	3	5	
Medium Voltage	20	5	10	

Figure 1 User interface of an External Grid

The External Grid represents the basic component of the whole grid. Due to the fact that there will be only one External Grid object in most of the projects, this object is not only being used to enter the parameters of the connection point itself like e.g. short-circuit power and frequency. Additionally ALL voltage levels to be used in the later designed grid as well as a default ‘increase factor’ and a CosPhi-value for the WTGs have to be specified. Considering the ‘increase factor’ and the CosPhi-value, minimum cross sections of cables are proposed performing the cabling of the grid (Cable Cross Section Assistant).

Naturally, it is possible to enter several External Grid objects e.g. to describe alternative connection possibilities. Doing so, the External Grid object which shall be considered in a calculation has to be chosen in the calculation setup, defining the calculation itself.

For the parameter input, different input alternatives like the specification of the short-circuit power S_k or the sub-transient short-circuit power S_k'' as well as the grid angle Ψ_k or the R/X-ratio are presented.

After data entry of all nominal voltage levels in the grid, which can be designated to an individual colour and displayed using this colour at the map, the nominal voltage for the External Grid as well as all other grid objects can be assigned using convenient drop-down menus.

Furthermore, it is also possible to designate the maximum allowed voltage variation to each voltage level. The compliance to this range is being checked for every single grid node after a calculation. The maximum allowed voltage levels can also be given at the time when the calculation is started.

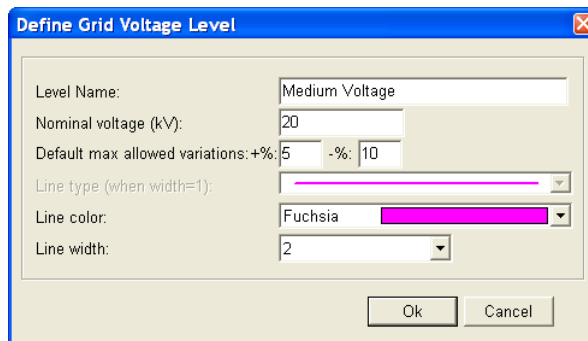


Figure 2 Definition of a voltage level. The name is free text, choosing e.g. “high”, “medium” “low” or similar, allow the user to redefine voltage levels without having incompatible names related to the specified voltages.

10.1.2 Input of a Transformer



After placing a transformer, the user interface for the entry of the relevant data (figure 3) appears.

The electrical data of a transformer is subdivided into three tabs. Information about the data source as well as a description can be included in a fourth tab. The first contains more or less standard information like manufacturer, short name, type, rated power, nominal frequency and rated voltages. Based on this information, the file name of a transformer is being produced, when you have specified a new transformer.

Transformer data	Values
Manufacturer	
Short name	
Type	Oil
Rated Power Sr (MVA)	25
Nominal Frequency (Hz)	50
Rated Voltage high (kV)	110
Rated Voltage low (kV)	20

Figure 3 User interface of a Transformer – Tab “Main specifications”

At the top of the user interface, a direct access to the transformer catalogue is given in order to choose a transformer. Under it, specifications of the nominal grid values have to be made. Due to the data input in the External Grid element, this is easily done. It is also possible to select the same voltage level for both sides to create an e.g. 20/20kV transformer in case of the utility demand to have a galvanic separation between the wind farm and the grid of the utility.

In main specifications the data giving the unique description of a transformer is given, like manufacturer, type etc. The main figure to enter here is the rated power (S_r) in MVA. For a wind farm of 10 MW with a $\cos(\phi)$ of 0,9, the minimum needs will be $10/0,9 = 11,1$ MVA. The rated voltages are the ones the transformer is designed for, but it can typically be used also for slightly different voltage levels.

The second tab includes data about the resistance of the transformer like short-circuit voltage and copper losses. Here, several input alternatives are presented.

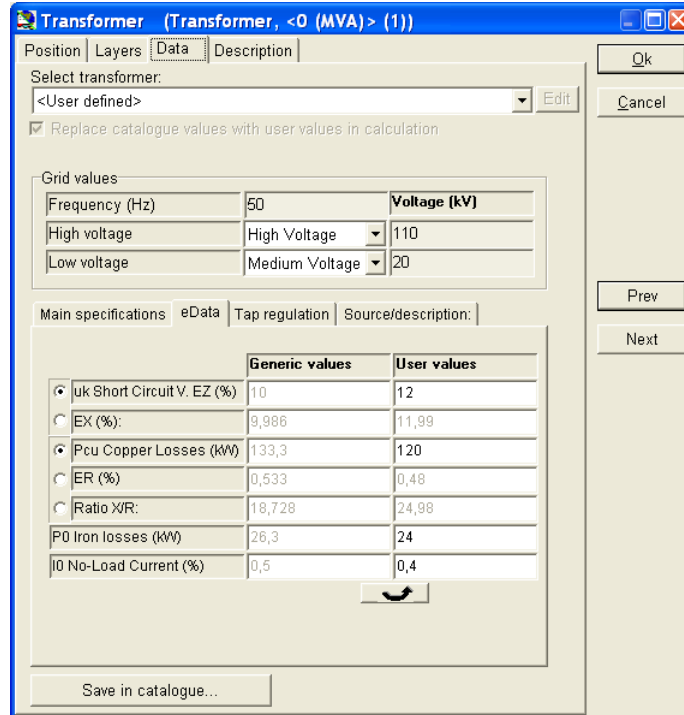


Figure 4 User interface of a Transformer – Tab “eData”

The electric specifications of a transformer basically consist of the reactance (X) the resistance (R) and the iron losses. The two first can be specified in different ways, see input form. Based on evaluation of the parameters for a number of transformers, formulas for calculation generic values have been developed and the software can calculate the values based on these automatically.

The third tab contains information about the transformer tap positions as well as the vector group.

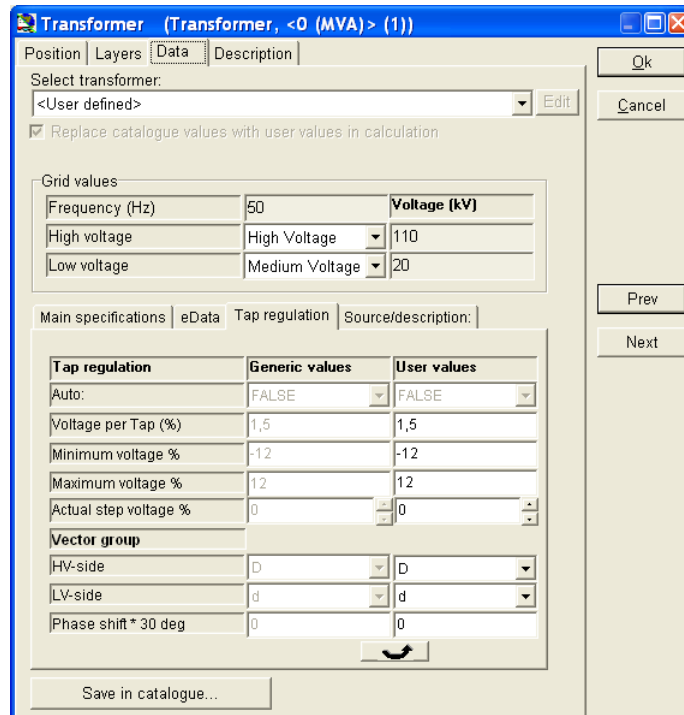


Figure 5 User interface of a Transformer – Tab “Tap regulation”

Tap regulation

Tap regulation mean that a transformer can be set to different transformation levels. This is used in a grid to adjust voltage drops in the grid. In a traditional consumer grid, the transformers nearest the high voltage substation will typically be set to decrease the voltage level further to the nominal decrease, while the ones at a long distance from substation will be set to increase relative to the nominal decrease to compensate for the higher voltage drop of the high voltage line from the substation.

Transformers at higher voltage levels (sub stations) typically can auto adjust the transformation level based on the actual load. In the first eGRID version, the user has to set the tap regulation manually. At a later stage it is planned to let the software automatically calculate the tap setting for these types of transformers.

Vector group

The vector group describes the construction of the transformer, how the windings are established at the high and low voltage side. These can be found in the transformer manufacturer catalogue and often the transformers can be delivered based on user specifications.

Save in catalogue

Via this button, a direct access to the transformer catalogue is given. It is possible both to select a transformer, which is stored in the catalogue or to store a transformer, defined using the several registers of this window, directly in the catalogue. For this, simply click on the button "Save in catalogue". An individual input can also be done by selecting a transformer from the catalogue, and choose the option "Replace catalogue values with user values in calculation" and then modifying the necessary data.

10.1.3 The Transformer Catalogue

As default, the transformer catalogue browser appears like depicted.

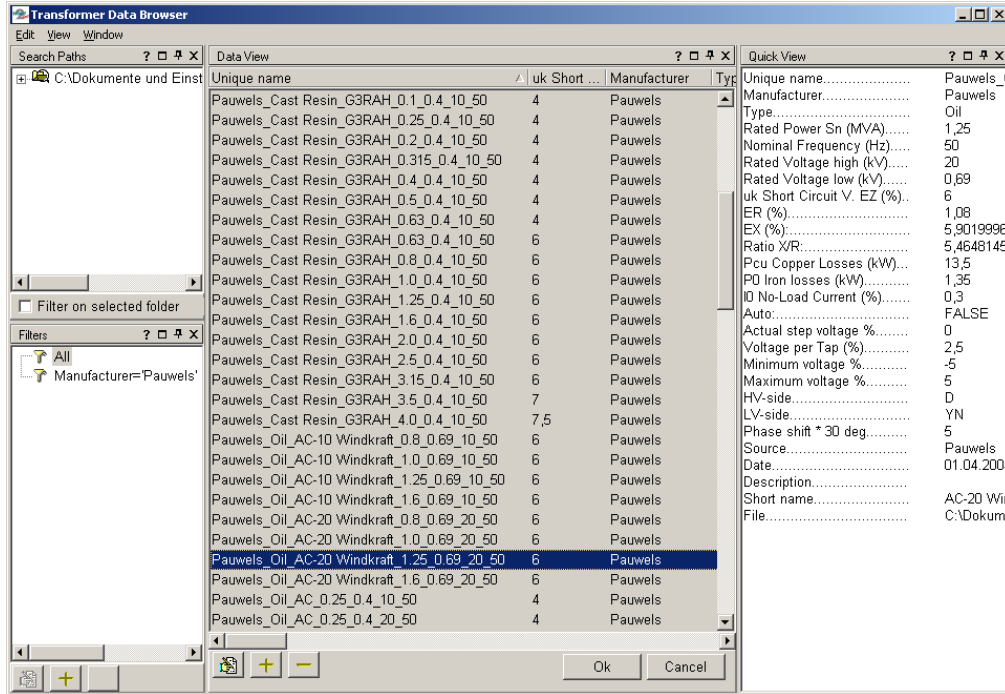


Figure 6 Browser of the Transformer Catalogue

At the upper left side, search paths can be defined. Within these paths, WindPRO is searching for relevant transformer data. Based on bad experiences with closed catalogues, the transformer data is located using individual files. Using the option "Filter on selected folder", solely the data sets which are located directly in this folder (without sub-folder data) is being depicted. At the lower left side, a search filter can be defined. A quick view of the selected transformer is presented at the right side. A transformer is chosen, by performing a double click at an entry. Using the right mouse button, you get access to the editor menu of the catalogue for editing and e.g. modifying the transformer data. As in the Windows-Explorer, the main information of the chosen transformer can be copied to the clipboard.

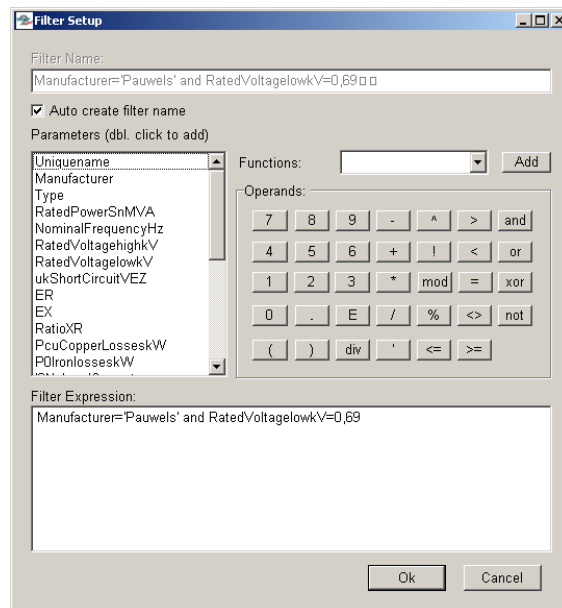


Figure 7 Search filter definition within the Transformer Catalogue. Double click at the parameter to get it into the filter expression and then add the expression.

Up to now, more than 1000 transformers are implemented in the catalogue. In order to find a specific transformer in the catalogue, free-defined search filters can be specified by using e.g. the type, material, name, short name, manufacturer, voltage levels, apparent power, etc.

The upper entry is being used for the name of the search filter. If selected, WindPRO will create this name automatically (Auto create filter names have to be activated). User defined names is optional. The search parameters for the definition of several search criteria are located in the left field. They are selected by a double click, e.g. on manufacturer. Now, you have to enter the condition of this parameter (e.g. = 'Pauwels'). After this, any other conditions e.g. a rated voltage at the low voltage side of 690V (RatedVoltageLowkV = 0,69) can be defined.

10.1.4 Input of a WTG, especially the WTG eGRID data



(Please read chapter 2 „BASIS“, part 2.5.2 for input of WTGs in general). It must be pointed out that eGRID makes no differences between new and existing WTGs.

For simple grid configurations or rough survey calculations, e.g. if only one type of WTG is being used in a wind farm or all turbines feed-in with the same power factor, it is possible to make all inputs, which are required for the calculation directly within the calculation definition, neglecting internal WTG transformers or using automatically generated generic transformers (please have a look at chapter 10.2 Calculation and Input of Calculation Properties). Thus, the generation of the following described eGRID data category isn't necessary under these circumstances.

The wind turbine catalogue has been expanded by an information category eGRID within the detail data. The required electrical data can be taken out of measurement reports dealing with the electric measurement of the individual WTG. In practice there are three different measurement protocols: A protocol which bases on IEC 61400-21, a protocol which bases on MEASNET guidelines and a measurement protocol published by the German "Fördergesellschaft Windenergie e.V." called FGW. In meantime, the last protocol was updated to the IEC protocol, so that it can be handled like this. In contrast to the IEC protocol, the MEASNET protocol contains additional data about harmonics and interharmonics. Due to the fact, that eGRID doesn't calculate any harmonics, the actual protocols are handled identically. There is only a separation from the old FGW protocol.

The category eGRID implements five tabs. The first tab contains data of the generator type as well as the power peak factors of the wind turbine. In this connection, it has to mentioned that no differences between the real power factor λ and the power factor $\cos\phi$ are being made for new WTG types. This factor is called $\cos\phi$ (CosPhi) within the eGRID module in general.

Also the short-circuit contribution which is being set to the generic values at this tab. If you have detailed information about the short-circuit parameters of the WTG, you are free to enter your own data. Additionally, you have to select if the used measurement protocol bases on the old FGW or on the new FGW, IEC or MEASNET guideline. Please note that data input at tabs "Flicker" and "Switching" will be different based on this selection.

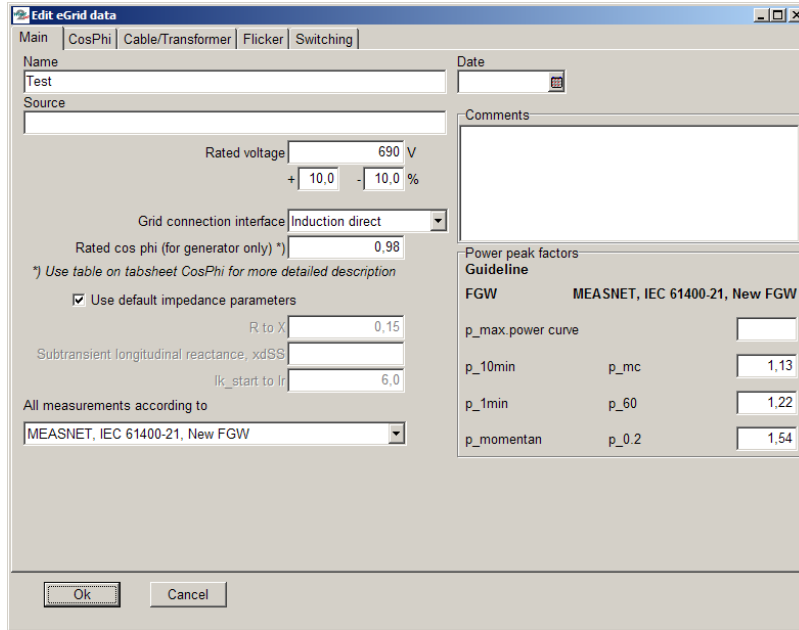


Figure 8 User interface of the WTG category eGRID – Tab “Main”

The second tab deals with the detailed information about the power factor in case the part-load operation as well as the operation of a WTG as a load shall be examined. For this purpose you have to uncheck the checkbox and select the way you want to enter the power data (active power, power factor, reactive power, apparent power).

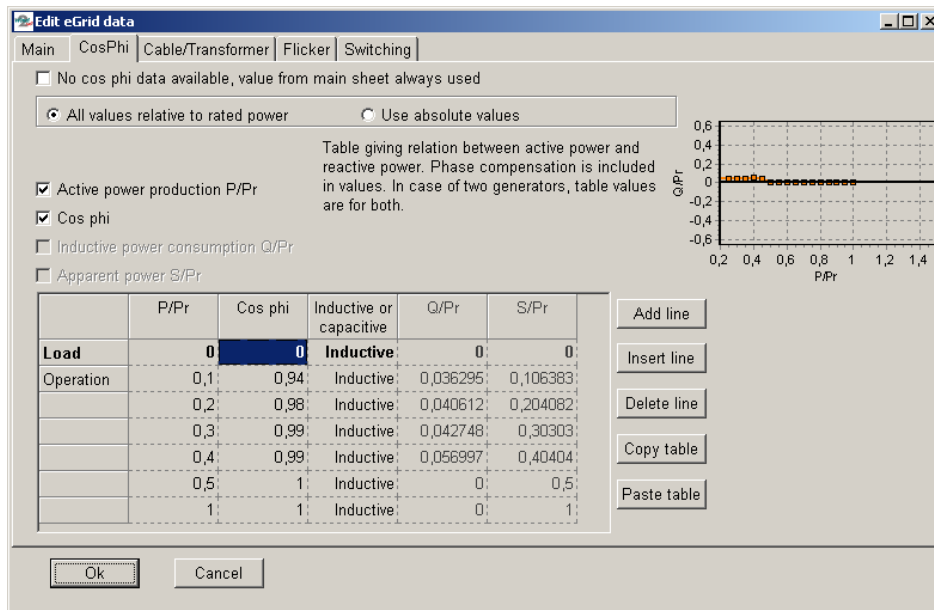


Figure 9 User interface of the WTG category eGRID – Tab “CosPhi”

The first row implements the WTG operation as a load. All other rows describe the trend of the CosPhi depending on the power. Necessary interim values, used for the calculation, are computed by linear interpolation.

Information about WTG internal objects; generator, cables and transformers can be entered by selection of the appropriate objects from the data libraries at the third register sheet. These data is only needed for calculation of internal voltages, losses etc. inside the WTG. This is normally not a requirement for documentation of the grid connection of a WTG, but it is an option for e.g. manufactures to help design the “inside” electric system of the WTG. Note that the electric power curve for a WTG normally gives the power output at the low voltage level at the WTG. Sometimes, the measurement protocols are based on the high voltage side of the transformer, e.g. 20kV. So, the power curve should include the losses in the build in transformer – this it might not always be so.

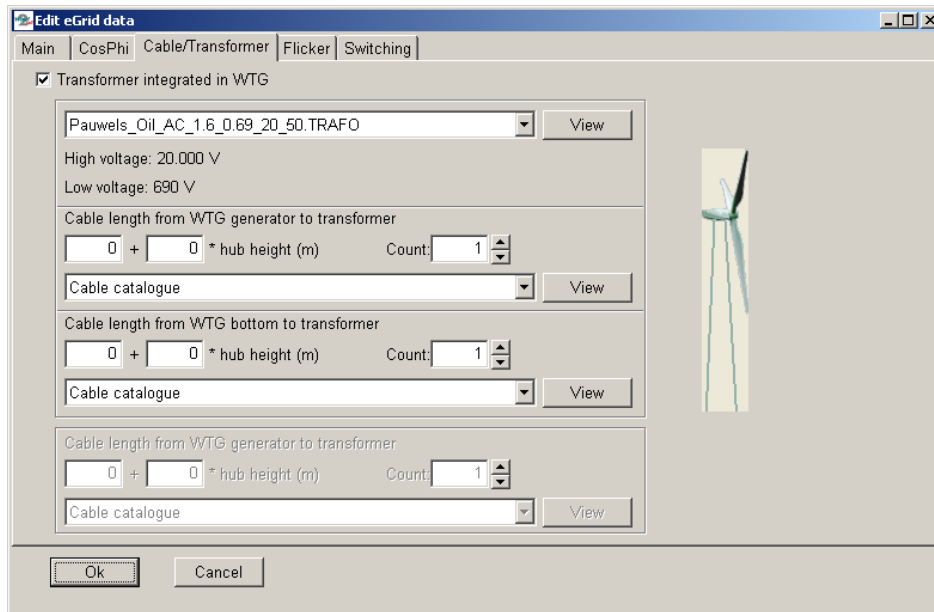


Figure 10 User interface of the WTG category eGRID – Tab “Cable/Transformer”

The fourth tab implements the flicker data. Please note that the user interface as well as the input data are different concerning the chosen measurement protocol (refer to the description of the Main tab). Using the old FGW measurement protocol, three kinds of flicker data specification can be handled:

- declaration of a flicker factor and a flicker angle
- flicker factor independent from the grid angle
- flicker table

Entering data based on the new FGW, MEASNET or IEC protocol, a data table dealing with the flicker factors at different mean wind speeds and several grid impedances has to be completed.

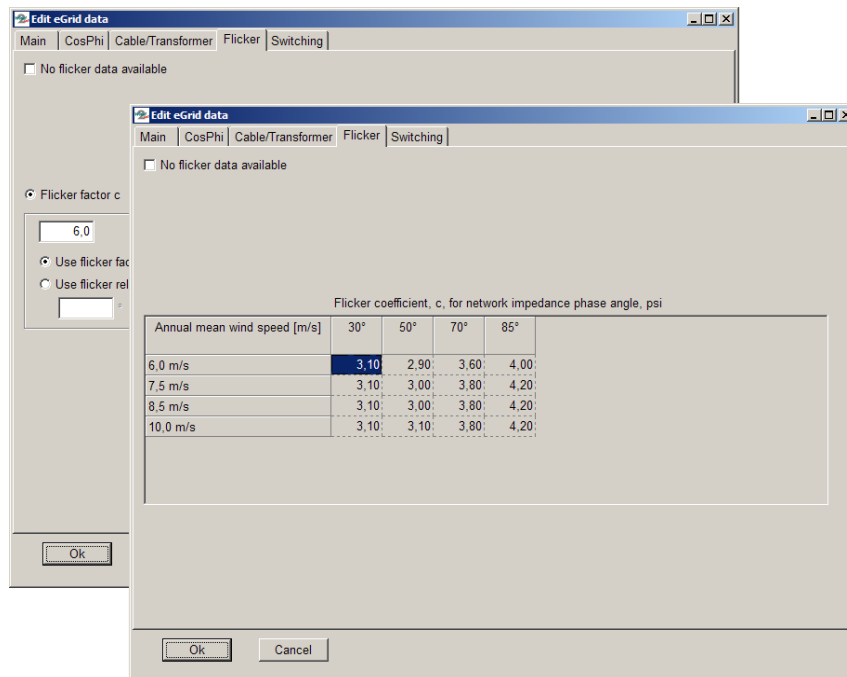


Figure 11 User interfaces of the WTG category eGRID – Tab “Flicker”

The data used for the calculation of voltage variations due to switching effects has to be entered in the fifth tab. Again, the input data are different concerning the chosen measurement protocol.

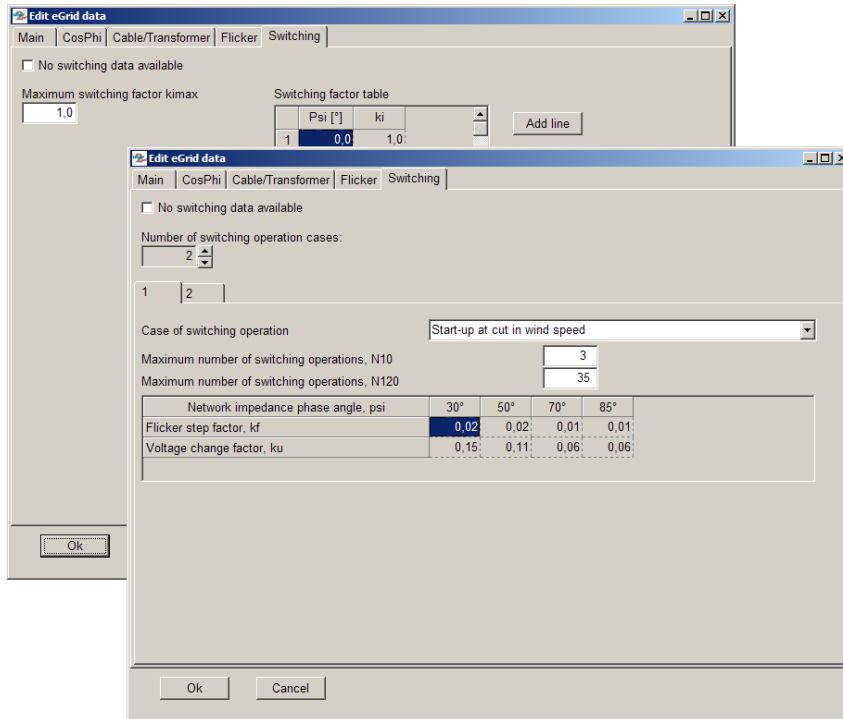


Figure 12 User interfaces of the WTG category eGRID – Tab “Switching”

Defining a corresponding “Flicker” or “Switching” calculation, no input – neither choosing an annual mean wind speed for the flicker calculation nor selecting a switching reason for the individual turbines – is necessary. Every single item is considered in the calculation automatically. As usual, generic values can be defined in the calculation setup for WTGs which don’t have the corresponding data in their data sets.

10.1.5 Input of a Load



The electrical data of a load is subdivided into two tabs. The first contains the nominal data of the load. For this, several input possibilities are provided. Additionally, it is possible to consider this load in part within the calculations as free-definable percentage values of active and reactive power values by choosing ‘Part load enabled’.

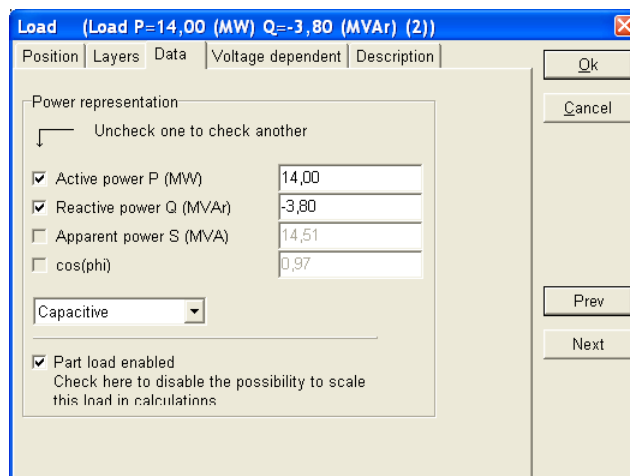


Figure 13 User Interface of a Load – Tab “Data”

You only have to enter parameters within the Data tab, if you want to define the load as voltage dependent - a load is defined as voltage independent as default. By doing so, the rated voltage and six parameters have to be entered in order to describe the load characteristic based on the equations:

$$P = P_R \cdot \left(K_{0P} + K_{1P} \cdot \left(\frac{U}{U_R} \right) + K_{2P} \cdot \left(\frac{U}{U_R} \right)^2 \right)$$

$$Q = Q_R \cdot \left(K_{0Q} + K_{1Q} \cdot \left(\frac{U}{U_R} \right) + K_{2Q} \cdot \left(\frac{U}{U_R} \right)^2 \right)$$

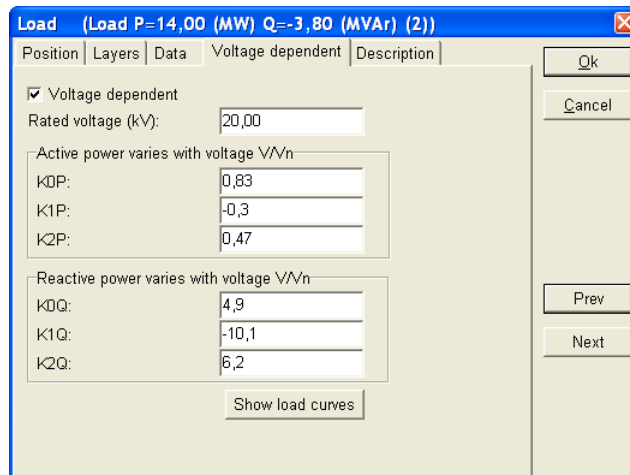


Figure 14 User Interface of a Load – Tab “Voltage dependent”

The defined load characteristic is pictured by selecting ‘Show load curves’. You are free to zoom in or out within the range of 0.8 to 1.2 of the rated voltage as well as to modify the chart to your individual demands by changing the parameter values of the load characteristic or performing a double click at the chart.

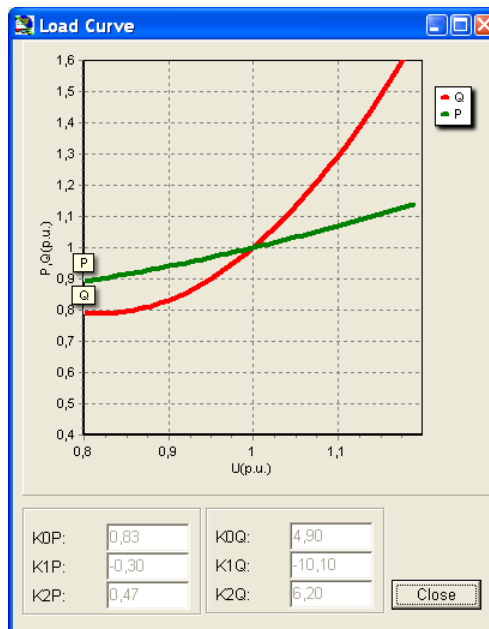


Figure 15 Presentation of voltage dependent Load Characteristic

10.1.6 Input of a Bus bar



After placing a bus bar, a separate window dealing with the position of this object appears. A bus bar doesn't contain any electric data. It is just a way to merge more electric cable/lines into one or make a star connection.

It should be mentioned that a bus bar is automatically generated when connecting one cable/line type with another.

10.1.7 Input of an Electric Grid



This object is the most “advanced” and the “centre” for designing the grid connection. The object works slightly similar to the line object in WindPRO (for height contour lines etc.). This means that the object just is a “fixpoint”, that can be placed anywhere on the map. When data (cables/lines) shall be entered or edited, the object must be in edit mode. When it is in edit mode, the data belonging to this object is the only ones that can be reached. So the object needs to be taken out of edit mode before other actions can be taken.

NOTE: An important difference to the line object with height contour lines to be aware of: Activating a line for changing properties do ONLY work on the line between two nearest points, not the full line. If you want to change properties for a “full line” select “Extend to whole cable line” in the right click menu.



Electric grid object on map – right click on object to get MENU or select (by left click on object) and press <Ctrl> + <e> to activate EDIT mode



Electric grid object on map in EDIT mode shown by a red dashed line around the object – the little black square in the middle shows the object is selected. <Ctrl> + <e> deactivate always EDIT mode (no selection needed).

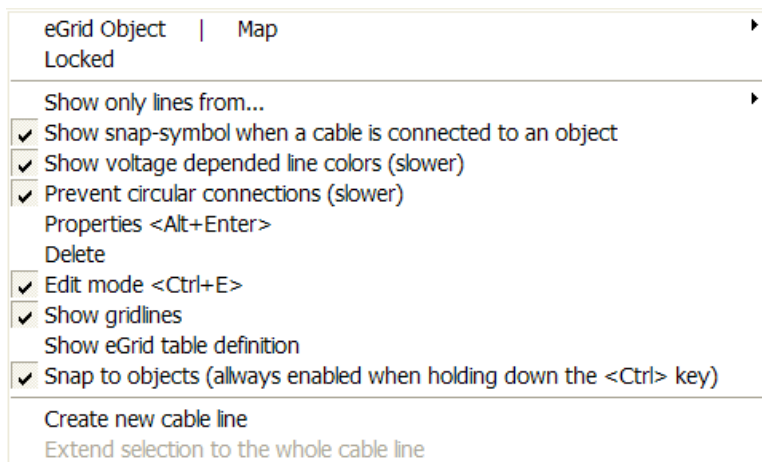
In general, the different connection possibilities (cable and overhead lines) are handled identically. In the automatically length calculation, taking end extension and “hanging lines” into consideration, different values can be defined for cables and overhead lines. Besides this current limiting factors for cables due to the surroundings (condition of ground) and e.g. isolation material in cable, can be given detailed, while overhead lines only can be limited by a power factor in the first version of the eGRID module.

In order to simplify the description, only the term cable is being used in the following.

After placing the object, the object properties appear. Here, you can select whether the connection of a WTG to a cable shall be checked or not on the basis of the rated voltage of the turbine. For this check, the WTG has to contain one eGRID data set. Turbines without electrical data can generally be contacted. Using slow computers or extensive grid structures, the check should be deactivated depending on the performance of the computer. Editing the properties of the Electric Grid object this is possible at any time.

After the placement, the Electric Grid object is in edit-mode, i.e. cables and overhead lines can be created for this object or previously created connections, belonging to this object, can be modified. Both happen predominantly by means of the context menu after clicking the right mouse button. Another possibility to create or handle connections is the connecting table, which will be described at the end of this chapter.

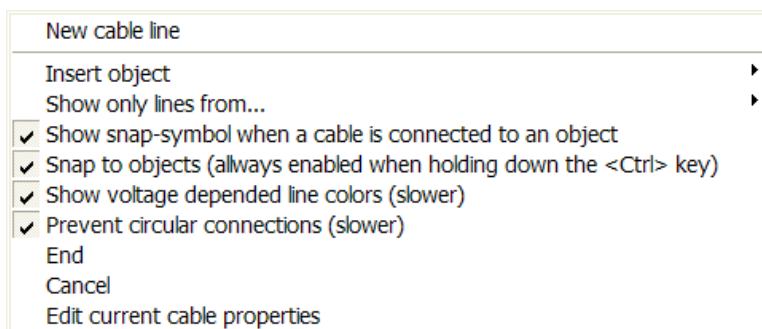
The right click menu



There are many options in the right click menu. Note that the menu depends on the situation, from which the menu is activated. Here shown from “scratch”, where no cables yet are established.

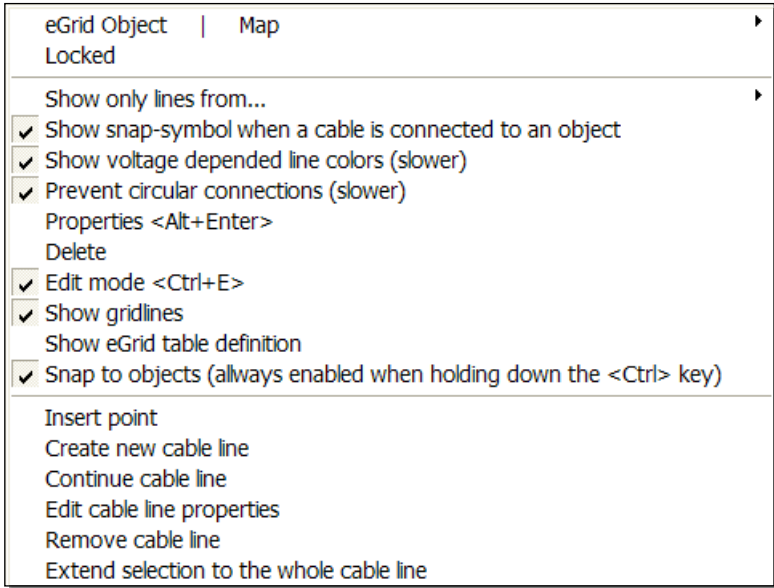
First time use will be to place cursor where a new line should be created, then right click and chose menu “Create new cable line”. As a result, the user interface for the input of the cable parameters is being opened (see later). If the cable was generated at an object, this object is registered automatically as starting point of the connection.

After the parameterization of the cable is finished (explained later), simply mark the cable route by clicking on your map on the screen. If the option “Snap to objects” is activated in the context menu or by pressing <Ctrl>, the unconnected end of the cable jumps to the nearest object, which can be connected based on the voltage level and the grid topology – the input of meshes is prevented. The connection to an object does not finish the digitizing process in order to accelerate the wiring of several objects with the same type of cable. A semi-circle around the connected object visualizes the connection of this object to the cable. In order to finalize the wiring process, the item instruction “End” has to be chosen within the context menu.



Right click when digitizing to get this menu. “End” will just stop digitizing, while “insert object” will give you the option to e.g. establish a transformer or WTG at the end of the cable – and afterwards continue with a new cable.

Selecting an existing connection by one mouse-click on the cable, the cable itself is being set into edit mode.



The menu at right click at a cable after activating this – clicking at a point will include the menu: “Remove point” instead of “Insert point”. Choosing “Edit cable line properties” give access to the cable input form explained after next figure. You also can perform a double click at the activated cable to open the cable line properties.

All points of the cable are represented and can be dragged with the mouse for more accurate positioning of the cable.

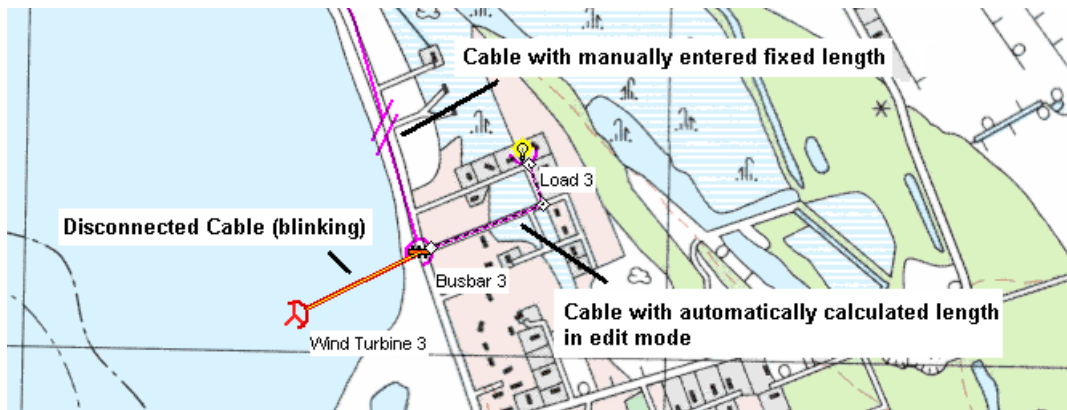


Figure 16 Different cable modes

10.1.7.1 Cable parameters

The cable parameters are differenced between laying and electrical data. The laying parameters like the terminator points of the cable, length, current limiting factors and the number of parallel layed cable systems (“number of parallel cores per phase) appear on the left side of the window.

Based on the electric data of typically used cables (systems of three single core cables in trefoil formation; type N2XS(F)2Y or NA2XS(F)2Y), you have access to “cable size calculator”, which is located in the left side of the window. It is explained in a separate section following this.

The right side contains data about the cable itself like e.g. name, structure and electrical data. Please note that the item “number of cores” deals about the cable design itself whereas the electrical data are given about a three-phase system. This can be one three-core cable as well as a system of three single-core cables in trefoil or flat formation. The laying mode of a system of three single-core cables (trefoil or flat) is being described at the tab “Source/description”.

The screenshot shows the 'Cable/Line definition' dialog box. On the left, under the 'Main' tab, there are several input fields and checkboxes. The 'From' field is set to '<7> WEA 7' and the 'To' field is '<19> Bus Bar, <20 (kV)> (5)'. The 'Length incl. extensions (m)' is 147, and the 'Limitation factor' is 0.81. The 'Number of parallel cores per phase' is 1, and the 'Aimed capacity (MVA)' is 4.35. There are two options for 'Max. voltage drop (%)': 'Max. voltage drop (%/km)' at 0.20 and 'Max. voltage drop (%)' at 2.00. The 'Short circuit duration (s)' is 1. Below these are fields for 'Cross section needed (mm2) due to' with values for '-aimed capacity' (39), '-max. voltage drop' (2), and '-Short circuit power' (140). On the right, the 'Select cable' dropdown is set to 'ABB_NA2XS(F)2Y_AI_150_20_50 Cable'. There are checkboxes for 'Replace catalogue values with user values in calculation' and 'Use Generic data'. A table shows 'Cable/Line data' and 'Catalogue values' for various parameters like Short name, Manufacturer, Insulation material, Material, Cross Section/Core (mm2), Nominal voltage (kV), Frequency f (Hz), and Number of cores.

Figure 17 User interface of a Cable – left side the laying data, right side the cable properties. Note: when checking “use Generic data”, cable – line data will be calculated automatic and updated automatic when a calculation is started so just the needed size is used.

As in the transformer menu, direct access to the cable catalogue is also provided. Again, it's possible to select a cable available in the database or to store a cable entered within this window directly into the catalogue. Also, an individual input can be made by selecting a similar cable from the database and choose the option “Replace catalogue values with user values in calculation” and then modify the necessary data.

Like for the transformers, based on an evaluation of the parameters for a number of cables and overhead lines, equations for calculation generic values have been developed and the software can calculate the values based on these automatically. Nevertheless, deactivating “Use generic data”, you can enter your own values.

The length can be calculated automatically based on the digitised cable on the map, which is recommended. But if a connection to a substation far from site is required, which is outside the map, the length can simply be entered and the end of the cable can just be put on an arbitrary spot at the map.

The length calculation gives different options for extensions of cables and lines. The elevation of the individually digitizing points is included in the length calculation if a digital height model (DHM) is established in a line object. But the contours between two digitizing points are NOT taken into consideration, so an exact calculation requires that enough digitizing points are established. Furthermore, a percentage offset can be entered at the tab “Length” (based on the fact that it is not possible to lay a cable as a straight line like drawing it on the map) as well as an absolute offset can be specified e.g. in order to take care about connecting the cable in a transformer cabinet.

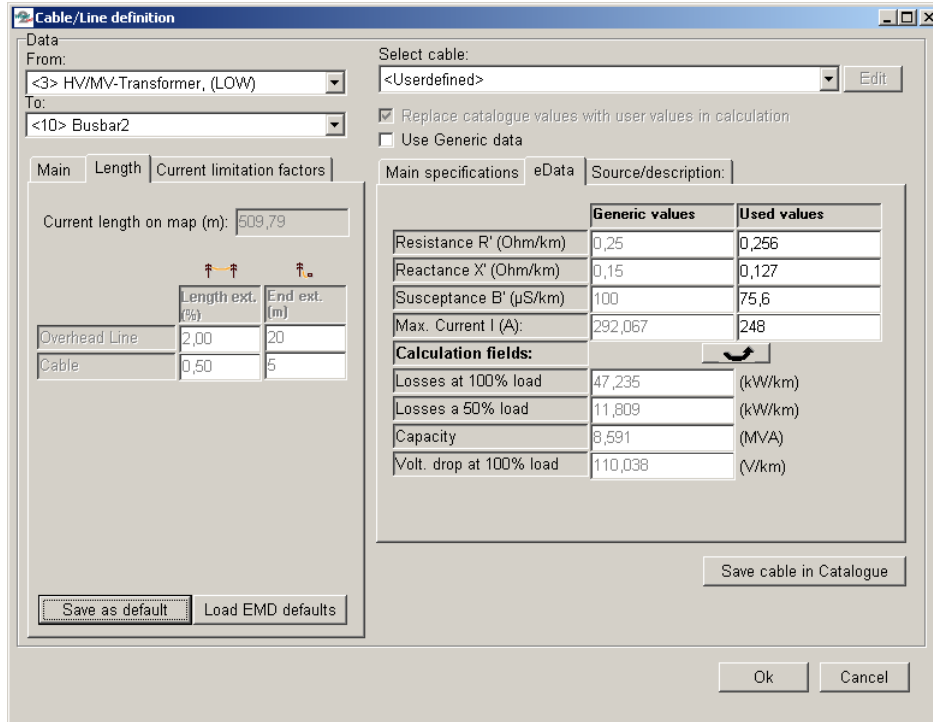
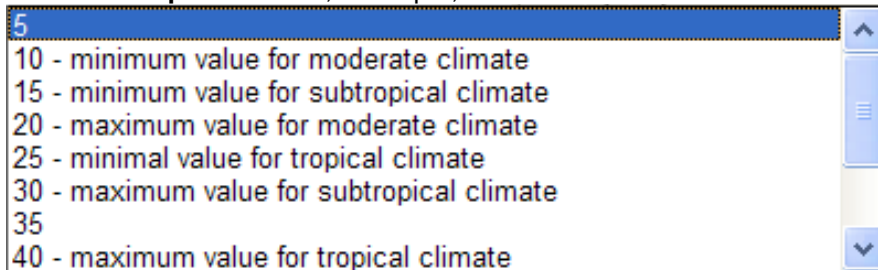


Figure 18 User interface of a Cable – left Tab “length”, right tab “eData”

At the tab “Current limitation factors”, several factors are combined. These factors should be considered in order to prevent cable overload which can lead to an accelerated aging of the cable or – in extreme case – heating-up resulting in melting the isolation material. The reduction factors are based on;

Ambient temperature in 0,7 m depth, see choices below:



Number of parallel 3-phase systems

Based on the data of several manufacturers, a fixed distance of 7 cm distance has been chosen concerning laying the cable directly in ground; if the distance differs from 7 cm, the user may try to be a little creative finding a suitable value, and at the final dimensioning consult the handbooks from the cable manufacturer. Note: the number of parallel 3 phase systems might differ from the number specified at main tab sheet, while there might be other cables, not included in this calculation, OR there might be more parallel 3-phase systems, but buried in separate channels or at a distance so large, that the influence shall not be taken into consideration.

In case the cable is being laid in a duct, the limitation factor also depends on the system sizes

The k-factor based on more parallel systems laid together is influenced by the laying – if it is in the ground or in a duct, and if the cables are of similar size.

Soil thermal resistance – here some different defaults are available. Input is divided in moist area, the “remote surroundings” and the dry area, the near cable surroundings, that is dry due to that the cable heat up this part of the soil. The last mentioned often differ from the original surroundings due to that the cable in laid in a bed of sand or other material that gives the cable better conditions.

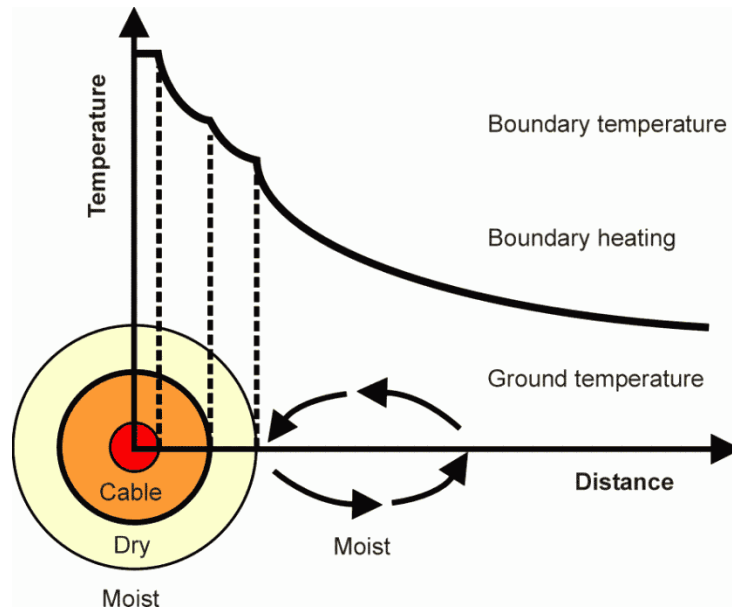


Figure 19 The cables heat up the near surroundings making this a dry area, which influences the transportation of heat from the cable.

Load factor might be the most important one. Hereby, it have to be mentioned that the maximum current values of a cable is presented by the manufacturers based on a so-called utility load, a special load condition with a medium power value of 0.7 times the maximum power value. It relates to a traditional consumer system, where full load only will be in peaks of maybe a few minutes. Due to the fact that a maximum power output has to be assumed for WTGs based on the fact that WTGs are able to feed-in maximum power over a long time period. This maximum load forces a current limitation factor of 0.81 which is automatically being used for all cables.

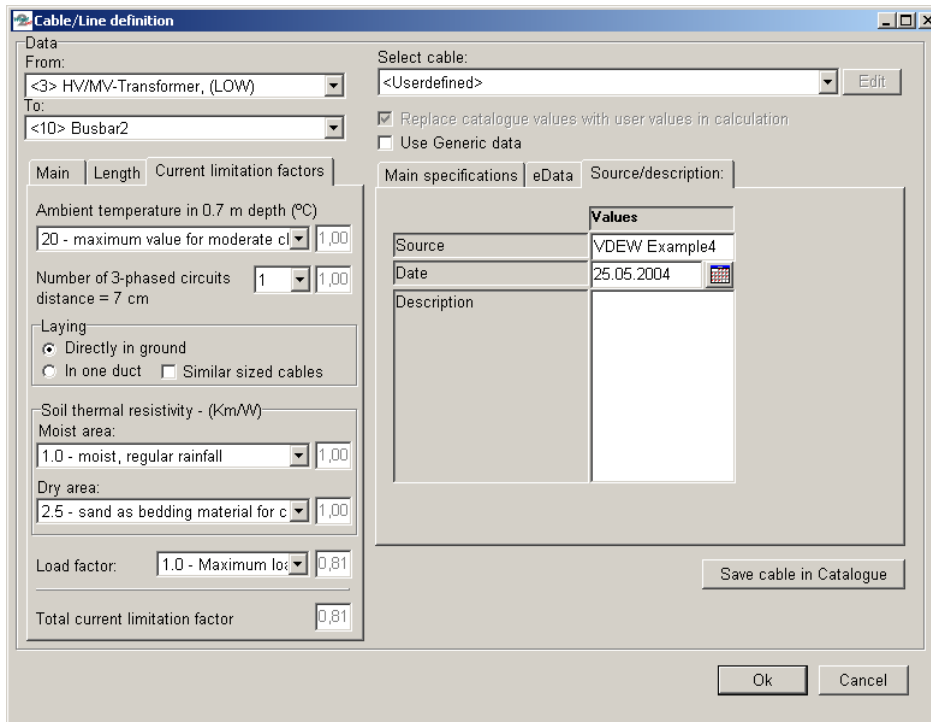


Figure 20 User interface of a Cable – left Tab “current limit factors”, right tab “Source/description”

Note: The current limitation factor is only be calculated for cables. You can enter a value at the main tab sheet for overhead lines – consult the line manufacturer to get this value. Additionally, the calculation of the total current limitation factor doesn’t relate to a special norm in detail. Several limitation factors given by different manufacturers are taken in order to provide a good reference value. Unfortunately, every single manufacturer provides only some and not all limitation factors. Furthermore, there is an interaction between several limitation

factors in reality, which is not being considered by the software. Due to this, the presented total limitation factor might not be the exact one but it offers definitely a good reference value.

10.1.7.2 Cable size calculator

An important feature at the left side of the cable input form is the cable size calculator. The calculator automates or gives assistance for dimensioning the size of a cable. Based on selected conductor material (copper or aluminium), the aimed capacity, which can be calculated automatically or set by the user, the maximum aimed voltage drop and the short-circuit current in case of a fault, the necessary cable size (cross section in mm²) is being calculated by the program based on the following cable properties:

- System of three single-core cables in trefoil formation
- Maximum cable temperature: 90°C
- Medium voltage level (10-70kV)
- Grounded at both ends
- Ground temperature: 20°C
- Buried directly in ground
- Laying deep: 0,7m (1m)
- Thermal resistivity of soil (moist area): 1,0Km/W
- Thermal resistivity of soil (dry area): 2,5Km/W
- Load Factor: 0,7 (utility load)
- Total current limitation factor as defined in the corresponding tab sheet taking into account the variations from the manufacturer data listed before

In general, the cross sections of cables which carry the energy of several WTGs are determined on the basis of the current values under normal operation condition. Based on the low current values of cables which are connected to a single turbine or only a few WTGs, the dimensioning of these cables would be too small. Here, the short-circuit operation has to be taken into account. Additionally, the voltage drop will be a dominating item for long cables. Using “generic values” (in the preliminary design phase), the tool will automatically update the values before calculation, when the cable layout is changed. This makes the assistant very efficient. The user do not need to care about cable dimensions before the final layout is decided, and “real” cables might be selected from the catalogue or entered for the final calculation.

When not using generic data, but “user defined”, the user can decide which of the calculated values (based on capacity or voltage drop) shall be used, or enter a value manually. Choosing from cable catalogue, the cross section of the corresponding data set is being used. Nevertheless, the assistant still nominates a size which should be taken from the catalogue. So, this information can be used to check your choice.

In general, using the cable size calculator the whole cabling can be performed only selecting e.g. the properties “type=cable” and “material=aluminium” after placing the WTGs in order to provide basic values for the capacity calculation of the cables.

Please note that the assistant considers only the normal load-flow operation and not a short circuit situation if the short-circuit power of the External Grid is set to infinite, i.e. only the normal feed-in of all WTGs to the External Grid object is being used for the cross-section calculation. This leads to very small cross-sections for cables which are connected to stand-alone WTGs. Additionally, the assistant presents just calculated cross sections – not normed values. Also, the power value of the WTGs which is specified in the properties of the External Grid is used to estimate the cross sections. In general, the 10-minute mean maximum power output of the WTGs should be used based on standard guidelines. If a WTG data set contains electrical data, the specified data are used (incl. the CosPhi-value). Otherwise the factors which are specified in the External Grid are taken.

10.1.8 Cable/line catalogue

The structure of the cable/line catalogue follows the one for the transformers, see section 10.1.3.

10.1.9 Cabling Table



As an alternative (or supplement) way to design the grid, the cabling table can be used. The table is activated by the corresponding button in the LEFT menu bar. In case of several existing Electric Grid objects in one project, you have to choose the object, which shall be shown.

Length	From Object	To Object	L. Factor	Cable Description
94	# <16> External grid (2)	* <11> WEA 10	0,9	<20 kV>, <240 mm²>, <A
381	* <11> WEA 10	* <12> WEA 11	0,77	<20 kV>, <150 mm²>, <A
234	* <12> WEA 11	* <13> WEA 12	0,9	<20 kV>, <150 mm²>, <A
357	* <11> WEA 10	# <17> Bus Bar, <20 (kV)> (5)	0,77	<20 kV>, <150 mm²>, <A
253	# <17> Bus Bar, <20 (kV)> (5)	* <10> WEA 9	0,9	<20 kV>, <150 mm²>, <A
179	# <17> Bus Bar, <20 (kV)> (5)	* <9> WEA 8	0,9	<20 kV>, <150 mm²>, <A
324	* <9> WEA 8	# <18> Bus Bar, <20 (kV)> (6)	0,9	<20 kV>, <150 mm²>, <A
202	# <18> Bus Bar, <20 (kV)> (6)	* <7> WEA 6	0,9	<20 kV>, <150 mm²>, <A
186	* <7> WEA 6	⚠ <15> WEA 13	0,9	<20 kV>, <150 mm²>, <A
122	# <18> Bus Bar, <20 (kV)> (6)	* <8> WEA 7	0,9	<20 kV>, <150 mm²>, <A
143	* <8> WEA 7	# <19> Bus Bar, <20 (kV)> (7)	0,9	<20 kV>, <150 mm²>, <A
196	# <19> Bus Bar, <20 (kV)> (7)	* <6> WEA 5	0,9	<20 kV>, <150 mm²>, <A
253	# <19> Bus Bar, <20 (kV)> (7)	* <5> WEA 4	0,9	<20 kV>, <150 mm²>, <A
242	* <5> WEA 4	# <20> Bus Bar, <20 (kV)> (8)	0,9	<20 kV>, <150 mm²>, <A
240	# <20> Bus Bar, <20 (kV)> (8)	* <4> WEA 3	0,9	<20 kV>, <150 mm²>, <A
46	# <20> Bus Bar, <20 (kV)> (8)	⚠ <3> WEA 2	0,9	<20 kV>, <150 mm²>, <A

Figure 21 Cabling Table

After checking one or several cables (Multi Edit function) and selecting “Edit Checked Cable(s)”, the already described user-interface of a cable appears with the exception that using several cables the start and end points are deactivated. Please take care about the fact that all – not only the modified – settings in this window will be allocated to the selected cables after pressing “OK”.

In order to generate a new connection, after selection of “Create new cable”, the start and end point can be indicated in the appearing parameterisation window.

Apart from the cabling options and the possibility to edit or delete objects, the cabling table contains another important characteristic: Elements can be generated, which do not appear on the map. This characteristic has been introduced for objects where no information is available, e.g. just having the information: “The wind park can be connected via a 4.5 km cable to a grid with the following parameters ...”. A connection of such objects is only possible by using the connecting table.

10.2 Calculation and Input of Calculation Properties

10.2.0 Introduction to calculations



After designing the grid and connecting to the relevant objects, go to the calculation menu. Here click on the green arrow at “eGRID” (if it is yellow, it means that you do not have licence for this module installed.)

Limiting values and calculation guidelines valid for the calculation have to be defined mainly at the tab sheet “Main”. Each calculation, selected within this tab sheet, leads to a further tab sheet at which the respective settings relating to the calculation properties as well as limit values for this calculation can be seen and changed, if necessary. A final decision about the grid, which shall be calculated (if more alternatives established), has to be made in the tab sheet “Grid objects”. Here it is also possible to chose between alternative wind farms if more alternatives, or to deselect one or more WTGs in the relevant calculation. In the tab sheet “Description” a detailed description can be entered e.g. the background for the calculation.

10.2.1 Tab sheet ‘Main’

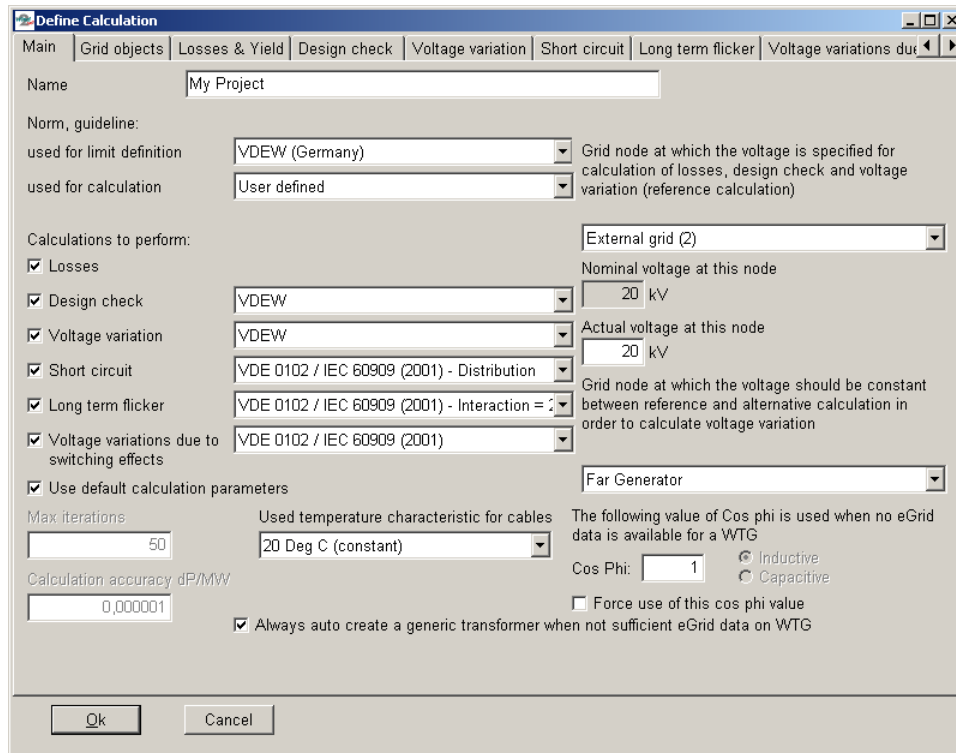


Figure 22 Calculation menu “Main” – Selection of the calculations to be performed

In addition to the possibility to name the calculation, the tab sheet “Main” is primarily used to decide which calculations shall be performed. Predefined settings for limits as well as for calculations to perform can be chosen. These are mainly related to German requirements in the first version. At the moment, either the German VDEW or the norm IEC 61000 can be selected in order to specify limit values. Naturally, it is also possible to define own values. Concerning the calculation properties, in addition to the possibility of a self-defined calculation, a calculation based on the German norm VDE 0102 respectively the IEC 60909, both in the variant of 1990 or 2001, can be selected for a calculation, which bases on a short-circuit calculation.

Regarding the VDEW guideline, the Design Check calculation corresponds to a dimensioning calculation. All settings, necessary for this calculation as well as for the calculation of the voltage variations are made automatically. The choice of a pre-defined calculation leads - with exception of the loss calculation - generally to the selection of all calculations.

Each calculation, selected in this tab sheet, leads to a further tab sheet, in which the respective settings can be viewed concerning the calculation properties and the limit values for this calculation and changed, if necessary.

The calculation accuracy as well as the maximum number of iteration steps can also be adapted.

The right side of this tab sheet contains additional information, necessary for the calculation. So, one voltage value at one grid node has to be defined for a loss, design check or voltage variation calculation. This voltage at this node is the basis for the calculation (for a voltage variation calculation, which bases of two load-flow calculations, it is the basis for the first calculation). Typically, this is the node at the next bigger transformer station or the Common Coupling Point. In the practical use, it is mainly the node of the External Grid.

Additionally, the grid node has to be noted at which no voltage variation should occur for the calculation of voltage variations. That mean at this node the voltage is fixed. Typically, this is at the Far Generator.

In order to enable the possibility to perform basic load-flow calculations without a lot of entries, it's also possible to define an overall CosPhi value used for all WTGs. For this type of calculation, it is not necessary to define several eGRID data entries within the WTGs prior to the calculation. It is also possible to use the defined CosPhi value for all WTGs (including WTGs with a eGRID data set), selecting "Force CosPhi value.

Additionally, selecting "Always auto create a generic transformer when no eGRID data on WTG", automatically generated transformers are used for WTGs which are connected to e.g. the medium voltage grid level without transformers, on the basis of generic transformer data.

Furthermore, a temperature dependency of the cable resistance can be chosen. In general, the electrical data of a cable are used like specified in the cable catalogue. These are the cable properties at a temperature of 20°C. Due to the fact that any current flow results in losses, the cable will become warmer which leads to an increased cable resistance. Here, a corresponding consideration can be chosen, respectively the grid can be inspected using the maximum cable parameters at 90°C:

- 20 Deg C (constant)
- Linear current dependency
- Quadratic current dependency
- 90 Deg C (constant)

Due to the fact that the losses, which cause the heating, increase with the square of the current value, the quadratic current dependency should be the most realistic one.

In order to calculate the actual cable resistance, which is being done individually for every single cable in the grid, a cable temperature of 20°C is assessed in case of no current flow and a temperature of 90°C is determined for the maximum current carrying capacity which is being calculated taking into account the given maximum current value for each cable (e.g. manufacturer data) AND the specified individual current limitation factors. Based on these two points, the cable temperature is being calculated for a linear or quadratic current dependency and the corresponding resistance value is specified via the equation

$$R_T' = R_{20}'(1 + 0,004(T - 20)) .$$

(T is the cable temperature in Deg Celsius).

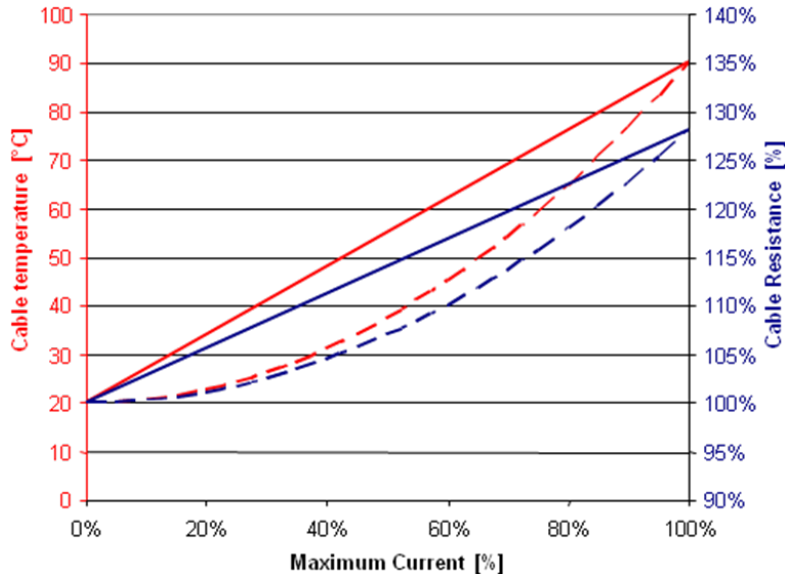


Figure 23 Current-Temperature dependency of the cable resistance

10.2.2 Tab sheet 'Grid objects'

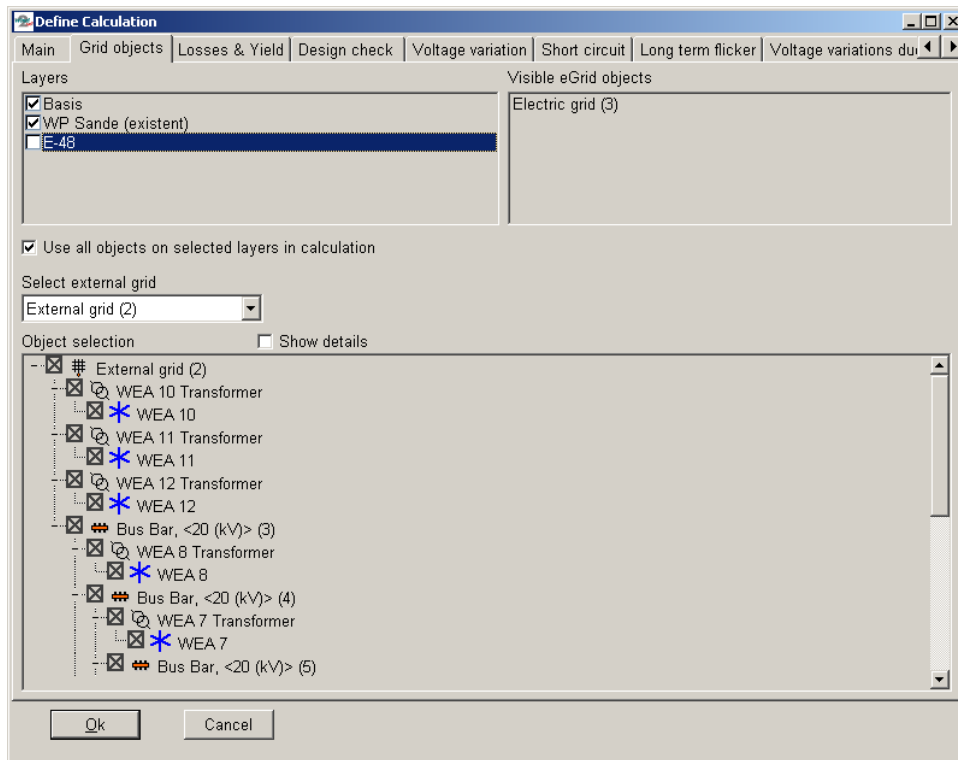


Figure 24 Calculation menu "Grid Objects" – Defining the final grid structure

Within this tab sheet, the grid structure (based on one or several Electric Grid object(s)) and grid objects (WTGs, etc.), which shall be considered in the calculation, have to be chosen. Mainly, this belongs to grids which include several Electric Grid and / or External Grid objects. This is typically done by choosing the layers on which the relevant grid objects are located. As default, all objects which belong to the visible layers at calculation start are chosen. Likewise, it is possible to deactivate specific objects for a calculation.

Due to the fact that the calculation algorithm implemented in the eGRID module cannot compute meshes, the arranged grid is being examined relating this item. A recognized mesh is announced.

10.2.3 Tab sheet 'Losses'

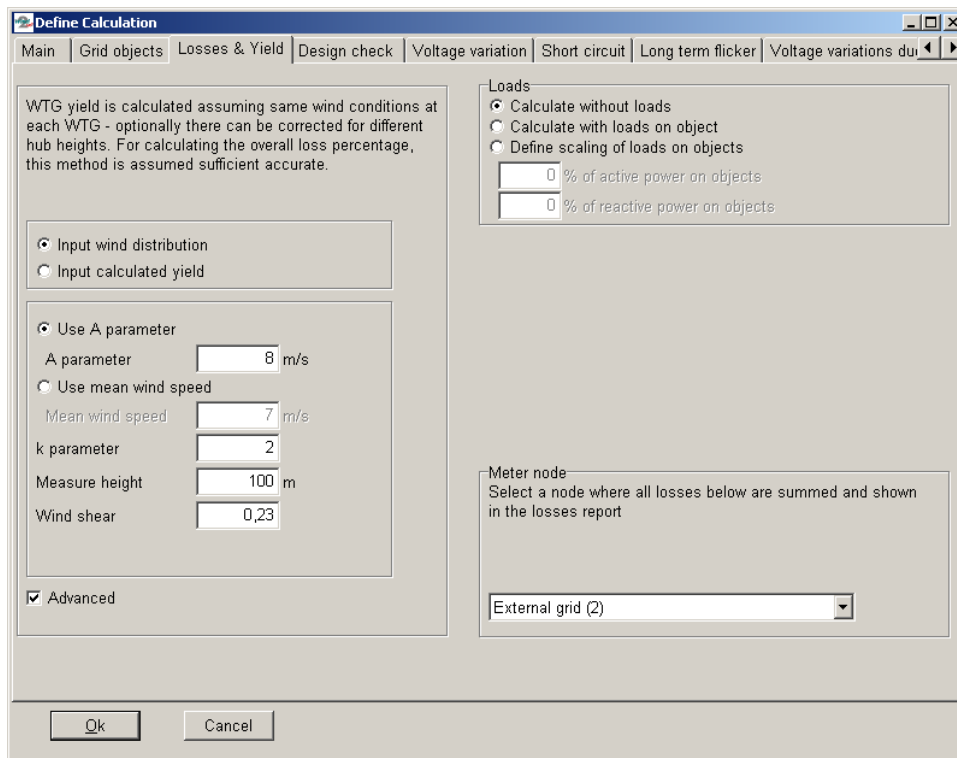


Figure 25 Calculation menu "Losses" – Defining a wind distribution

Within the tab sheet "Losses", the calculation conditions for the calculation of the annual losses within the cables and transformers have to be defined. The calculation determines the annual losses based on the wind frequency distribution. For this purpose, the rated power output of the WTGs is divided into 12 classes. For these classes, the frequency (hours per year) is calculated for each power class. Either the Weibull distribution with an A-parameter and/or a mean wind speed and the k-factor in hub height or the annual yield of the whole wind park can be selected as basis for the frequency distribution. When working with the Weibull distribution and selecting "advanced" (settings), even different hub heights between the WTGs and the distribution can be included. By using the calculation based on the annual yield, with the help of a standard k-factor, an A-parameter is determined. These values are the basis for the frequency distribution. If you additionally select the "advanced" settings, you get the possibility to change the k-parameter and to define the reference hub height as well as the wind shear (Hellman exponent) (see chapter Energy 3.2.2).

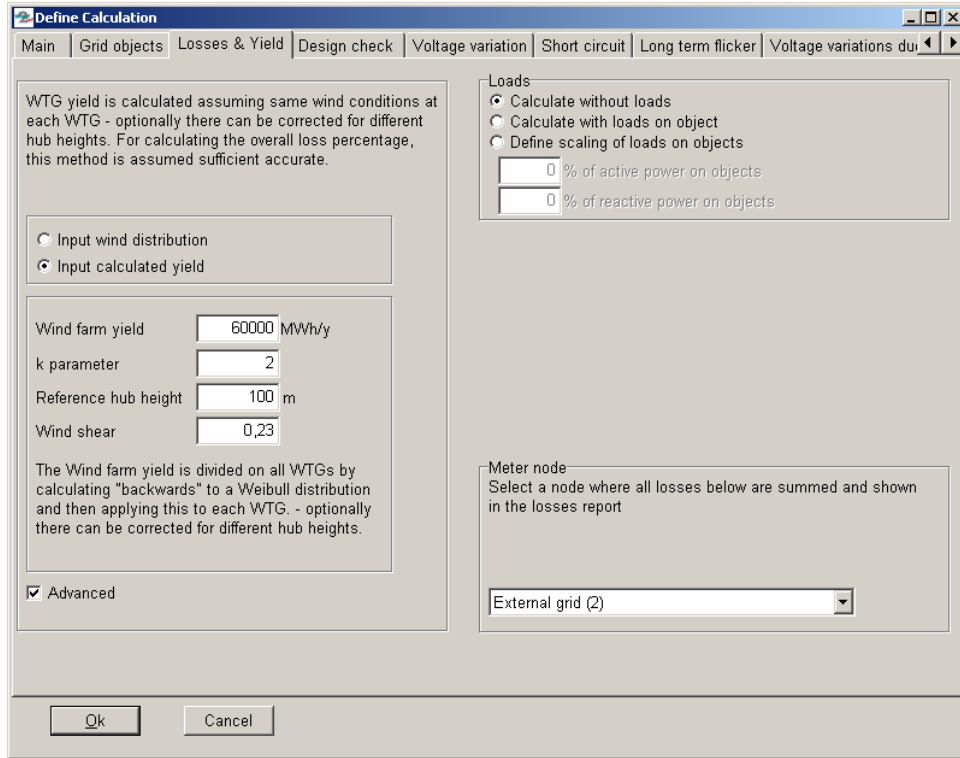


Figure 26 Calculation menu "Losses" – Input of a calculated yield

10.2.4 Tab sheet 'Design check'

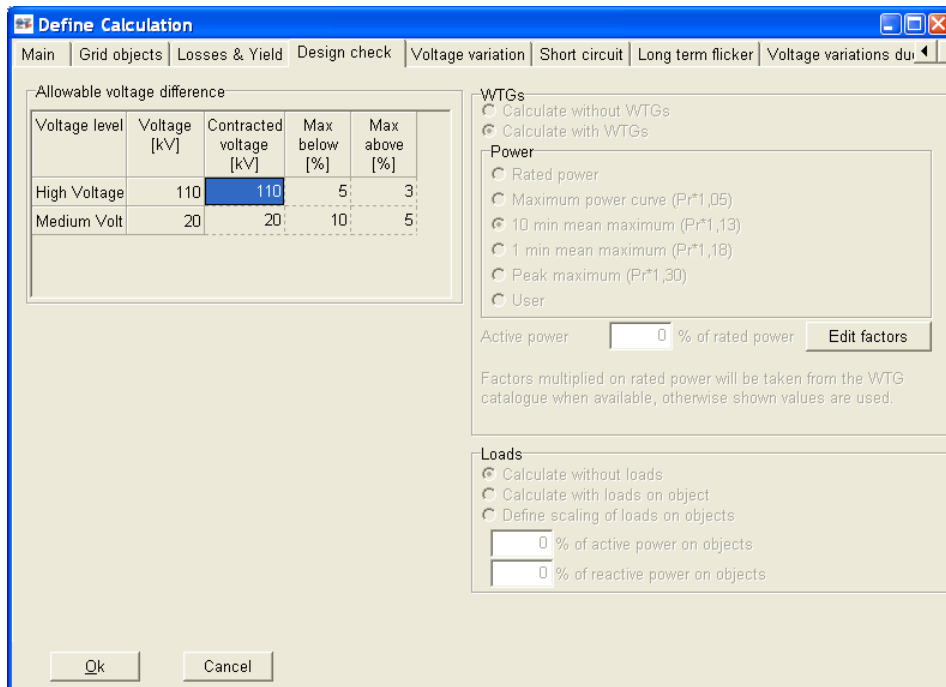


Figure 27 Calculation menu "Design check"

An individual load flow calculation can be defined within the tab sheet "Design check". If in the tab sheet "Main" a pre-defined calculation method is being selected, modifications of the settings at the right side of the tab sheet are not possible. Otherwise, the feed-in power of the WTGs can be defined up to the treatment as consumers (the data for this operation have to be indicated in the eGRID data of the turbines). Additionally, there's the possibility to define default values according to WTGs, no eGRID data have been entered, or those WTGs, the selected

entry is missing (e.g. the 10-minute maximum power value of the WTG). Concerning the loads a calculation without, with and with proportional presence of the consumers can be defined.

At the left side, permissible voltage variation values can be entered, which normally refer to the nominal voltage entered in the external grid. If a deviating reference voltage is agreed with the utility, this value has to be specified in the column “Contracted voltage”. Then, the permissible proportional voltage deviations refer to these voltages. If pre-defined limit values were selected in tab sheet “Main”, no changes are possible in this table relating the limit values.

10.2.5 Tab sheet ‘Voltage Variation’

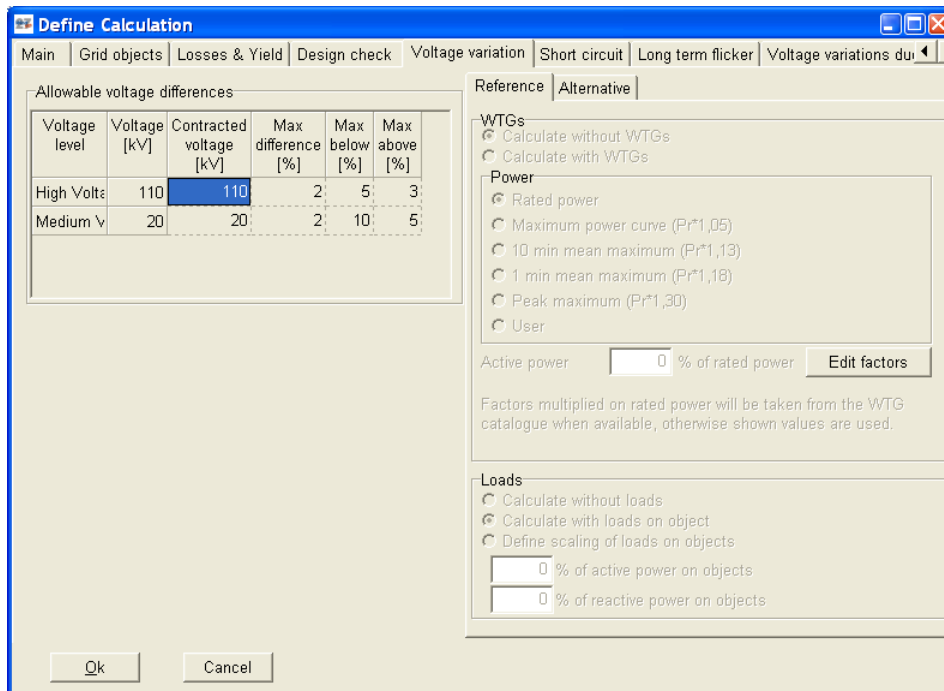


Figure 28 Calculation menu “Voltage variation” – reference calculation

The tab sheet “Voltage variation” offers the possibility to compare the grid voltages of two different operating conditions of the grid. Here, the voltage variation at each grid node is calculated, based on both operating conditions, and examined on the basis of the allowable limits, which are defined in the table at the left side. Otherwise, all settings are identical to the possibilities described in the tab sheet “Design check”.

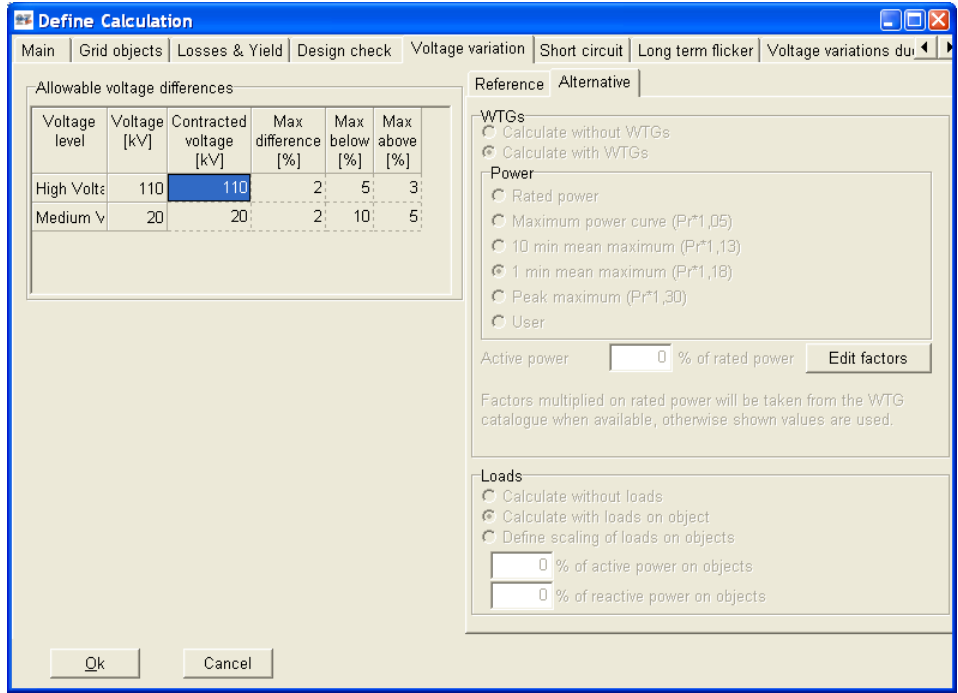


Figure 29 Calculation menu “Voltage variation” – alternative calculation

10.2.6 Tab sheet ‘Short Circuit’

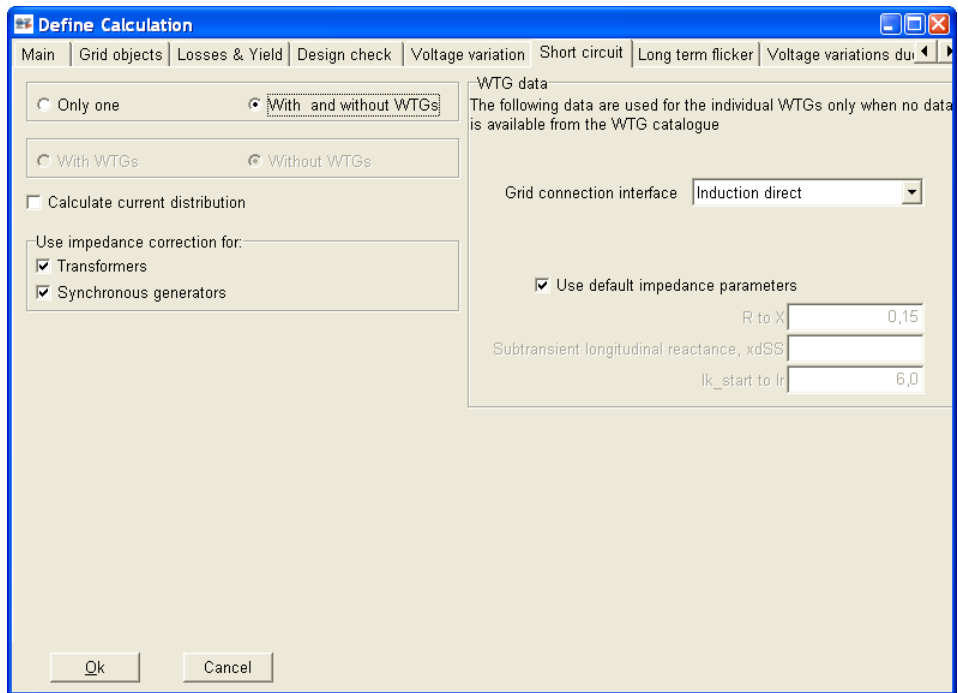


Figure 30 Calculation menu “Short circuit”

While the first three tab sheets “Losses”, “Design check” and “Voltage variation“ are based on load flow calculations, the other tab sheets are based on short-circuit calculations.

If a user-defined calculation is adjusted in the main tab sheet, you can select if one (without or with WTGs) or two (without and with WTGs) calculations shall be performed and further if the current distribution of the short-circuit current should also be calculated. Additionally, the use of impedance correction factors for transformers and/or synchronous generators can be activated. These factors, which are defined in the standard VDEW 0102 and/or IEC 60909 (versions of 2001), lead to a decrease of the impedances of these components and thus to a higher short-circuit current.

10.2.7 Tab sheet 'Long term flicker'

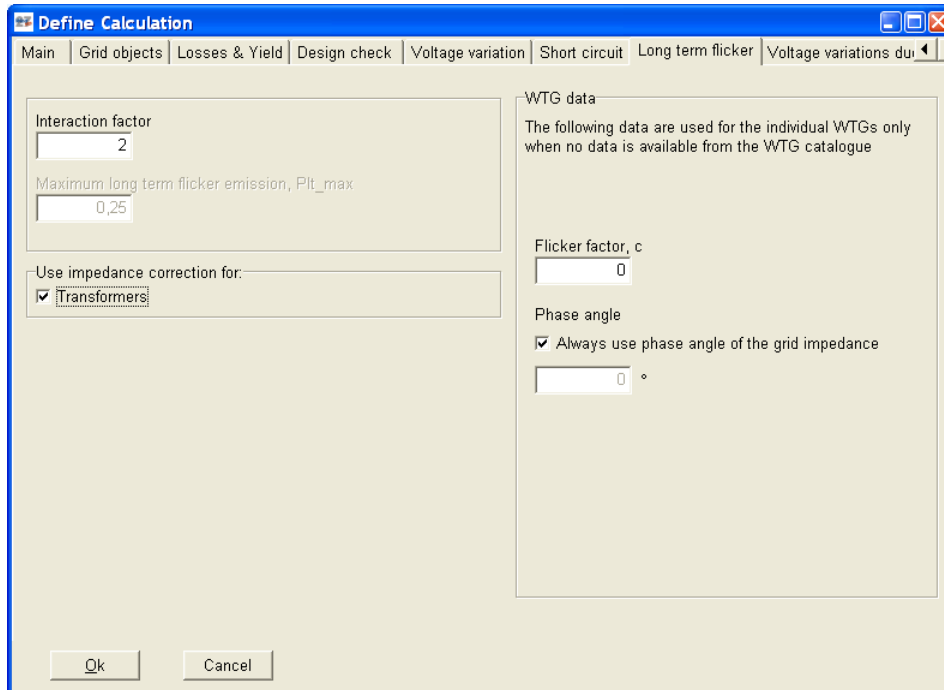


Figure 31 Calculation menu "Long term flicker"

At the left side of the tab sheet "Long term flicker", the interaction factor relating the flicker contribution of single WTGs, which is normally given to '2', and the maximum permissible total flicker value (P_{lt} or A_{lt}) have to be indicated. Additionally, equivalent to the tab sheet "Short circuit" you have to define if an impedance correction according to the standards of 2001 shall be used for transformers. Due to the fact that the flicker calculation bases on a calculation of the short-circuit power without generators, this indication is only necessary for transformers – in contrast to the tab sheet "Short circuit".

At the right side, you can indicate default flicker data. These values are used, if no eGRID data have been entered for a WTG or no flicker data are defined for a turbine.

10.2.8 Tab sheet 'Voltage variations due to switching effects'

The screenshot shows the 'Define Calculation' dialog box with the 'Voltage variations due to switching effects' tab selected. The dialog is divided into several sections:

- Allowable voltage difference:** A table with columns 'Voltage level', 'Voltage [kV]', and 'Max difference [%]'.

Voltage level	Voltage [kV]	Max difference [%]
High Voltage	110	2
Medium Volt	20	2
- Use impedance correction for:** A checkbox labeled 'Transformers' is checked.
- Check for long term flicker contribution of switching effects:** An unchecked checkbox.
- Interaction factor:** A text input field containing '3,2258'.
- Maximum long term flicker emission, Plt_max:** A text input field containing '0,25'.
- WTG data (top):** Radio buttons for 'Use interpolated ki,psi (FGW) resp. ku,psi (MEASNET/IEC). Tables required.' (selected) and 'Use maximum switching factor ki,max (FGW) resp. max. value of all ku,psi (MEASNET/IEC)'. Below is a text input field for 'ki,max (FGW) resp. ku (MEASNET/IEC)' with the value '0'.
- WTG data (bottom):** Text input fields for 'Flicker step factor, kf' (value '0') and 'Maximum number of switching operations' (value '0').

Buttons for 'Ok' and 'Cancel' are at the bottom.

Figure 32 Calculation menu "Voltage variations due to switching effects"

The tab sheet "Voltage variations due to switching effects" equals the tab sheet "Long term flicker". Beside the data for the maximum permissible voltage variation and whether an impedance correction for transformers shall be used, at the right side, an indication whether the maximum or an interpolated switching factor (if several switching factors were entered in tabular form) should be used for the calculation. Additionally, there's the possibility to define a default switching factor, if no eGRID data have been entered or no switching factor has been defined for a WTG.

If the flicker contribution of the switching process should be calculated, the corresponding option has to be checked. As in the definition of a flicker calculation, the interaction factor of the WTG individual flicker contributions has to be defined at the lower left side as well as the maximum value. At the lower right side of the window, flicker data can be defined which is being used for WTGs without any corresponding electrical data.

10.3 The Results – Printouts/reports

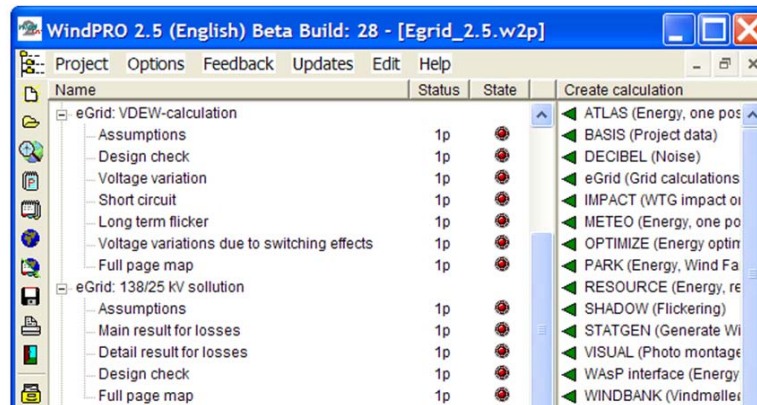


Figure 33 After calculation the results appears on the window of the calculation manager.

In the tree structure, usual for Windows, the individual reports and results can be pre-viewed and/or printed. Each kind of calculation produces its own report in which the respective conditions for calculation and results are contained. Within the results, first the main results and afterwards additional results are designated. Further it is informed whether the entered limit values are fulfilled or exceeded.

Losses: This report is divided into 'Main results' and 'Detail results'. The annual active and reactive power losses in the transformers and cables are calculated on the basis of the entered wind distribution and wind profile. The loss is also given as a percentage of the wind farm production.

Design Check: The calculated grid voltages are presented as the main result, followed by the utilization as well as the active and reactive power losses of the transformers and cables.

Voltage variations: The main result of this calculation, which is based on two individual calculations (reference and alternative calculation), is the proportional voltage variation at each node. Subsequently, the result of each individual calculation is specified as with the calculation of the design check.

Short Circuit: In dependence of the selected calculation variant (calculation with and/or without WTGs; calculation of short-circuit current distribution within the grid) the contents of this report varies. First the short-circuit power, the grid angles and the short-circuit currents of all nodes, possibly for both calculations, are shown. If demanded, additionally the current distribution for each object is being presented.

Long term flicker: As in a losses calculation, the report of this calculation is divided into a main and a detailed report. In the main report of a flicker calculation, only the total long term flicker values at any grid node are presented, followed by an assessment which bases on the defined limit value. Also, the short-circuit values which are very important for the calculation are shown. Within the detailed report, the contribution of each WTG as well as the used flicker factor in order to calculate the contribution is indicated for each grid node.

Voltage variations due to switching effects: This calculation is divided into a main and a detailed report also. In the main report of a switching effect calculation, the maximum voltage variation at any grid node is presented as well as the WTG and switching reason which are responsible for it. In case there identical results for other turbines, only one is being presented. Additionally, the maximum long term flicker values are shown, followed by an explanation which switching process leads to the maximum value. If "Worst case" is being presented, the maximum value is the result of different switching processes for different WTGs. Both values are checked regarding their limit values, which results into a combined assessment. Again, the short-circuit values which are also very important for the calculation are shown. Within the detailed report, the used switching factor and the contribution of each WTG are presented equivalent for the presentation of the long term flicker values for each grid node.

Map: The actual calculated grid with all used objects is presented on the map.

10.4 eGrid – Theory behind the calculations

Medium voltage distribution grids, to which most of the decentralized power supply structures are connected, have nominal voltages of 20 or 30 kV in accordance to DIN IEC 38. In order to have a high reliability of power supply, medium voltage grids are normally built up as ring grids, ring grids with cross connections or meshed grids. Under normal conditions, often they are operated as radial networks. In the case of repair and/or disturbance, individual parts of the grid can be switched off or switched over by existing grid interfaces.

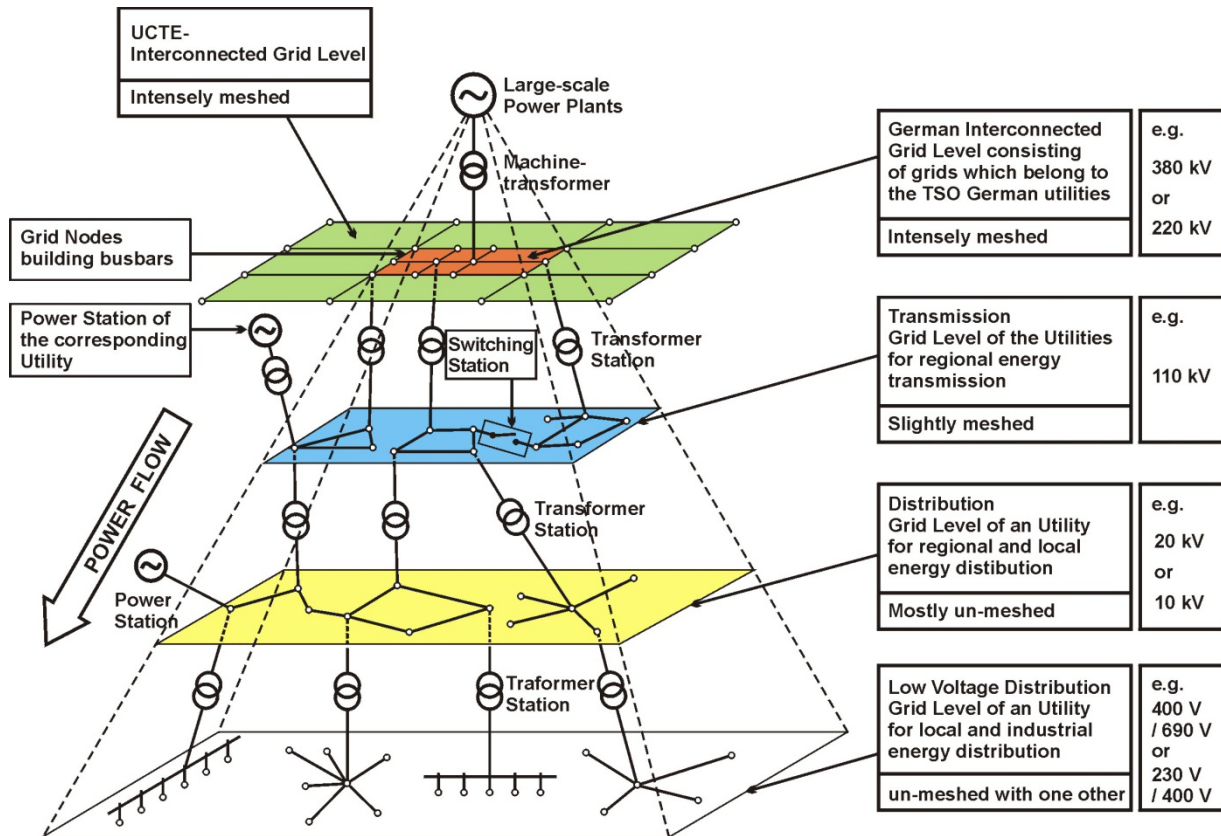


Figure 34 Different voltage levels and grid structures of the electrical grid in Germany

Usually, also a wind park has a radial grid, because one or more wind turbine generators are connected to one grid node. Due to this, the calculation algorithm was adapted to this grid configuration (radial grid). Meshed grids will not be calculated.

10.4.1 eGrid – Component Modeling

In order to simplify the electrical grid input, only components which are primarily important for the electrical grid calculation are implemented. Ancillary equipment like protection devices is not implemented. The components, relevant for the grid calculation, are:

- External Grid
- Transformers
- Electrical Grid (Cables / Overhead Lines)
- Busbars
- Loads / Compensation Devices
- WTGs

10.4.1.1 External Grid

Differently to other grid calculation programs, in the load-flow calculation the External Grid is implemented as an RX-serial connection – in the same manner as in the short-circuit calculation. Thus, this component also contains power losses and a voltage drop. This has the advantage that the voltage at the grid connection point (input voltage of the External Grid) is not constant every time. It can rise or fall in the case that there is no regulation about the connection point of this component.

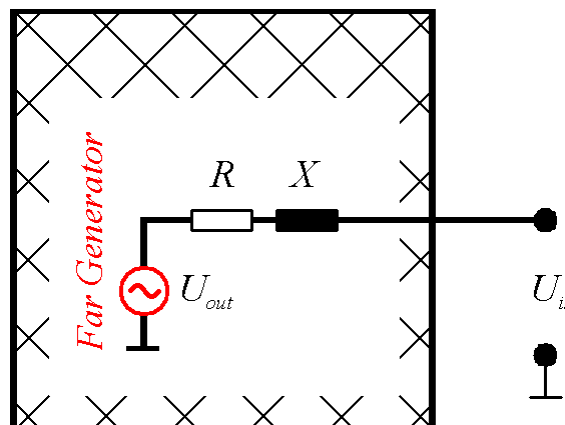


Figure 35 Circuit diagram of the 'External Grid' component

Certainly, this approach can be confusing for utilities which have all-embracing grid models. But, – normally – a non involved person gets only the characteristics (S_K'' , Ψ_K and the rated voltage U_R) of a possible connection point. The voltage of this grid node must not be constant in practice, in opposite to e.g. a large transformer station at which the voltage is regulated.

At the end of the total load-flow calculation, all angles are modified based on the angle of the output voltage of the 'External Grid' element – the Far Generator - which is set to '0'.

10.4.1.2 Two-Winding-Transformers

A Two-winding-transformer is integrated by its equivalent T-circuit diagram. Therefore, the impedance of a transformer has to be split into two equal portions.

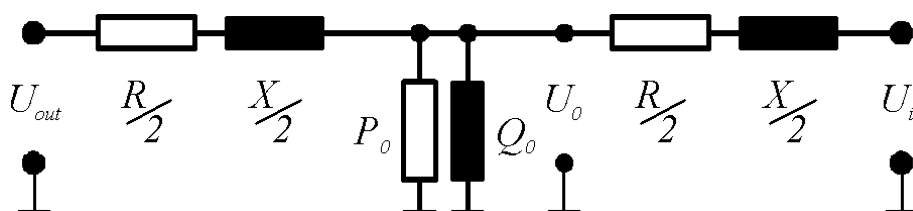


Figure 36 Circuit diagram of a two-winding-transformer

All calculations are performed at the high voltage level. So, there must be a voltage conversion from the lower- to the higher voltage level of the transformer. Due to the fact, that – depending on the polarity of the transformer –

this conversion has to be done at the input or output side of the transformer using the transformation factor, the transformation is not pictured in the circuit diagram.

10.4.1.3 Electrical Grid

In the medium voltage level, the cross sections of the overhead lines and cables lie in a limited range, which is determined by the mechanical and electrical characteristics of the lines. The maximally permissible cross section of overhead lines is limited by the mechanical stability of the supporting masts of the overhead line and may not exceed 120 mm² [12, 13]. The minimum cross section does not amount less than 16 mm² in consideration of the permissible mechanical wire stresses [12]. However, in practice no cross sections for overhead lines and cables under 35 mm² are used due to economic reasons.

For the simulation of the cables or overhead lines, the equivalent Π -circuit diagram is used in the calculation algorithm.

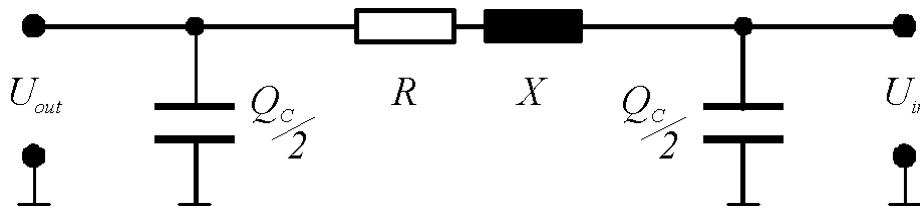


Figure 37 Circuit diagram of a cable or overhead line

While the voltages are calculated in the same manner as by the External Grid, by the calculation of the power values the reactive power production of the capacities have to be considered.

10.4.1.4 Loads / Compensation Devices

The loads are regarded as passive grid elements with an active power demand.

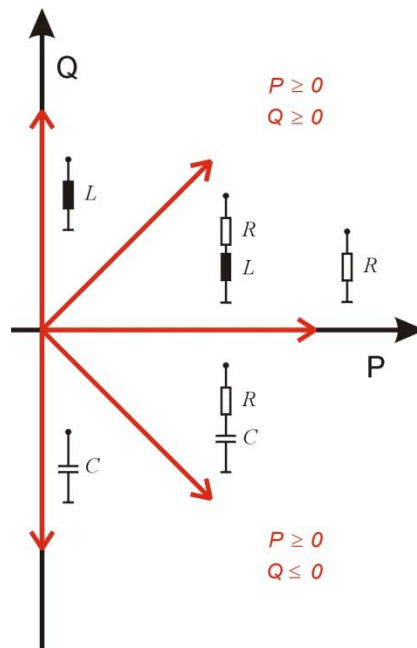


Figure 38 Different load classes

Normally, the power demand of the loads depends on the actual voltages. This dependency is not linear. The accuracy of the mathematical description of this relationship, the so called load-characteristics, mainly defines the calculation accuracy of all parameters of the operating condition of the grid like the voltages of the nodes, power losses and voltage drops. In practice, the consumer characteristics are very various. So, assumptions are inevitable. The literature [7, 8, 9] gives some theoretical recommendations, which are only conditionally applicable in practice. The available programs solve this problem differently. Each program developer uses his own “tricks” in order to reach a solution (convergence) of the mathematical grid model.

In the educational books as well as in the available grid calculation programs, the power dependency (active and reactive power) referenced to the actual voltages is integrated via a power function. The value of the exponent varies among the different sources from ‘2’ down to ‘0’.

$$P = P_R \cdot \left(\frac{U}{U_R}\right)^n ; \quad Q = Q_R \cdot \left(\frac{U}{U_R}\right)^m$$

The dependency is pictured in the following figure for several exponents.

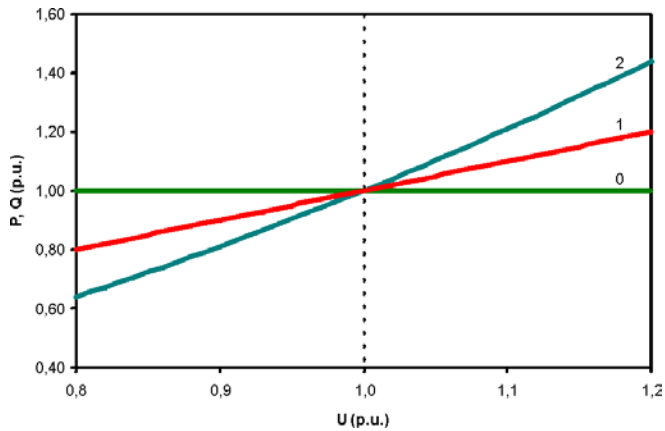


Figure 39 Common load characteristic

This description of the dependency has the advantage that – if the grid calculation leads to no result (does not converge) – the convergence of the calculation can be forced by changing the exponent towards ‘0’. Unfortunately the user is not informed about this adjustment.

In our calculation algorithm, this dependency is integrated via the average load characteristics based on [10, 11],

$$P = P_R \cdot \left(K_{0P} + K_{1P} \cdot \left(\frac{U}{U_R}\right) + K_{2P} \cdot \left(\frac{U}{U_R}\right)^2 \right) ; \quad Q = Q_R \cdot \left(K_{0Q} + K_{1Q} \cdot \left(\frac{U}{U_R}\right) + K_{2Q} \cdot \left(\frac{U}{U_R}\right)^2 \right)$$

which correspond to the load conditions within the medium voltage level at best in our experience. On the basis of the parameters K_{0P} , K_{1P} , K_{2P} , K_{0Q} , K_{1Q} , K_{2Q} , it is possible to adapt the characteristics to the real load conditions without much effort. A variation of these characteristics, which are represented in figure 40 with realistic values ($K_{0P} = 0.83$; $K_{1P} = -0.3$; $K_{2P} = 0.47$; $K_{0Q} = 4.9$; $K_{1Q} = -10.1$; $K_{2Q} = 6.2$), does not take place in the calculation program. However, the user is informed in the case that the calculation did not converge.

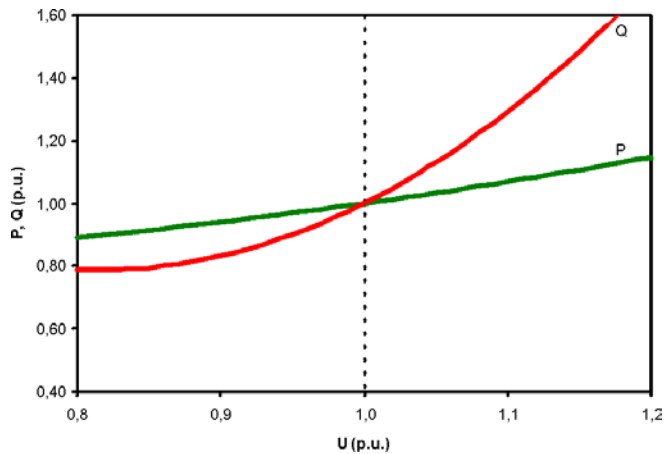


Figure 40 Average load characteristic based on [10, 11]

10.4.1.5 Generators / Wind Turbine Generators

All generators – including wind turbine generators – which are available on the market can be divided into four main classes:

- Synchronous generators
- Induction generators
- Double-fed induction generators
- Generators which are connected to the grid via a power electronic converter, so that the generator itself is not important for the behavior of the total generator system any more.

Each of them can be specified by similar parameters in static operation. Hereby, it is assessed that the feed-in power does not depend on the actual voltage at the connection node of the generator.

It is obvious, that the feed-in power of wind turbine generators depends on the wind speed. The dependency between wind speed and the active power output was already implemented in WindPRO for many marketable wind turbines.

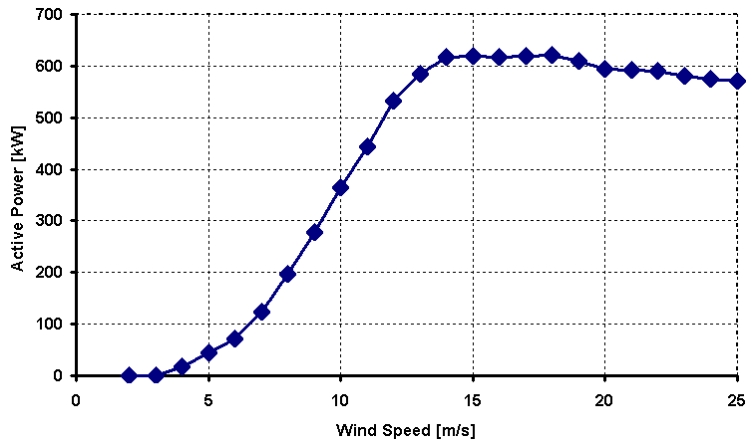


Figure 41 Dependency between wind speed and active output power by a Nordex 43 wind turbine [5]

Regarding the reactive power, the relationship between the active power and the power factor, which is not constant, had to be included in the dataset. Actually the calculation of the reactive power is performed by linear interpolation on the basis on few sampling points, which are taken out of measurement reports, made by international acting measurement institutes.

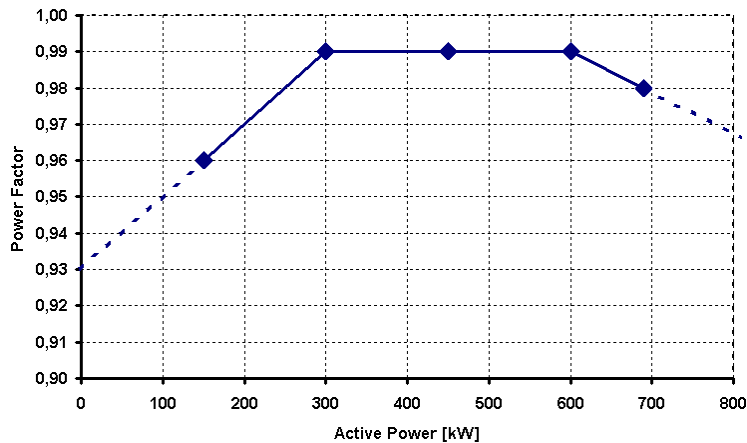


Figure 42 Implemented power factor characteristic of a Nordex 43 wind turbine [4]

Due to the way, that the calculation of the power factor via few sampling points contains a loss of accuracy, this calculation has to be replaced by another algorithm. But the fact, that for a normal user there are many unknown parameter settings in a wind turbine which have directly effects to the power factor, like the switching points of compensation capacities, an exact characterization seems to be impossible.

10.4.2 eGrid – Calculation Methods

The purpose and the scale of grid calculations are determined by a concrete and individual task, which can be very different in each case. For example, the existing connection capacity has to be evaluated in order to decide about the connection of a further wind turbine generator to the grid, which is described via technical criteria. In accordance with the guidelines for parallel operation of own generation plants with the grid of the utility [2, 3], these criteria refer with:

- Voltage variations also by flickers
- Variations of the short-circuit current
- Power factors
- Harmonics

These criteria can be affected by the normal operation of a wind turbine generator. Using modern wind turbines, in which IGBT inverter technology is implemented, the last two items can be neglected. Thus, the first two criteria represent the characteristics, which are to be considered as the main topics for the grid calculation. The grid, at which the connection of wind turbine generators is to be examined, is regarded as an energy distribution system with two areas: the infinite bus and the affected grid area, as presented in the following picture.

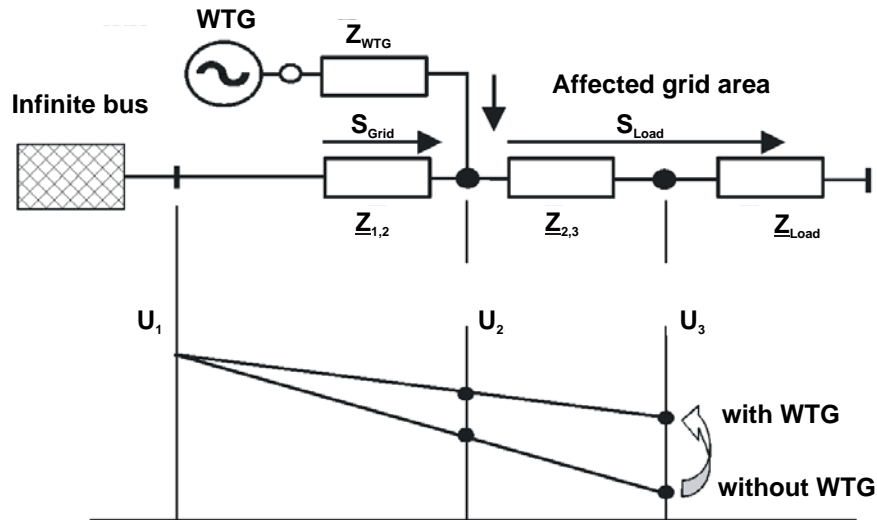


Figure 43 Typical example of a wind turbine connection to the grid

Due to the problem definition specified above, only two calculations are selected from the large scale of the grid calculation tasks: the load-flow calculation and the short-circuit calculation. The voltages of the grid nodes could be obtained by load-flow calculations. So, on the basis of two calculations (calculation with/without wind turbine generators), voltage variations can be determined. The short-circuit calculation specifies the available short-circuit power of a grid node, which can be used for the estimation of flicker effects.

As already mentioned, the electrical calculation implements two independent calculations: the load-flow and short-circuit calculation. Differently to other calculation programs, which have to handle large matrices in order to calculate a meshed grid, due to the concentration on radial grids, the calculation algorithm of the eGRID module bases on recursion, a very powerful calculation method. Doing so, several simplifications or neglections, necessary to handle large matrices can be avoided.

10.4.2.1 Load-Flow Calculation / Calculation of Voltage Variations

The voltages of the grid nodes are worked out by the load-flow calculation. This happens by setting the individual nominal voltage value for each grid node in a first calculation step. On the basis of the active and reactive power of the generators and loads, which are known due to the voltage set before, now the power losses in the components are calculated. The calculation is made through the entire grid toward the 'External Grid' component, by which it is presumed that it can absorb or provide any power rates. On the basis of the – in such a way determined – load-flow, a specifying of the voltages takes place in a next step. Based on a fixed voltage of one grid node, given by the user, the voltages of all grid nodes are calculated again.

Due to these new voltages and an eventually voltage dependency of the loads, a new calculation of the load-flow can be necessary (next iteration step). After calculating the power values, new voltage values are calculated again and so on.

This calculation (iteration) is broken off, if the difference between two calculation steps achieves the given calculation accuracy. In [14] it is shown that under the multiplicity of all possible abort criteria the active power difference represents a reliable criterion.

$$\max(\text{abs}(P_i - P_{i+1})) < \varepsilon$$

The calculation accuracy can be given by the user. The default value is 1e-6 kW. However, a fundamental characteristic of the iteration calculation is that the calculation leads to no result, i.e. that it does not converge. Therefore, a maximum number of iteration steps is specified, which can be also set by the user. Here, the default value is 50.

Due to the nature of a load-flow calculation, all voltages in the grid are calculated based on one grid node (the voltage is regulated at this node), i.e. there has to be a specified voltage value at a specified node. So, the parameters for a single load-flow calculation are

- the grid node for which the voltage is given

- the voltage of that node

Also it is possible, that there is no voltage regulation within the examined grid, this means the regulation is implemented within the Far Generator. In this case, the internal voltage of the 'External Grid' is kept on the specified voltage (see also chapter 10.4.1).

The calculation of the voltage variations includes two load-flow calculations, the calculation of the grid e.g.

- without generators and
- with generators.

Thereby, a grid node can be assigned, at which no voltage variation takes place, i.e. the voltage is constant. So, for the calculation of voltage variations, there must be another parameter:

- the grid node for which the voltage is constant.

Naturally, this can be the same node with the given voltage value.

10.4.2.2 Short-Circuit Calculation

In all practical cases it is possible to determine the short circuit current at fault location via the method of the equivalent voltage source at the short-circuit location. During the short-circuit calculation, this source is the only existing voltage source within the grid [15, 16].

In principle, the calculation of the currents during a short circuit is a calculation of transient processes which requires the solution of differential equations. However, in practice frequently only a quasi-stationary calculation of the sub-transient current I_K'' and the sub-transient short-circuit power S_K'' is performed.

The computation is based on the determination of the impedance of the entire grid related to the fault location. Hereby, all components which feed-in into the grid i.e. the 'External Grid' and all types of generators are replaced by their internal impedance's. Further, the capacities of the cables and overhead-lines, the parallel admittance's of the no-rotating loads, the impact by the static loads, the tap position and the no-load losses of the transformers can be neglected. So, the 'External Grid', the cable and overhead-lines, the transformers as well as the generators are only described by their individual R-X serial impedance, whereas loads are ignored.

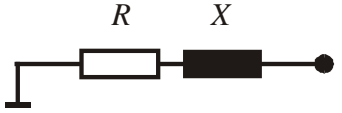
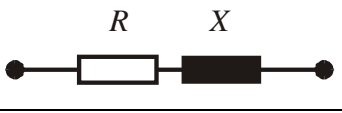
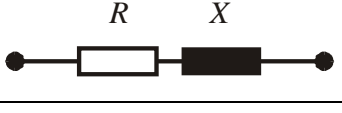
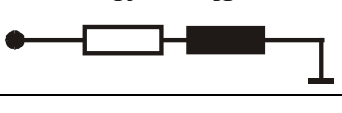
External Grid	
Cable / Overhead Line	
Transformer	
Generator	
Load	ignored

Figure 44 Equivalent short-circuit diagrams

Normally the short-circuit currents and the short-circuit power are determined for all grid nodes. Hereby, in each case only one fault location is chosen and analyzed.

Concerning the tasks of the project it is necessary to calculate only the symmetrical short-circuit in all grid nodes.

10.4.2.3 Flicker calculation

The flicker calculation bases on the results of the short-circuit calculation. Hereby, the short-circuit power and the grid angle of an inspected grid node is used, calculated by a short-circuit calculation without generators.

Basics

Based on the calculation algorithm of different wind turbines in the grid, the flicker contribution of each wind turbine can be estimated by the equation

$$P_{lt\ WT} = 1.1 \cdot \frac{c \cdot S_{R\ WT}}{S_k''} = \frac{c \cdot P_{R\ WT}}{\lambda_{R\ WT} \cdot S_k}$$

concerning the medium voltage level.

Hereby, the phase angles of the wind turbine and of the grid impedance are assumed as worst case. Within this formula, factor c is the flicker factor of the wind turbine, normally given by the manufacturer. $S_{R, WT}$ represents the rated apparent power of the wind turbine and S_k'' is the initial short-circuit power of one grid node, a single wind turbine affects to.

Normally, the inspected grid node is the point of common coupling (PCC), the connection node of a whole wind farm, due to the fact that this node is affected most of all. Relating the grid nodes within a single wind farm or by the calculation of a grid with several wind farms (several PCC), different calculation algorithms exist in order to calculate the resulting flicker values in these nodes. The implemented algorithm bases on a publication of DEWI (Deutsches Windenergie-Institut GmbH).

In this algorithm, it is possible that the initial short circuit power of a grid node has to be taken into account in order to calculate the flicker contribution of one wind turbine, although this node is neither the grid node, at which the turbine is connected, nor the node, for which the long term flicker is being calculated. The allocation of the node will not be presented within this manual.

The interaction of each single flicker value to the total flicker is described by the equation

$$P_{lt\ res} = m \sqrt{\sum_{i=1}^n P_{lt\ WTi}^m}$$

whereas factor n represents the number of wind turbines and factor m represents an interaction factor normally set to 2. If all wind turbines are of the same type, i.e. they have the same apparent power and the same c -value, the combination of these equations leads to the popular formula for the flicker calculation concerning the PCC node or superordinated grid nodes.

$$P_{lt\ res} = 1.1 \cdot \frac{\sqrt{n} \cdot c \cdot S_{R\ WT}}{S_k''}$$

In case of additional flicker sources in the grid, basing on different energy sources like wind or water, the factor m can be set up to 3, which corresponds to

$$P_{lt\ res} = 1.1 \cdot \frac{\sqrt[3]{n} \cdot c \cdot S_{R\ WT}}{S_k''}$$

As already mentioned, within the equations above the phase angles of the wind turbine and of the grid impedance are assumed as worst case. For an exact flicker calculation, the angles have to be considered using a second flicker factor, the flicker relevant phase angle.

$$c_{exact} = c_{worst\ case} \cdot \left| \cos(\Psi_k + \varphi_f) \right|$$

Due to several reasons, which should not be represented within this manual, the term $\cos(\Psi_k + \varphi_f)$ cannot be '0'. If the value is lower than '0.1', the result of this term is set to '0.1'.

Different methods providing flicker data

Due to the fact, that there are three different ways to present the relevant flicker data of a wind turbine, the implementation of the flicker calculation has to consider these methods.

Method A: Flicker factor and the individual flicker relevant phase angle

Here, the provided data are the flicker factor and the individual flicker relevant phase angle. The contribution of one wind turbine to the total long term flicker is being calculated via the equations described before.

Method B: Flicker factor and a dependent flicker relevant phase angle ($\varphi_f = -\Psi_k$)

The available data are the flicker factor and the flicker relevant phase angle $\varphi_f = -\Psi_k$, e. g. by an Enercon E40 (500 kW).

Ψ_k	0°	15°	30°	45°	60°	75°	90°
c	6	6	6	6	6	6	6

Table1 Flicker data of an E40 (500 kW)

Using this phase angle – due to the fact that the cos-term always is set to '1.0' – for the flicker contribution of the wind turbine always the worst case is considered.

Method C: Various flicker factors subjected to the grid angle Ψ_k

Here, the provided data are various flicker factors subjected to the grid angle Ψ_k , e. g. an AN Bonus 1.3 MW.

Ψ_k	0°	15°	30°	45°	60°	75°	90°
c	14	12	10	7	3	3	6

Table 2 Flicker data of an AN-Bonus 1.3 MW

Due to the fact that the calculation of the long term flicker requires the flicker factors of all grid angles, interim values are calculated using linear interpolation.

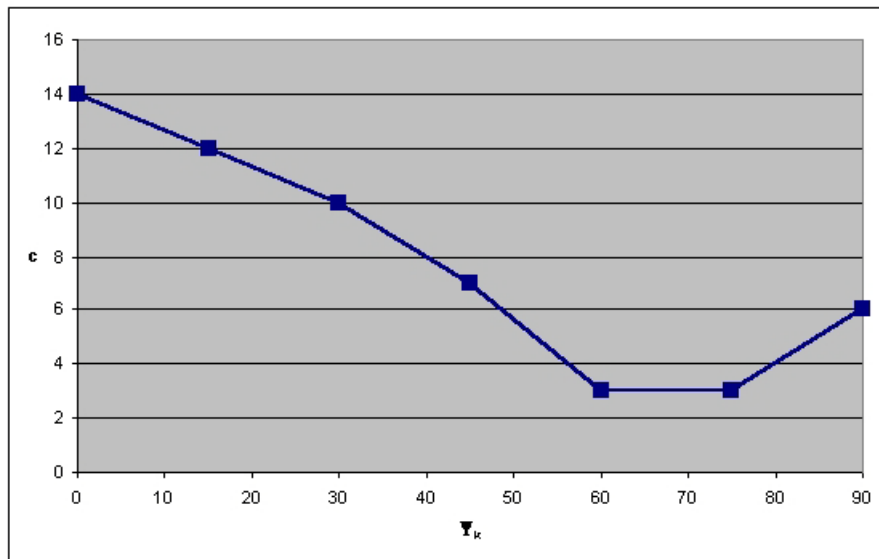


Figure 45 Interpolation of the AN-Bonus data

If the flicker data should not be given within the range of 0°-90°, e. g. a turbine by Vergnet (300 kW),

Ψ_k	30°	50°	70°	85°
c	12.6	11.4	9.0	6.3

Table 3 Flicker data of a Vergnet turbine (300 kW)

the values at the border areas are calculated again by linear interpolation, using two adjacent values.

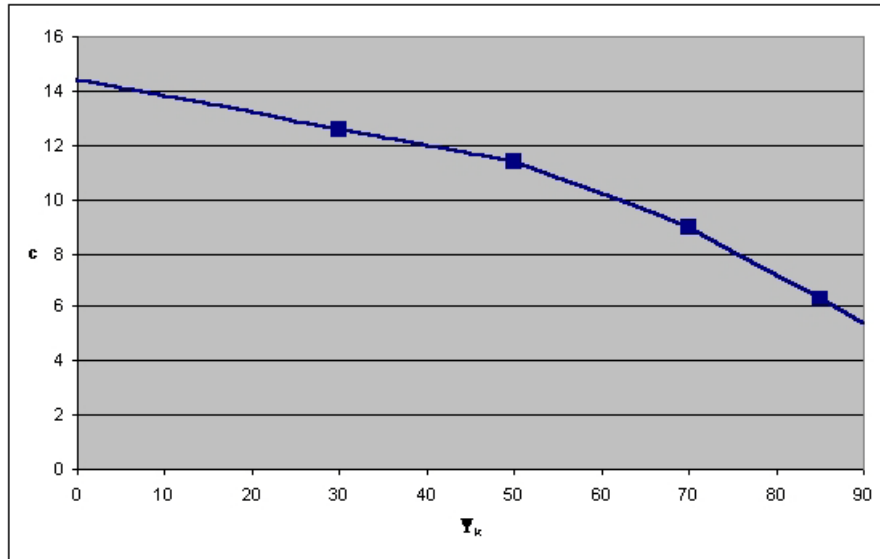


Figure 46 Interpolation of the Vergnet data

Due to the fact, that the angles at such border areas are not realistic anyway, for those areas a major tolerance to the real value seems to be acceptable.

10.4.2.4 Voltage Variations due to Switching Effects

Concerning the medium voltage level, the height of the voltage variations due to switching effects of each wind turbine can be calculated by the equation

$$\Delta u_{\max} = 1.1 \cdot \frac{k_{i \max} \cdot S_{R,WT}}{S_k} = \frac{k_{i \max} \cdot P_{R,WT}}{\lambda_R \cdot S_k}$$

The calculation process is very similar to the flicker calculation. Here, factor $k_{i \max}$ represents the maximum contribution of one wind turbine. Again, the height of this contribution depends on the grid angle. Equal to the flicker calculation, factor $k_{i \max}$ can be replaced by a factor $k_{i\psi}$ which represents the contribution at the specified grid angle Ψ_k .

Normally, the $k_{i\psi}$ values are given as a table incrementing in 5°-steps.

Ψ _k	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90
$k_{i\psi}$	1.3	1.3	1.2	1.2	1.2	1.2	1.1	1.0	1.0	0.9	0.8	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.0

Table 4 Switching factors of an AN-Bonus 1.3 MW ($k_{i \max} = 1.2$)

Again, interim values are calculated using linear interpolation.

10.4.2.5 Interaction of the flicker contributions of switching processes

Based on the IEC Guideline as well as the actual BDEW Guideline (Germany), the long term flicker which is being created by a switching process of a WTG has to be calculated using:

$$P_{lt,E} = 8 \cdot N_{120,i}^{0,31} \cdot k_{f,i(\psi)} \cdot \frac{S_{rE}}{S_{KV}} = \frac{8}{S_{KV}} \cdot N_{120,i}^{0,31} \cdot k_{f,i(\psi)} \cdot S_{rE}$$

Due to the fact that there shouldn't be a difference whether a single turbine has e. g. 30 switching processes in a time frame of two hours (N_{120}) or each turbine of a group of ten WTGs switches only three times in the same time frame, a grouping is being performed within WindPRO: same type of WTG, same apparent power value S_{rE} , same value for the 'Flicker Step Factor' k_f and same grid connection point respectively short-circuit power value of the grid connection point S_{KV} (this node can be different based on the inspected grid node). The total flicker contribution effect of the grouped WTGs is being calculated using:

$$P_{lt,E} = 8 \cdot (n \cdot N_{120,i})^{0,31} \cdot k_{f,i(\psi)} \cdot \frac{S_{rE}}{S_{KV}}$$

Here, factor n is the number of the grouped turbines.

Unfortunately there isn't a calculation instruction in the IEC guideline or the old German guideline how to calculate the total flicker contribution based on an interaction of the contributions of different turbines or same kind of turbines with different grid connection points. Thus, so far (incl. WindPRO 2.6) a quadratic interaction factor has been used in WindPRO:

$$P_{lt} = \sqrt[2]{\sum_{i=1}^{N_E} P_{lt,i}^2}$$

Now, there is a calculation instruction in the German BDEW guideline:

$$P_{lt} = \frac{8}{S_{KV}} \cdot \left(\sum_{i=1}^{N_E} N_{120,i} \cdot (k_{f,i(\psi)} \cdot S_{rE})^{3,2} \right)^{0,31}$$

Regrettably this equation only relates to the grid connection point of a whole wind farm because there is only one short-circuit power of a single grid node which is being assessed for all turbines to calculate their contribution.

In order to get a general equation the equation has to be modified.

$$\begin{aligned} P_{lt} &= \frac{8}{S_{KV}} \cdot \left(\sum_{i=1}^{N_E} N_{120,i} \cdot (k_{f,i(\psi)} \cdot S_{rE})^{3,2} \right)^{0,31} \\ &= \frac{8^{0,31}}{S_{KV}^{0,31}} \cdot \left(\sum_{i=1}^{N_E} N_{120,i}^{0,31} \cdot (k_{f,i(\psi)} \cdot S_{rE})^{3,2 \cdot 0,31} \right)^{0,31} ; 3,2 \cdot 0,31 = 0,992 \approx 1 \\ &= \left(\sum_{i=1}^{N_E} \frac{8^{\frac{1}{0,31}}}{S_{KV}^{\frac{1}{0,31}}} \cdot N_{120,i}^{0,31} \cdot (k_{f,i(\psi)} \cdot S_{rE})^{\frac{1}{0,31}} \right)^{0,31} \\ &= \left(\sum_{i=1}^{N_E} \left(\frac{8}{S_{KV}} \cdot N_{120,i}^{0,31} \cdot k_{f,i(\psi)} \cdot S_{rE} \right)^{\frac{1}{0,31}} \right)^{0,31} \end{aligned}$$

using

$$P_{lt,E} = \frac{8}{S_{KV}} \cdot N_{120,i}^{0,31} \cdot k_{f,i(\psi)} \cdot S_{rE}$$

result to

$$P_{lt} = \left(\sum_{i=1}^{N_E} P_{lt,i}^{\frac{1}{0,31}} \right)^{0,31}$$

or in another way of writing:

$$P_{lt} = \sqrt[0,31]{\sum_{i=1}^{N_E} P_{lt,i}^{\frac{1}{0,31}}}$$

Thus, the same equation like before can be used in case an interaction factor of

$$\frac{1}{0,31} = 3,2258$$

is being taken into account.

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ENERGY - 11 MCP

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11.0 Introduction to MCP and step-by-step guide

This document gives an introduction to the Measure-Correlate-Predict tools (MCP) that are included in WindPRO. The MCP module in WindPRO consists of the following features:

Included in license is free download of EMD Online data from METEO object
 Load of time series data from WindPRO Meteo objects – filtering features available
 Correlation: Extraction of concurrent data and correlation analyses on those
 Linear Regression MCP
 Matrix method MCP
 Weibull Scale MCP
 Wind Index MCP
 STATGEN – generation of wind statistic from MCP result
 Write back long term corrected time series to METEO objects

The Measure-Correlate-Predict toolbox in WindPRO (MCP) enables the user to calculate long term corrected wind data directly in WindPRO. The MCP module provides not only a direct access to different MCP-methods, but also provides reporting through overview-reports and detailed reports for each of the methods available. The global set of like NCEP/NCAR long-term reference data as well as SYNOP and METAR data is available for WindPRO users with an Internet connection and license to the MCP module. In addition purchasable data from selected providers are available for easy use for MCP.

Data that are used by the MCP-methods are contained in the WindPRO Meteo object(s). This object is the data container for wind data saved as either time series data, table data or Weibull distribution parameters. Most MCP-methods require two overlapping time series, each holding a concurrent time series for long-term reference data and site data (local measurements). But the long-term reference data could be divided in a concurrent time series for the duration of the local site measurements and “just” a Weibull distribution or table data (histogram) for the entire reference period.

The result from the MCP analysis is – typically – a wind statistic generated with WAsP based on a terrain description and the long term corrected site data. Then the data can be used directly for WAsP PARK calculations or wind resource map calculations. But for non WAsP use (or further analyses) the long term corrected site data can be written back to an auto generated Meteo object. This Meteo-object is located at the exact same position as the one holding the short-term site measurements.

11.1.1 About the Application of MCP

MCP is the abbreviation for Measure-Correlate-Predict techniques, which is widely in use for establishing a long-term wind statistic using limited wind data from the local site and long-term data from a more-or-less nearby site.

The task of any estimation of a long-term wind statistic is to establish a transfer model between the available short-term local data and the concurrent data from a long-term reference data set. The transfer model can be grouped into (at least) four different types:

1. Physical models (e.g. CFD flow models)
2. Statistical models
3. Empirical models
4. Other (combinations of the above, e.g. like WAsP)

MCP-models may belong to any one of the categories or a combination hereof, indicating that the application of MCP-models has a very wide scope:

Some MCP-models operate on large timescales – like index correction methods, where monthly data typically are used. Other MCP-models tries to decode a one-to-one relationship between wind speeds and wind directions on site and at the reference mast, calling for high quality measurements. In some

situations, MCP-methods are applied in order to correct the lack of ability for a model to take long-term variation into account. This is the case when using local short-term site data in a WAsP analysis. Unfortunately, not all methods will perform equally well in all situations, calling for the user to get acquainted to the performance and limitations of the individual methods.

In general, the applied MCP method modifies one or more of the following descriptive data:

- Wind energy index
- WTG energy index (measured production from the WTGs)
- Weibull A-parameter + Weibull k-parameter
- Wind speed and possibly also wind direction

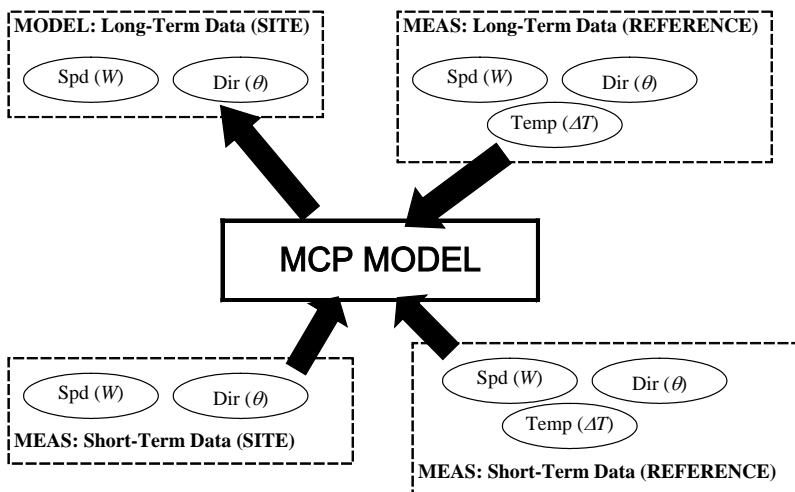
In WindPRO methods working on (1), (3) and (4) are implemented.

11.1.2 A Conceptual Model for the MCP-Framework

A conceptual model for the measure-correlate-predict model is shown in the figure below. From this figure it is seen that three potential different measured datasets are input to the MCP-model:

- Reference data: Long data
- Reference data: Short term data (concurrent data)
- Site data: Short term data (concurrent data)

The long-term data could be any type of distribution, e.g. Weibull data, table data (joint wind distribution) or time series data. The concurrent datasets are typically required to be time series data. Not only measurements on wind speeds and wind direction could be used as input to advanced MCP models but also temperature differences could prove useful. However none of the models in WindPRO currently uses other input than wind speed and wind direction.



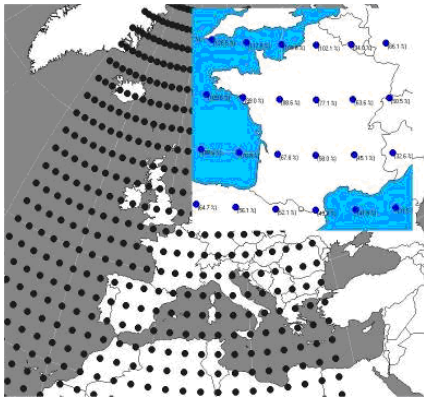
Conceptual Model for Measure-Correlate-Predict Models.

Note: When doing MCP calculations in WindPRO, the input data are always internally treated as three different input sources. However, in many cases the long term reference data and the concurrent reference data series may come from the same time series data source. In such situation, WindPRO will automatically select the same series for both input sources.

11.1.3 The MCP facilities in WindPRO

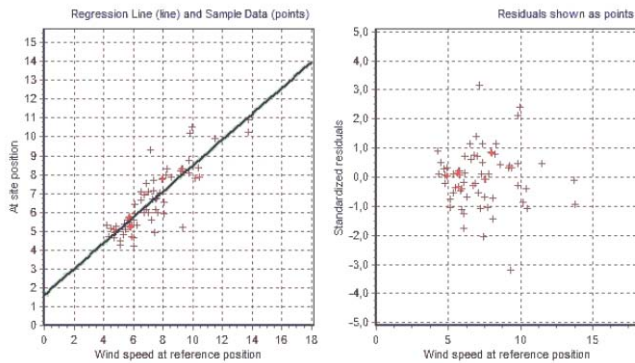
Below is a list of sub-sections briefly outlining the MCP facilities, which are available in WindPRO

11.1.3.1 ON-Line data extraction



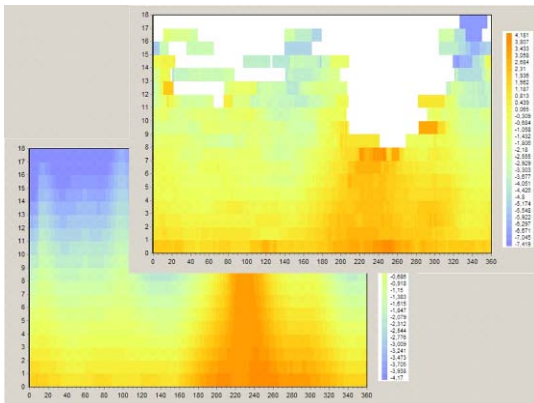
Data from the several different sources like NCEP/NCAR reanalysis project is available to users of WindPRO if the local PC has access to the Internet. The download is started from a METEO object, choosing option “ON-Line data”. A list of available data sources for the project site is generated and specific data sets can be selected and downloaded. Also purchasable data are available. The available data sources are constantly improved and more added. When new data are available they are included in the online generated list – no local software update is required.

11.1.3.2 Linear Regression MCP



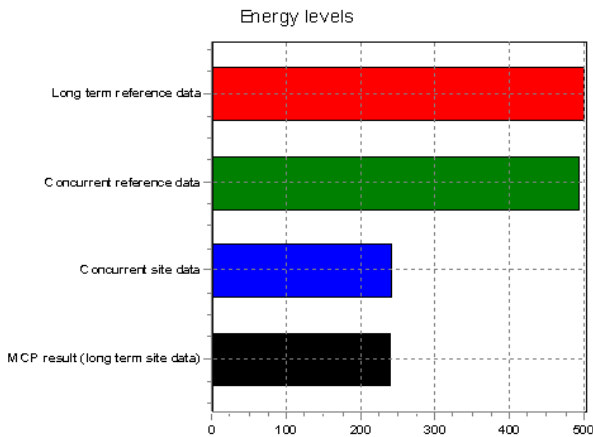
The (Linear) regression tool enables the user to inspect the fit directly through an animated graph. If the fit is not satisfactory, a wide range of parameters may be fine-tuned to provide a better fit. The regression tool is not limited to linear regression, but also higher order polynomials may be used in modeling wind speeds and wind veer.

11.1.3.3 Matrix Method MCP



The matrix method in WindPRO models the changes in wind speed and wind direction through a joint distribution fitted on the ‘matrix’ of wind speed bins and wind direction bins. The user may choose to either use polynomials fitted to the data statistics or – where appropriate - to use the measured samples directly when doing the matrix MCP.

11.1.3.4 Weibull Scale MCP

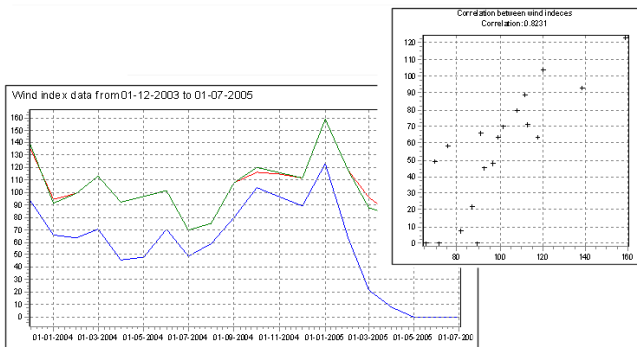


The Weibull Scale method is a very simple empirical method, which does its manipulation directly on the Weibull form and scale parameters (A,k) as well as on the frequency distribution.

The Weibull scale method has the advantage, that it will match the nature of the wind at most places, but beware that application of this method should be done with caution on locations with significant non-Weibull distributions.

11.1.3.5 Wind Index MCP

Period	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	55.4	94.4	83.5	46.4	26.4	24.0	35.1	24.5	58.7	79.8	104.0	-	90.9
Standard deviation	36.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0
Minimum	0.1	65.8	63.4	22.0	7.5	0.1	0.1	0.1	58.7	79.8	104.0	-	88.9
Maximum	123.1	123.1	63.7	70.9	45.3	48.0	70.1	48.9	58.7	79.8	104.0	-	92.9
Number of samples	19	2	2	2	2	2	2	2	1	1	1	0	2



The index correlation method is a method typically making the MCP analysis by using monthly averages of the energy yield, thus disregarding the directional distribution of the winds. Even though this method may seem rather crude and primitive when comparing to other more advanced MCP methods, it has its advantages in stability and performance – even in the cases where other MCP methods seem to fail.

The Wind Index MCP method in WindPRO offers the opportunity to calculate the wind indexes using real power curves from the wind turbines included in the wind turbine catalogue in WindPRO. Also a generic power curve may be chosen.

11.1.4 Step by step guide

Prepare two time series in one or two Meteo objects: a local data series (short) and a reference data series (long). See chapter 3.3.2 for details. Prepare eventually several long term reference data series, where more ON-Line data sources typically are available.

Set up a site data object for purpose Statgen with link to roughness, orography and obstacle description. See chapter 3.3.1.1 for details. (Only needed if you want to use the WAsP method later)

Start calculation module MCP from the main menu.

On **Measure** tab sheet, select the local data series and the reference data series and press Load data. Inspect the time series and make any necessary filtering of the local or reference data. If any filtering has been selected press “*apply filter values to time series*”.

Go to **Correlate** tab sheet and press Load data to get the time series of the concurrent data points.

Inspect the data and test for correlation. There are many options for that. Use e.g. the Graphics - Correlation feature or print the Report. That might give feed back on periods with erroneous data. These can be disabled, easiest at the Graphics – time series by right clicking on the graph for isolating and disabling of data periods.

Go to the **Predict** tab sheet. Select a prediction method: Regression, Matrix, Weibull scale or Wind index method.

Each method has individual settings, but all has reasonable default parameters, so it is possible to click next through the pages without selecting any specific parameters.

Linear regression and Matrix produce a graph comparing observed and predicted values for the concurrent period. Wind index compares local and reference monthly index.

Run a **Statgen** calculation producing a wind statistic by default at the end of the prediction run. Note: Requires a Site data object for Statgen and the WAsP software.

Run eventually additional methods (or change to other long term reference data, which require you go back to “load” on the Measure tab). Each result is listed in the Predict table for easy comparison.

It is possible to go back to the Measure tab sheet and select a different reference and then repeat the process and compare results both based on different methods and reference data.

View reports on individual combinations of reference data and methodology and hopefully get an idea of what seem to work best or find an average between the ones you feel comfortable with.

Select the best qualified and either **Save wind statistic** or **write to METEO**, which will create a Meteo object at the location of the local Meteo object with the long term corrected data.

Exit the MCP module with OK and “Start calculation” (Generate report and save the settings/results for later inspections/modifications).

Create a Site data object for WAsP calculation selecting the newly produced wind statistic. You can now perform an energy calculation (e.g. PARK or wind resource map).

11.2 MCP users guide

11.2.1 Preparation for a MCP

11.2.1.1 Meteorological data

Before running an MCP calculation, data must be prepared. Essentially the MCP requires four sets of data:

Site data

Long term reference data

Concurrent site data

Concurrent reference data

If data exist as time series it is only necessary to specify the site data and the reference data. But if the long-term reference is only available as an accumulated distribution (a .tab file or weibull) then the concurrent part of the reference must be available as a time series and thus three data sets are needed (two for the reference and one for the local data).

The data sets are prepared in the Meteo object. For details, please refer to chapter 3.3.2. It is important that the Meteo object with site data is located on the actual location of the mast and with the correct measurement height; but the position for the reference data is irrelevant.

11.2.1.2 Site data object

In order to get the full use of the MCP module the user can prepare a Site data object for purpose Statgen. Here a description of roughness, orography and obstacles around the local mast must be defined. The reason for this object is that the MCP module can calculate a wind statistic based on the long term corrected data and thus save you the extra step of running a STATGEN calculation. If you do not have WAsP interface module or do not wish to calculate a wind statistic from the MCP module you can skip the Site data object and instead write a long term corrected time series data set to a Meteo object. For details on the Site data object please refer to chapter 3.3.1.

11.2.2 Measure

11.2.2.1 Loading data

Start the MCP calculation from the main menu by left-clicking the MCP text or by the green arrow. If the arrow is yellow you do not have a valid license for this module.

You enter the MCP calculation on the Measure tab sheet and will work your way through the tab sheet towards the right. The Measure tab looks like the window below.

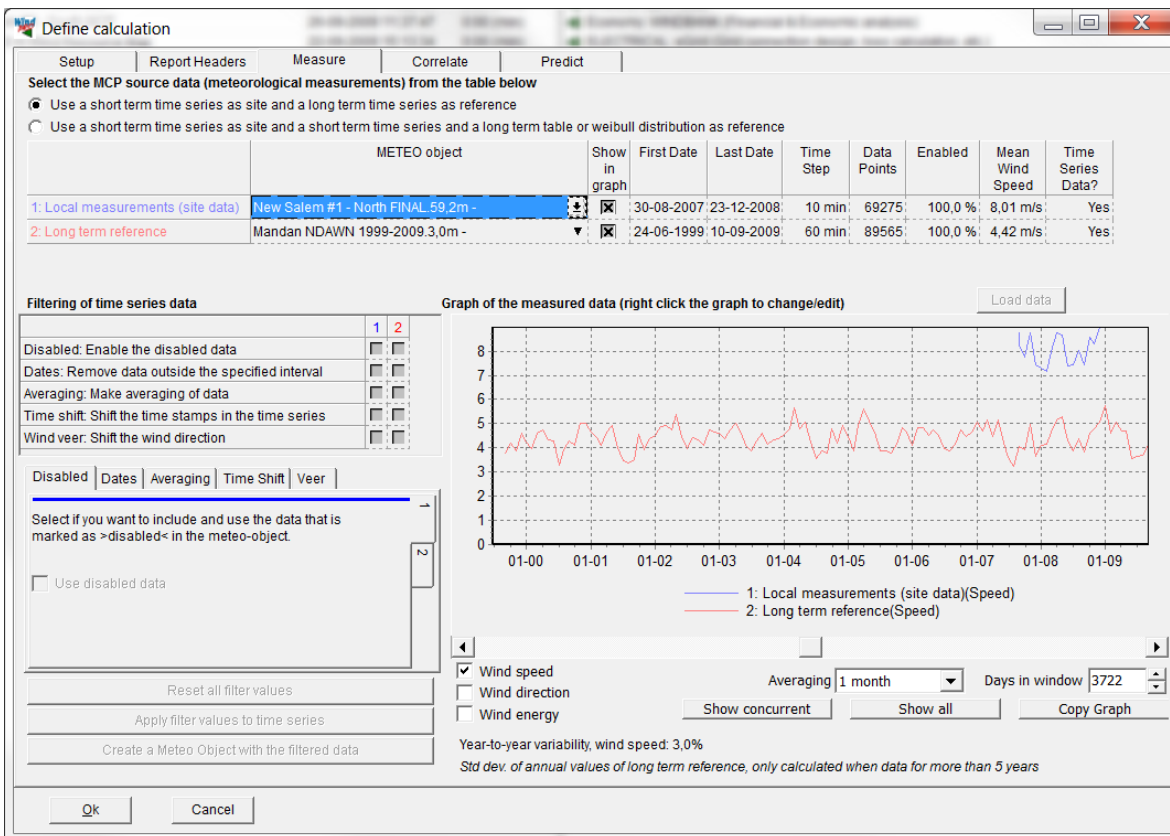


Figure 1 Note that the Year-to-year variability is calculated for the long term reference (if at least 5 y) and shown in the lower part of the screen. This can be used later in the LOSS & UNCERTAINTY module.

The first thing to do is selecting local measurements (site data) and long-term reference. Click on the little arrow by Select data next to Local measurements to select the Meteo object and height holding the local data. It may take three clicks to activate, select and open the selection menu. Repeat this for the long-term reference data. NOTE: If the long term reference data do not hold a time series, there will automatically appear a third line for selecting the concurrent reference data when you press LOAD data.

Press LOAD data to accept the selection and load the data. The full period time series will now appear in the graph window. If the 3rd line appears, select concurrent reference data time series and press LOAD data again.

The local data are identified with a blue color and the reference with a red color.

Use the selection buttons below the graph to select between wind speed, wind direction and wind energy index (using generic power curve unless otherwise specified). As default an averaging of 1 month is used on the data for display purpose, but this can be changed with the Averaging selection. Also the number of days in window can be changed. A more useful view can be obtained by pressing the Show concurrent button, which limits the view to the concurrent period. Show all reverts to the full period as defined by the long-term reference.

NOTE: The most important task at this screen is to evaluate if the long-term data seem to be consistent. Often long term reference data from meteorological offices has a trend. E.g. trees have grown up around the reference mast over the years and the wind speed decrease continuously. Such data cannot be used for long-term correction! One way to see if it is so can be to start loading an alternative source for long-term data, e.g. the EMD-Online data from NCAR as "Local data" and then compare the two long-term data series.

11.2.2.2 Filtering the data

The blue and the red graph provide a first visual indication of correlation. Matching graphs mean that variations in climate are represented in both data sets, which is a minimum requirement for correlation.

However data can be offset in different ways that can hide or spoil a good correlation. Such offsets can be compensated using the filtering options on the left side.

The upper part contains check boxes for each type of filtering, where it can be selected whether the filtering should be done to the local data or the reference data. The combinations selected become active in the lower part.

The lower part holds five small tabs referring to five different kinds of filtering. Each tab is divided into two vertical tabs referring to local data (blue) and reference data (red). The possible filter settings are:

Disabled

Here it can be selected whether the data, which was disabled in the Meteo object, should be included in the MCP calculation. By default the disabled parts are not included.

Dates

A specific period can be selected, which excludes data outside this period.

Averaging

This averages the data selected and it is possible for example for create hourly average values based on 10 minute data series. The averaging is a moving average and is made on the preceding period up to the time stamp indicated. Since the averaging time for local data should be the same as for reference data. This function is particularly useful when the reference data are hourly or 3-hourly data, but an average of the period and not the standard last 10 minutes of the period.

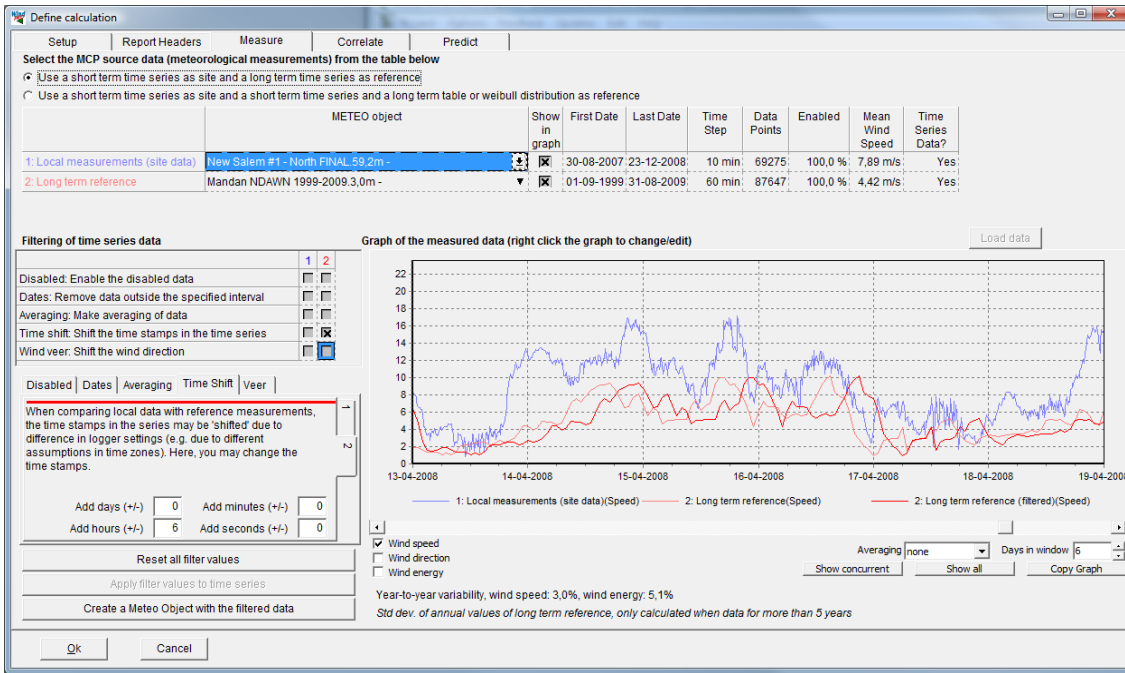
Time shift

If there is a time shift between local and reference data this can be corrected here. Days, hours, minutes or seconds can be added or subtracted. Since some of the correction methods build a transformation between matching concurrent data, it is important that the time stamps refer to the same moment in time.

Wind veer

Adds or subtracts an offset in the direction to local or reference data.

When one or more filtering options have been selected and specified, press Apply filter values to time series. You will now notice that the time series you filtered have split in two: a fat graph, which is the filtered values and a thin line, which is the unfiltered data.



Reset all filter values will reset your settings. Create a Meteo Object with the filtered data will just establish a Meteo object at the location of the Local data with the filtered data time series at local data measurement height.

11.2.3 Correlate

The idea with the Correlation tab sheet is to test for the correlation of the concurrent datasets. Actually this is a process that started in the Measure tab and will continue in the Predict tab when the individual prediction method has been chosen (and thereby also different correlation methods), but the Correlation tab is the place where much of the correlation analyses will be done.

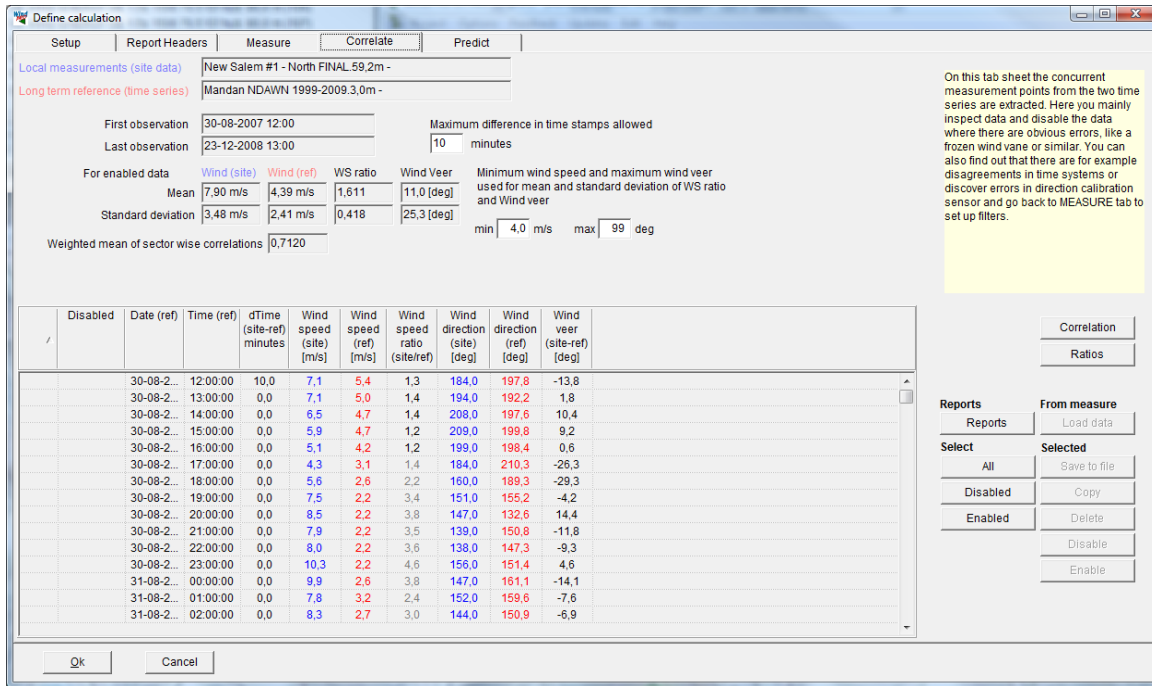
Correlation is simply when a systematic relation between the two data sets can be found. This relation can be linear, polynomial, nonlinear or on an aggregated monthly level. The point in analyzing the correlation is that if the correlation between the local and reference data are too poor, the long term prediction will also be poor, and in worst case give massive errors in the later calculated energy production. Reasons for poor correlation can be that the reference mast has another wind climate than the local mast, e.g. at the other side of the mountain, where wind conditions could be totally different. But poor correlation could also be due to poor data quality based on e.g. systematic errors in data collection equipment. If just parts of the concurrent data do not correlate well, these can be disabled. A reason could be temporarily frozen equipment in one of the data sets. Then only the well correlating data will proceed to the prediction models.

NOTE: The purpose of the correlation analyze is NOT just to disable all non-correlating data. This would give a false basis for the prediction. If the correlation in general really is poor an extract of the few good correlating data for the prediction might result in large errors!

11.2.3.1 Loading data

Go to the Correlate tab sheet and press Load Data. This will extract the concurrent period of matching time stamps from the Measure tab. If a filtering has been applied it is the filtered data, which are loaded.

WindPRO can allow a specified deviation in the time stamp between local and reference data and still call them concurrent. This allowance can be specified in the Maximum difference in time stamps allowed box.



The concurrent data are organized in a long table, which can be inspected directly in the table. Sort the table by columns by clicking on the column header. While all concurrent data are included in the table wind speeds less than a specified velocity and records with difference in wind direction larger than a specified veer are grayed out and not included in the calculation of the correlation. Standard limits are 4 m/s and 99 degrees.

11.2.3.2 Correlation

At the tab “Correlate” some basic statistics on the wind speed, wind speed difference and difference in wind direction (Wind veer) is shown. Below these is the key figure “The weighted mean of sector wise correlations”. This is the correlation boiled down to a single figure. It comes from the correlation calculated for each 30-degree direction bin weighted with the frequency of that particular sector at the reference.

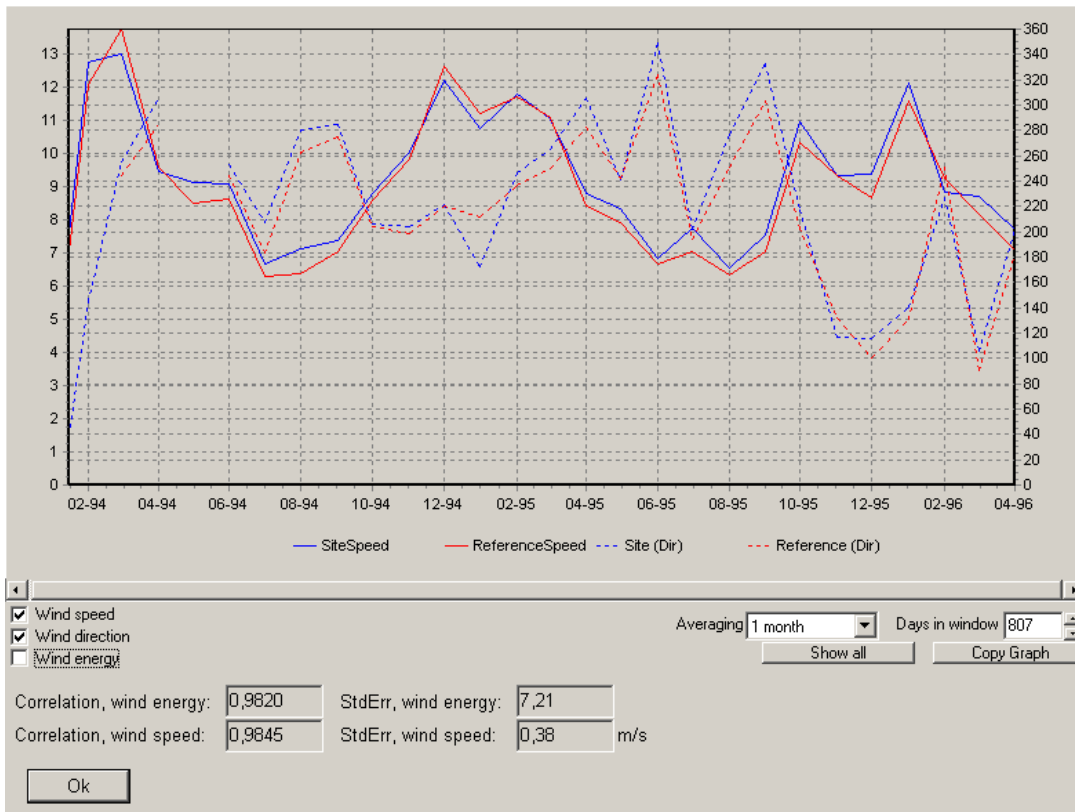
Correlation Coefficient	Quality of reference
0,5 to 0,6	Very poor
0,6 to 0,7	Poor
0,7 to 0,8	Moderate
0,8 to 0,9	Good
0,9 to 1,0	Very good

The table gives a qualitative rating of the quality of the reference as a function of correlation value. It is not certain that a high correlation means that the reference is good and likewise, a poor correlation can be sufficient for a good prediction. However, the correlation coefficient is a good indication of quality.

If a linear regression is performed, the correlation coefficient is identical to the “r” parameter. In Excel “r²” is often given when doing regression analysis, but the connection to the correlation coefficient is only valid when the regression is linear.

The right side buttons on the Correlate tab

The “Correlation” button presents the concurrent period as yearly, monthly, weekly or daily averages, or not averaged at all.



It can be selected to show the wind speed, wind direction or wind energy index (calculated by specifications on the Setup tab sheet). Correlation and Standard error is calculated based on the chosen averaging.

The object of this display is to give a visual impression on the correlation during the concurrent period. The two datasets must hint at the same climate and so catch the same highs and lows. With the wind energy index a representation is given on what kind of relative production can be expected for each month, as this is often what really matters.

Report

Reports

- Measure data - overview
- Concurrent data - overview
- Concurrent data - wind speeds
- Concurrent data - wind veer (direction)
- Concurrent time series plot - wind speeds
- Concurrent time series plot - wind veer (direction)

Report language (local for these reports)

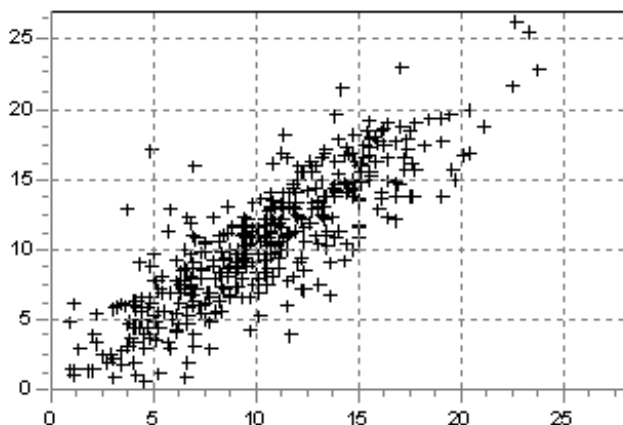
English

The report button gives a number of detailed results of the analyses visualized and documented.

A few examples are shown here, but the reports are in general self-explanatory.

Correlation in sector from 225 to 255 degrees

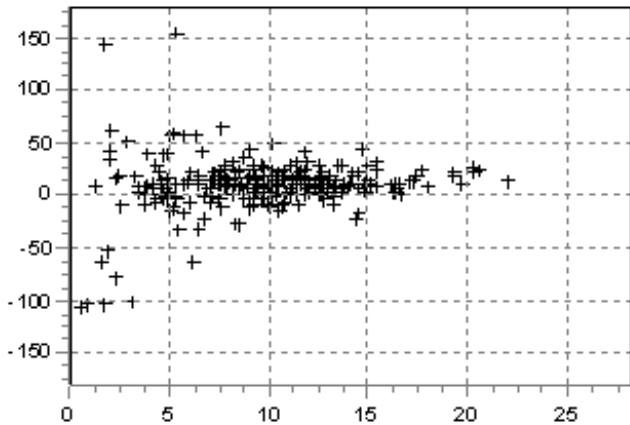
Correlation: 0,8493



Wind speeds: Site data as function of reference data for each sector with calculated correlation.

This is the correlation typically referred to. If there is no good correlation it could be due to a change in wind direction. This issue some of the prediction methods handles, so even with a poor correlation here, the final results might come out quite well.

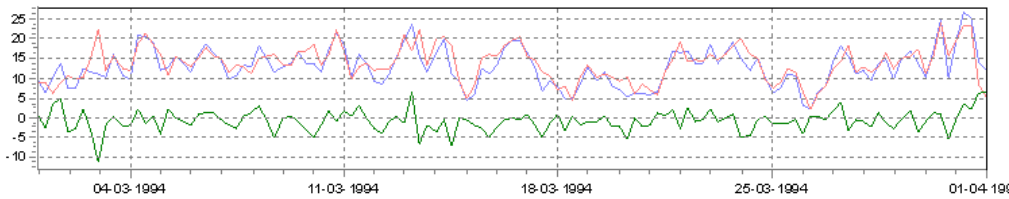
Correlation in sector from 105 to 135 degrees
Correlation: 0,1435



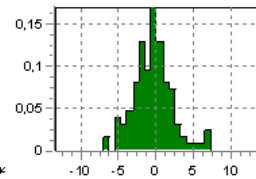
Wind veer for each sector as function of wind speed.

What is interesting here is not so much the correlation value, since the direction change should be independent from the wind speed. Actually, the veer should be constant with the wind speed. At low wind speed the veer varies significantly, but at higher wind speeds where the transformation function must perform well the veer must be well defined and not changing with wind speed.

Time series data from 01-03-1994 to 01-04-1994



Distribution of deviation
Mean = -0,6, StdDev = 2,6



Time series sections with wind speed differences.

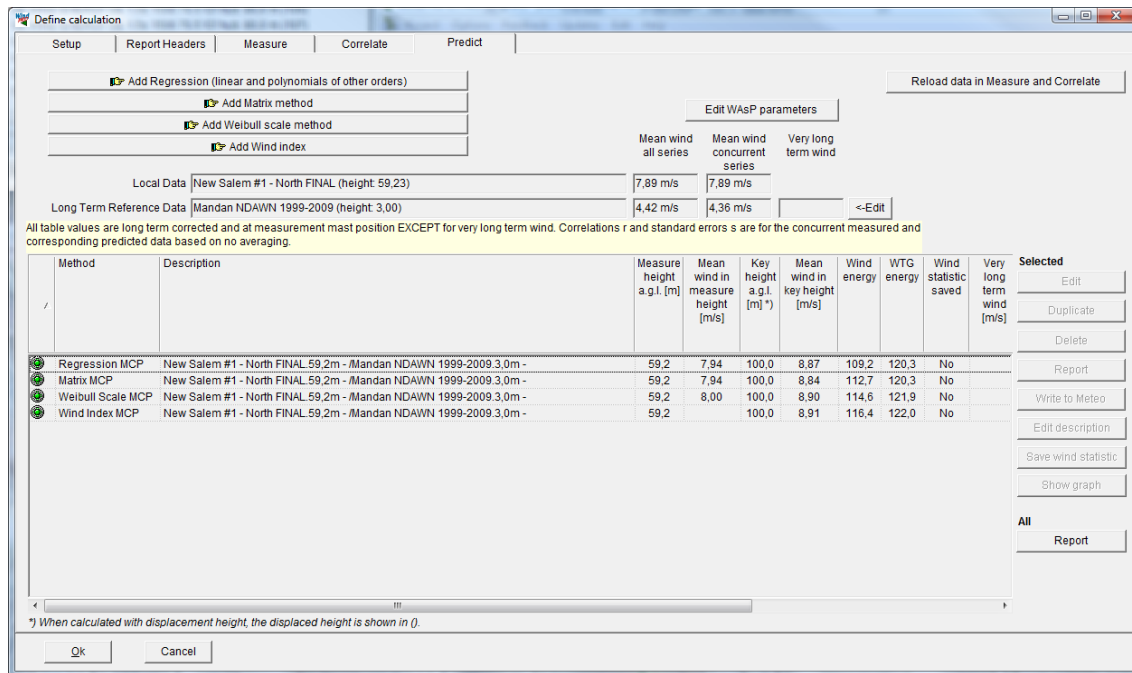
Extracted sections of the time series with the wind speeds of the reference and of the local data, and the deviation of the wind speeds. For each section the deviations are plotted in histograms and will most often resemble normal distributions, which confirms or refute whether the Matrix assumption is valid (see later).

11.2.4 Predict

Go to the Predict tab to perform the actual corrections and predictions.

Here four different methods can be applied on the data sets chosen in Measure and for the concurrent part extracted and fine tuned in Correlate. When a method has been applied the result will appear as a row in the lower part of the form and another method can be applied resulting in a second row. In this way a number of different methods can be tested with different parameter settings. Another reference can also be selected in the Measure tab and loaded through correlate to compare with the first selection.

When a preferred setting has been found the relevant calculation can be selected and either saved as a wind statistic with the "Save wind statistic" button or written to a Meteo object at the location and height of the local data with the "write to Meteo" button.



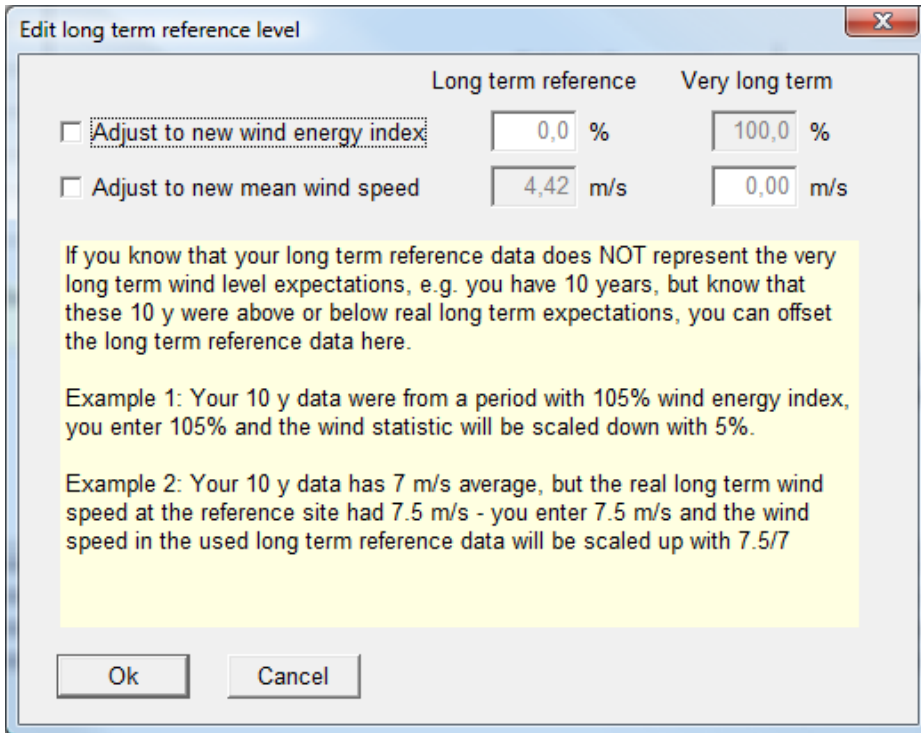
At the "predict" form different prediction methods can be started and the results evaluated, compared, reported and saved as results, either in a Meteo object or as a wind statistic.

Data basis

The data resource for the prediction is listed in the two rows in the top; Local data and Long-term reference data. These rows give the mean wind speed of the entire length of the data set and the concurrent part.

WindPRO will retain information on which time series were used the last time the MCP calculation was run, but it will need to reload the data series every time you restart the MCP calculation. Pressing the "Reload data in Measure and Correlate" is a one-touch way to do that.

If it is known that the correct long-term level (here called the very long term level) is different from that of the long-term reference it is possible to change this with the Edit button.



The adjustment of wind energy index level makes a correction to the resulting wind statistic, which is applied when it is used to calculate production output.

The adjustment to a particular new mean wind speed adjusts all the wind speeds in the resulting time series so the new average becomes this value.

11.2.4.1 Long-term correction methodologies

The long-term correction methods are described in detail in the theoretical section. The following text only deals with the practical application and gives a short guide to best practice.

Regression and the **Matrix** methods are both classical MCP methods. They build a transformation function based on the concurrent data, which is used to convert the reference data to the conditions on the site of the local measurement. The success on this conversion is largely based on the ability to successfully transfer the reference data to the site and, secondly, consistency in reference data outside the concurrent period with the local data.

The first requirement is covered by the correlation coefficients, but this should include a well-defined relation between the wind directions at the two sites and a sufficient frequency of measurements, particularly for the reference data. Well correlating ground stations will usually be predicted well with these methods, while reanalysis data will often be too infrequent and with too poor directional correlation to give an adequate prediction. If the relation is linear of nature the Linear regression method will often be a good choice, while non-linear relations are often best handled by the Matrix method.

Long-term consistency is more difficult to detect from the data. Sudden jumps in data or sloping trends can indicate inconsistency. This is most easily detected when comparing two different long term data sets in the Meteo objects (or at the measure tab sheet by loading an alternative long term data series as local data). But most often the inconsistency will be detected by studying the history of the metering. The most common sources for inconsistency are:

The mast has been moved

The anemometer was changed to a different height

The anemometer was replaced with another instrument of different calibration

Houses or trees were placed or removed from the fetch of the mast

Growing trees are a particularly sneaky contamination because it happens gradually over many years.

Particularly low masts are suspect to this kind of influence

It is more difficult to look at the history of reanalysis data because they consist of so many different sources of input. That makes them less vulnerable to individual contamination, but not impregnable and the sources have been changing over time.

As a rule of thumb reference data can be used as far back as the latest source of inconsistency.

When the quality of the reference is not good enough, like with reanalysis data, the **Wind index** method is an option. With this method the energy study is performed on the actual measured data and only the final result is adjusted with a correction factor. This factor is based on the relationship between the entire reference and the concurrent part of the reference and only relates to wind speed converted to wind energy. Therefore a wind direction correlation is not so necessary and a good match on the matching concurrent data points is not so important if the correlation exists on the larger scale, like monthly basis.

The **Weibull scale** is the maverick method that does not really involve a transformation function and with a linear scaling of the Weibull parameters does not even involve good math. Nevertheless, because it scales the wind data with the distribution that best describes them, it is able to predict the long term wind regime surprisingly well. Therefore it is an excellent second opinion method that attacks the problem from another angle.

11.2.4.2 Regression model

To run the Regression model press the Add Regression button.

This opens the parameter selection window. The parameters are pre-selected with settings and values, which will be suitable for most situations. Only in cases where special tests are wanted or data require special attention there will be a need for change of parameters.

The screenshot shows the 'Regression MCP' dialog box with the following settings:

- Transfer Function Setup:**
 - Find transfer function for each 1 degree:
 - Find transfer function for each sector:
 - Sector window [deg]: 30,00
- Data Constraints:**
 - Skip angle differences larger than [deg]: 360,00
 - Skip wind speeds less than [m/s]: 2,00
- Wind Speeds: Regression Model:**
 - Regression Model: Linear (1st order polynomial) (recommended)
 - Residual Model: Advanced Gaussian: Mean and std.dev. conditioned on win
- Wind Directions: Regression Model:**
 - Regression Model: Constant (0th order polynomial) (recommended)
 - Residual Model: No model (recommended)

A yellow highlighted text box at the bottom of the dialog reads: "Residual resampling" means that the information from the scatter of the regression analysis is used in the modelling of the long-term corrected time-series, not just the average (or direct use of the regression line). This generally improves the long-term correction, that can otherwise be biased based on the regression method used. Using the advanced 1st Order Gaussian model, which takes into account the change in standard deviation versus wind speed is experimentally proven to give the most correct result, while using either no model or the normally distributed Gaussian model tends to give biased results. Using the advanced 2nd Order Gaussian model is only recommended for experimental use!

The dialog box has a 'Name' field containing 'New Salem #1 - North FINAL.59,2m - /Mandan NDAWN 1999-2009.3,0m -' and 'Next >' and 'Cancel' buttons.

Parameters for transfer function calculations including residual resample model.

The parameter settings are from the top down:

Transfer function type - Sector handling

The transfer functions can be made for either x sectors or for 360 directions, meaning 360 transfer functions. Division in a number of sectors (typically 12) is the typical way for “home made” Excel applications. This should be chosen for comparison with such calculations. But letting the software tool do the hard work, making 360 transfer functions based on a specific window size will be more accurate and is here chosen as default.

Sector window

Each transfer function will be made on the basis of data from a range of directions centered on the direction in question. The directions refer to the reference directions and 30 degrees is default. If 360 are chosen only one transfer function is made based on all data.

Skip angle difference larger than

Particularly at low wind speeds the angle between matching reference and local data may deviate significantly and cause a lot of noise. By rejecting point with large difference in direction this noise can be reduced. However this means discarding information that could be important. Default all data are included.

Skip wind speeds less than

As very low wind speed contribute with a lot of noise and often deviate from the linear relation seen at higher wind speeds it is useful to simply discard them from the transformation function. This does not mean that they are discarded from the full reference data set being transformed though. Depending on the amount of noise and actual wind speeds at the reference this limit can be set freely but 2 m/s is default.

Regression model (wind speed)

Here the type of regression on the wind speed is selected. Linear regression means first order and a two component linear regression will usually be preferable to a regression through origo (0,0) as this provides a better fit in the wind speed range relevant to production. This is also default. An alternative is a 2nd order regression, which will fit a parabolic curve to data. This may create a better fit, but allow deviating extreme wind speeds to influence the fit at high wind speeds.

Regression model (wind direction)

Usually the direction change is independent from wind speed and so a 0th order regression should be used.

Residual model

The residual resampling method from v2.5 had the limitation that the regression plot needed to have the same spread in the scatter at all reference wind speeds and that the scatter had to be centered on the regression line. Basically the transfer function became $y = ax + b + e$. Applying this method on data sets with poor correlation or oddly distributed scatter could lead to an error, often seen as an over-prediction. In such cases the advice would be to simply not do residual resampling.

In v2.6 and later it is still possible to perform the residual resampling in the same way as used in v2.5. It is now called “Gaussian resampling”. In addition we have added an “Advanced Residual Resampling” method. This method is a function of the reference wind speed so that the regression formula now is: $y = ax + b + e(x)$. The reference wind speed range is divided into a number of intervals. Within each interval the observed scatter is found as a standard deviation of the scatter together with the bias on the observations. Both are then applied when transferring the reference data to the site. The bias of the mean of data can be illustrated by switching on a LOWESS fitting to the regression curve. The observed standard deviation is modeled as either a first or a second order polynomial and is displayed in the scatter plot on the right (see Figure 52). The result is a much more dynamic fit than a standard linear regression. On well and fairly well correlating data, internal tests have shown a significant improvement on the precision of the long term prediction. The second order residual resampling do have the problem that few very scattered points at high wind speed can exaggerate the resampled scatter unreasonably. It is therefore recommended to use it carefully and if in doubt stay with the default first order advanced Gaussian residual resampling.

Press Next to calculate the regression functions.

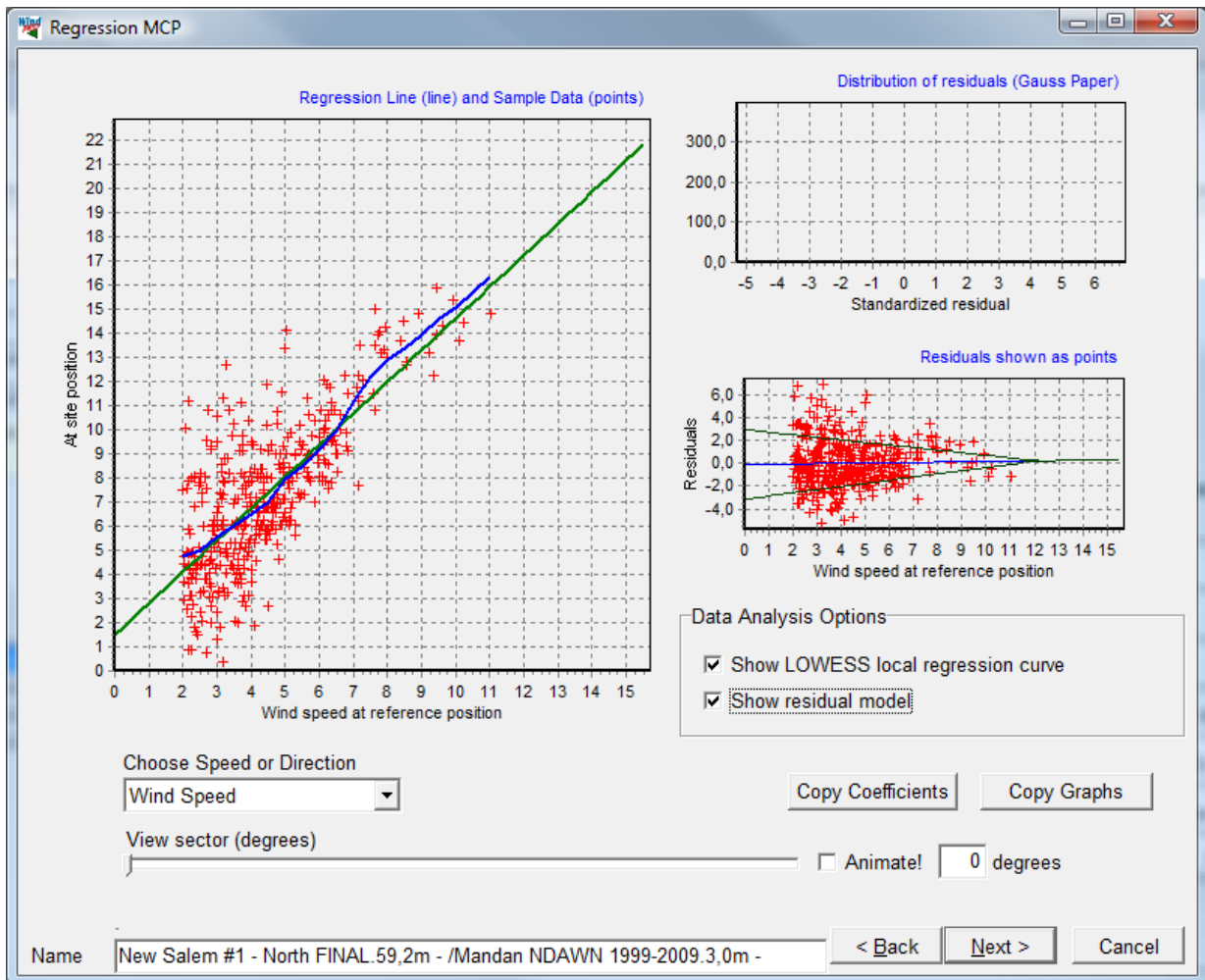
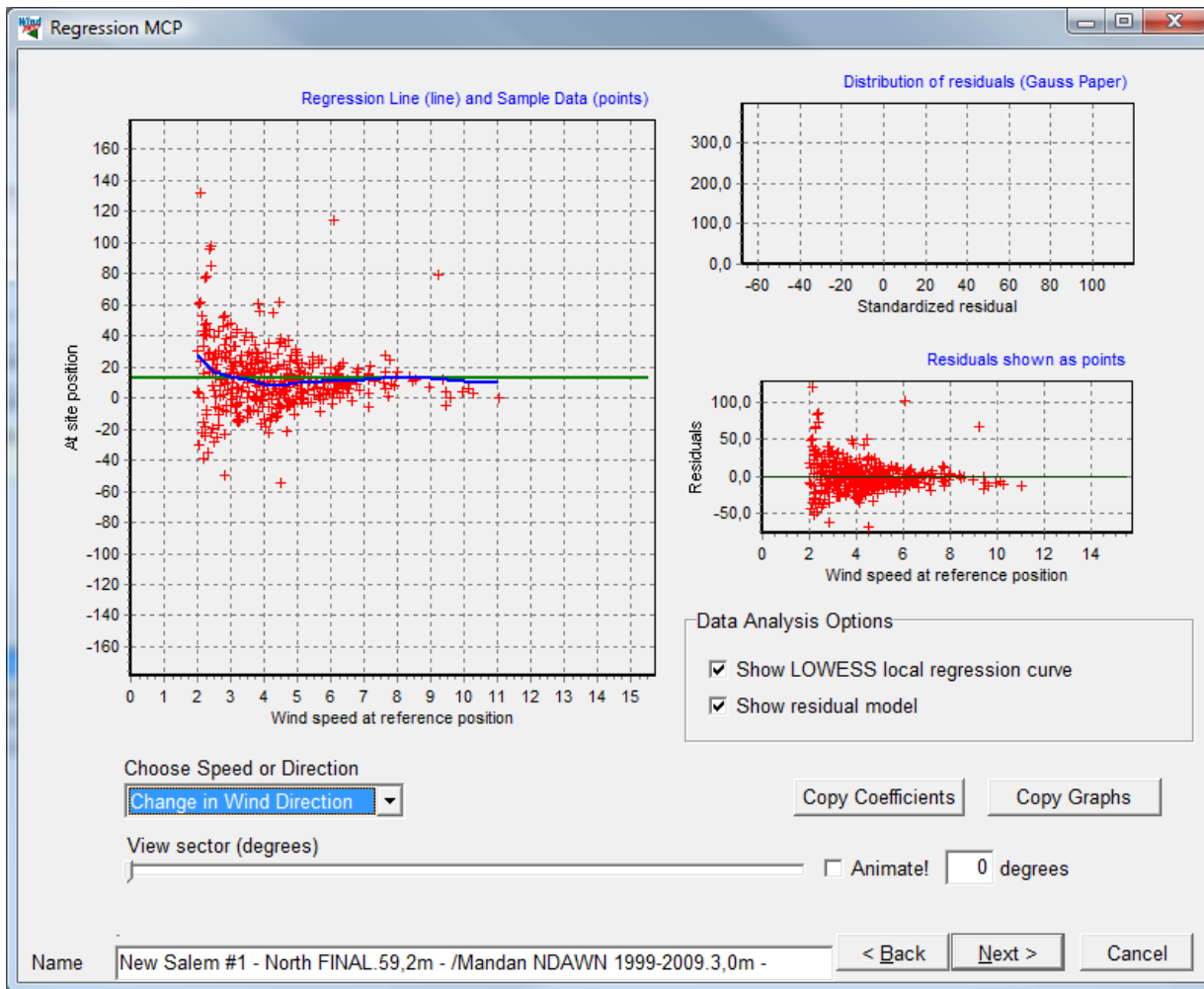


Figure 2 Linear regression fitting illustrating the LOWESS local regression curve (blue fitting) and the advanced residual model (green curves in scatter plot).

Three graphs are presented as described in the theory: The site wind speed against the reference wind speed and the best fit, the residuals and the distribution of residuals.

The presentation of the regression fits is divided into a wind speed page (above) and a wind direction page (below). The wind direction for which the regression has been made can be viewed using the bar or the selection field below the graphs. Animate will slowly scroll through the directions. The direction shown is the center angle and the points shown those within the window width specified at the previous form.

The closer the data points are to the regression fit the better prediction can be expected. How much the residuals scatter can be seen on the Residuals shown as points plot, where the modeled residual re-sampling is also shown. If this modeling of the residuals seem to fit the actual distribution of the residuals the residual model is a good choice to the transformation.

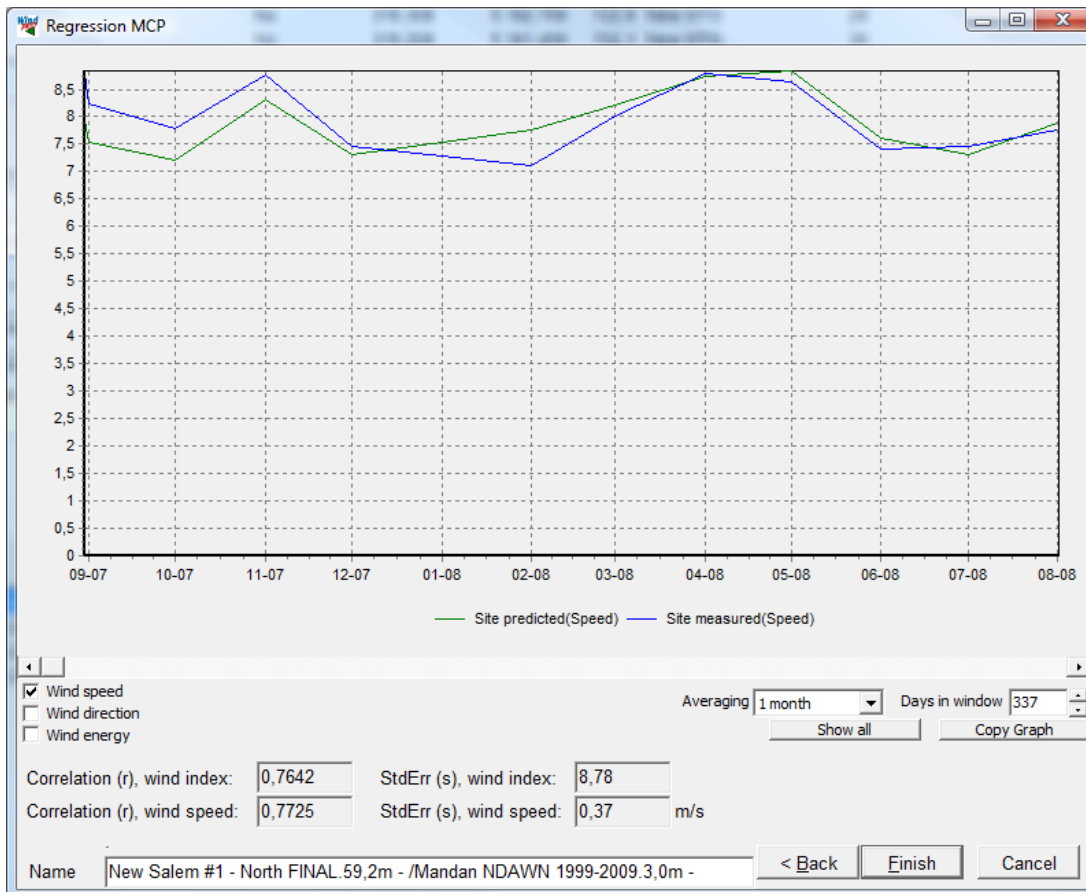


The wind direction page is similar, though the regression fit is different. Direction changes get better defined with higher wind speed but the average value should not change.

Copy Coefficients will copy the regression parameters to the clipboard (typically for paste into Excel) in 15 degree sectors, while Copy Graphs will copy the graphics to clipboard (typically for paste into documentation).

The wind direction page is similar, though the regression fit is different. Direction changes get better defined with higher wind speed but the average value should not change.

Press Next to perform the conversion and test how close the prediction is to the measured values.



Comparing predictions with the measured data is the “ultimate” test of how well the prediction model performs.

This page is similar to the Correlation graph of the Correlation tab, except for a few extra key result fields. The correlation on wind speed and wind energy tests the correlation between the predicted and the measured wind speed using the selected averaging. Because of the smoothing over the longer periods this parameter often correlates better with a longer averaging, but such a correlation is not comparable with correlation using shorter averaging periods. The standard error gives the typical difference between concurrent values in the resulting graphs.

For a transfer function to perform satisfactorily it must be able to transform the concurrent part of the reference time series into something resembling the measured time series. A good correlation on monthly energy averages is a good indication of successful prediction of production output.

When pressing finish, WindPRO asks to continue to generate a wind statistics (or just end with the meteo data). The wind statistic will be based on the entire long term corrected local data set.

To start the calculation of a wind statistic the program will call WAsP. Two calls will actually be made: One for generating the windstatistic and one for calculating the wind speed based on the wind statistic – both based on the coordinates of measurement mast position.

A row will have appeared with key figures for the calculation. The row will contain the following parameters:

Measurement height of local data

Predicted mean wind speed at measure height (based on Weibull fit)

The key calculation height selected in the Setup tab

Predicted mean wind speed at key height based on a WAsP calculation

Relative wind energy level for using the wind statistics relative to 3300 kWh/m²/year for roughness class 1 and 50 m hub height

Relative WTG energy level for using the wind statistics relative to 1025 kWh/m²/year for roughness class 1 and hub height 50 m. This figure is directly related to the production output resulting from using these data. That makes it possible to compare the consequence of applying different models, parameters and references directly measured in relative calculated wind energy production.

A flag set if the wind statistic is saved.

The very long term wind speed level

The very long term wind index

Correlation factor r on individual measured and predicted wind speed

Standard error on individual measured and predicted wind speed

Correlation factor r on monthly mean wind energy indexes

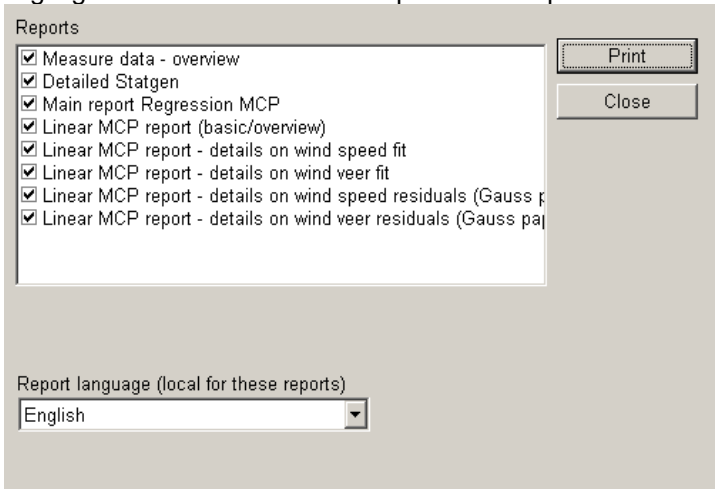
Standard error on monthly mean wind energy indexes

Time stamp for the calculation

To the left of the row a green button will indicate that the result up to date and ready for export. A red button indicates that the result needs to be rerun to be updated as the resulting time series and wind statistics are not preserved when leaving the MCP module. A yellow button means that the raw data needs to be reloaded before updating the calculation.

Regression report

Highlight the calculation row and press the Report button to view the result printout.



The available reports from regression MCP.

The reports should be self-explanatory.

11.2.4.3 Matrix

Press Add Matrix method to start the wizard. This opens the first parameter page.

Parameters for transfer function calculations.

The parameter settings are from the top down:

Sector window

Each transfer function will be made on the basis of data from a range of directions centered on the direction in question. The directions refer to the reference directions and 30 degrees is default. If 360 are chosen only one transfer function is made based on all data.

Skip angle difference larger than

Particularly at low wind speeds the angle between matching reference and local data may deviate significantly and cause a lot of noise. By rejecting points with large difference in direction, this noise can be reduced. However this means discarding information that could be important. Default all data are included.

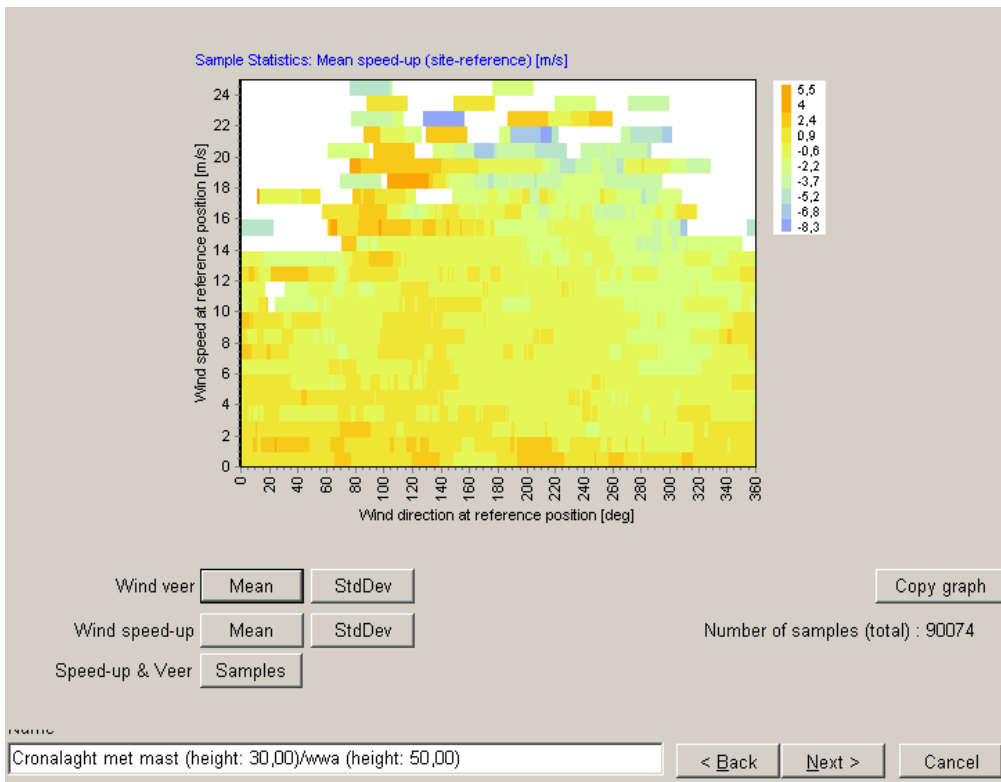
Wind speed window

Since the Matrix builds a list of possible outcomes for the transformation for each degree and each 1 m/s wind speed bin, you can decide to include also neighbor wind speed bins for each bin in calculation. Default only the wind speeds within the bin in question is used.

Press Next to calculate the measured relations between reference and local data for concurrent data sets.

The distributions are plotted in colorful plots presenting the mean and standard deviation of the lists of wind speed and wind direction changes registered for each bin. The color-coding indicates the magnitude. The standard deviation on the wind direction change is often large at low wind speeds, but decrease with higher wind speeds. In general the lower the standard deviation the better precision on the transformation, however it is a strength of the Matrix method that it can cope with the scatter.

The samples button presents a plot of the location of the concentrations of samples. This number is much larger than the actual number of concurrent data points because each data points typically are used like 30 times if a 30 degree window were chosen.



The measured transfer functions

Press next to proceed to the second parameter page.

Modeled transfer functions

Minimum records behind bin to accept in polynomial fitting:

Direction window size for polynomial fitting [Degrees]:

The Matrix model will calculate transfer functions for all 1 m/s wind speed and 1 degree direction bins based on interpolations/extrapolations in measured transfer functions using a polynomial fitting within a specified direction window size. Bins with too few records behind not will be used. To picture it, imagine a smoothing surface that will be "draped" on top of all the transfer functions to eliminate extremes and to establish correspondence to neighbor bins. As well average ratios/changes as standard deviations are a part of the transfer functions

Direction change [degrees]	Average	Minimum	Maximum	Polynomial order
Mean	14,55	-80,20	61,37	<input type="text" value="0"/>
Std.dev.	28,24	1,99	134,03	<input type="text" value="1"/>
Wind Speed ratios				
Mean	0,30	-4,02	3,98	<input type="text" value="1"/>
Std.dev.	2,41	0,38	5,97	<input type="text" value="2"/>

You can decide the order of polynomial to be used in the fitting process - normally you should not change the defaults. The statistic shown is based on the settings in the form "Measured transfer functions" - if you find this unacceptable, go <Back> and change.

Cronalaght met mast (height: 30,00)/wwa (height: 50,00)

< Back Next > Cancel

Set up for Matrix model calculation

Now the measured transfer functions will be converted to a “full model”, so also the direction-wind speed combinations that did not have enough data to get a measured transfer function, will get one. But also a smoothing of the calculated ones could be an improvement.

Minimum records behind...

To avoid bins based on very few data records to influence the model, these can be filtered.

Direction window size...

Transfer function regression will be based on all transfer function within a specific window width.

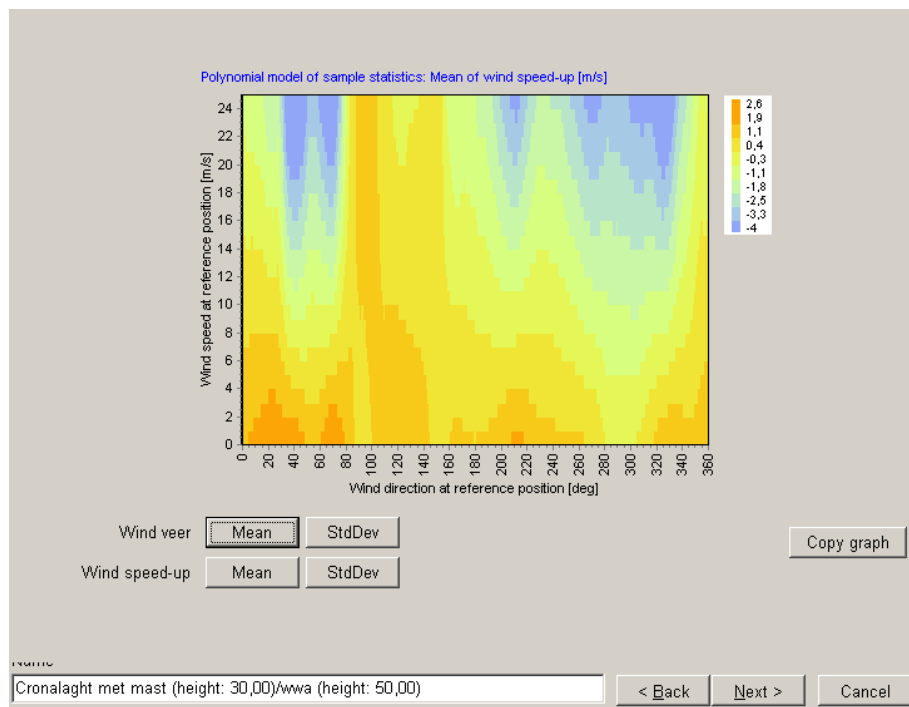
The observed extreme minimum and maximum values of mean and standard deviation on direction and wind speed change are listed. Extreme values indicate highly uncertain transformations. If this shall be changed, you must go back to the setup of the parameters for calculating the transfer functions.

Polynomial order

For each of the parameters a polynomial regression can be fitted to describe the transformation function. The order can be freely chosen and can even be different from parameter to parameter. The default choice for mean wind speeds is a 1st order fit as this is less sensitive to deviating extreme values. For mean change of wind direction a 0th order polynomial is default (wind speed independent direction change). For the standard deviations, 1st order higher is recommended for wind veer and 2nd order for wind speed.

Press Next to continue

On this display page the model parameters can be viewed in the form of mean changes and standard deviation of the changes.



The modeled transfer functions

Press Next to continue.

Matrix method output

Use modeled transfer function for all bins
 Use measured transfer function if the minimum number of data records the bin is based on is at least:

Using measured transfer functions bring the corrections closer to the observed nature. But the modeled might better smoothen out faulty/extreme observations and could be better if less good data quality.

Output options for transferring long-term reference data to local site.

Use modeled transfer function for all bins

If this is chosen only model transfer functions will be used, which give more smoothening. Alternative is to use the measured transfer functions directly, if at least x records behind the transfer function. Using measured transfer functions mean that each reference data point is transferred to the site by randomly picking a destination value among the observed values for that particular bin.

Original data

The data being converted with the transformation function will usually be taken from the time series and in that case be in sequential order rather than random order as this allows the predicted time series to be compared with the measured one. However if the full reference is only available as a directional distribution (.tab file) data must be taken from the table tab or the Weibull tab of the Meteo object and sequential transformation is not possible.

The next page is the comparison between predicted and measured data of the concurrent period. This page is described in detail for the Regression model. Note that because of the random scatter nature of the Matrix transformation the individual data records may be predicted less good than with linear regression. With longer averaging periods however this difference has been evened out.

When pressing finish, WindPRO asks to continue to generate wind statistics (or just end with the meteo data). The wind statistic will be based on the entire long term corrected local data set.

A new row is created in the history list.

Matrix report

Reports

- Measure data - overview
- Detailed Statgen
- Main report Matrix MCP
- Matrix MCP report (basic/overview)
- Matrix MCP report - details on wind speed fit
- Matrix MCP report - details on wind veer fit

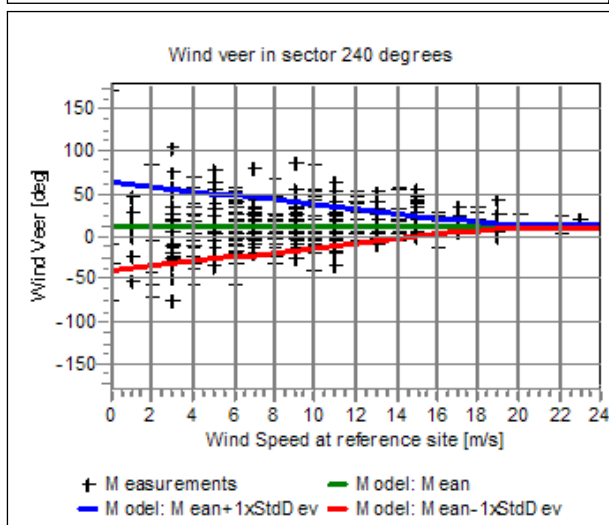
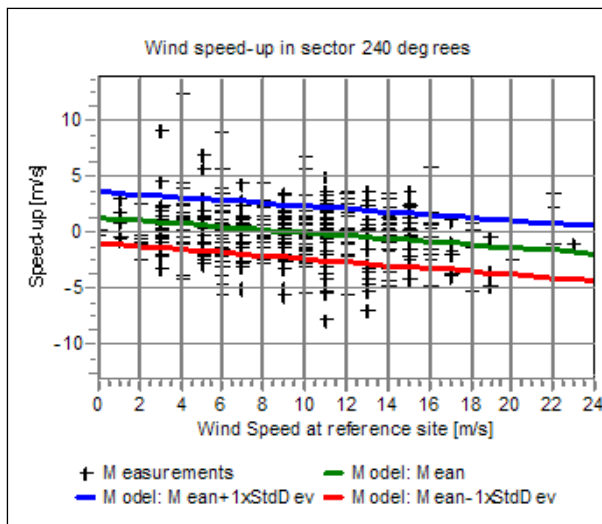
Report language (local for these reports)

English

Print

Close

Reports should be self-explanatory. Some examples from reports are shown below.

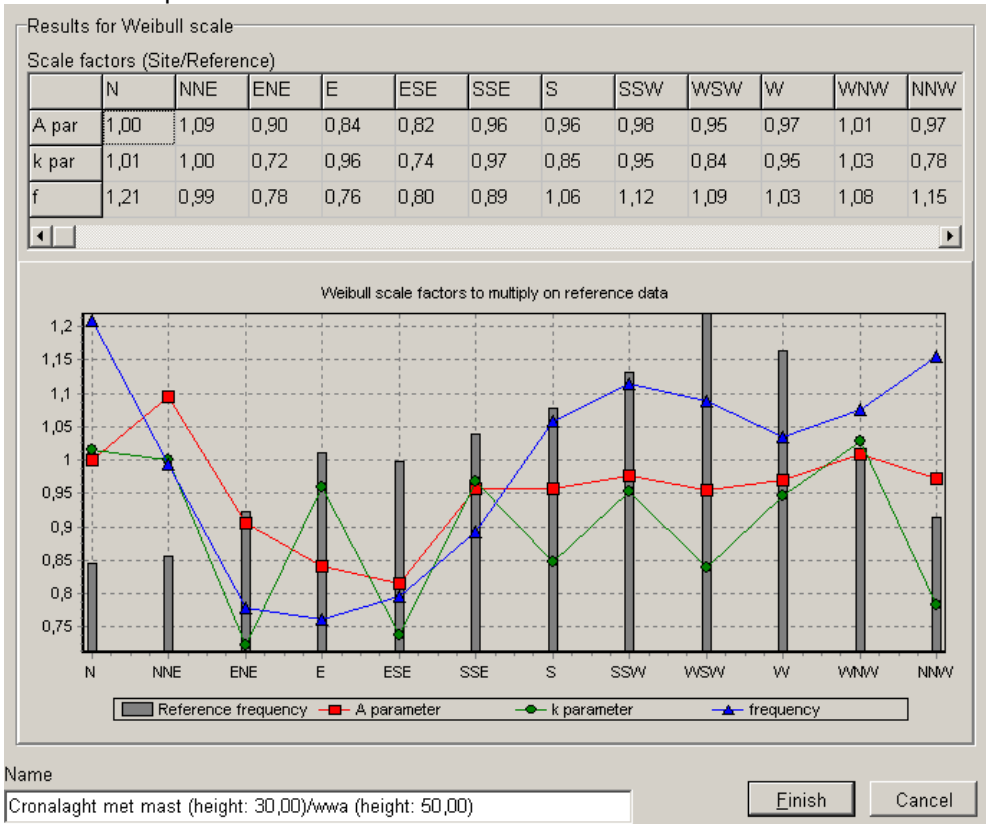


In the report each direction sector are plotted visualizing measurements and model.

11.2.4.4 Weibull scale

The Weibull scale solver is started by pressing Add Weibull scale method.

There are no parameters to be chosen.



Weibull scale shows the calculated scale factors for Weibull A, k and frequency.

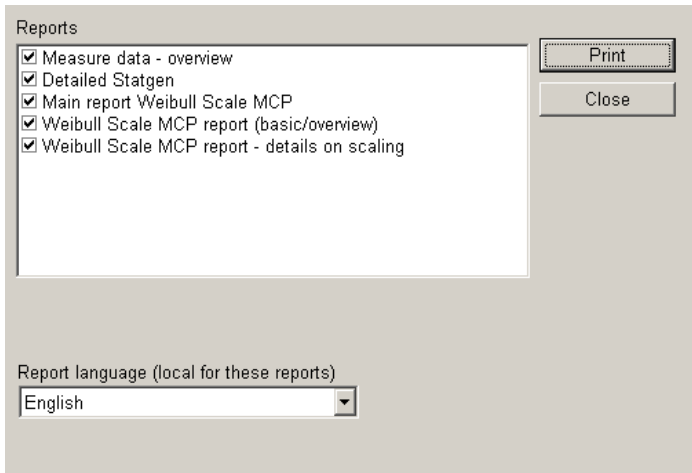
When pressing finish, WindPRO asks to continue to generate wind statistics (or just end with the meteo data, here no time series will be established, only the Weibull distribution). The wind statistic will be based on the long term corrected local data set.

A new row is formed in the history list. With this model no correlation between measured and predicted concurrent period can be calculated, as the method does not generate a transformed sequential time series. These figures are therefore missing from the result row.

Weibull report

Page one is identical to page one of the regression model.

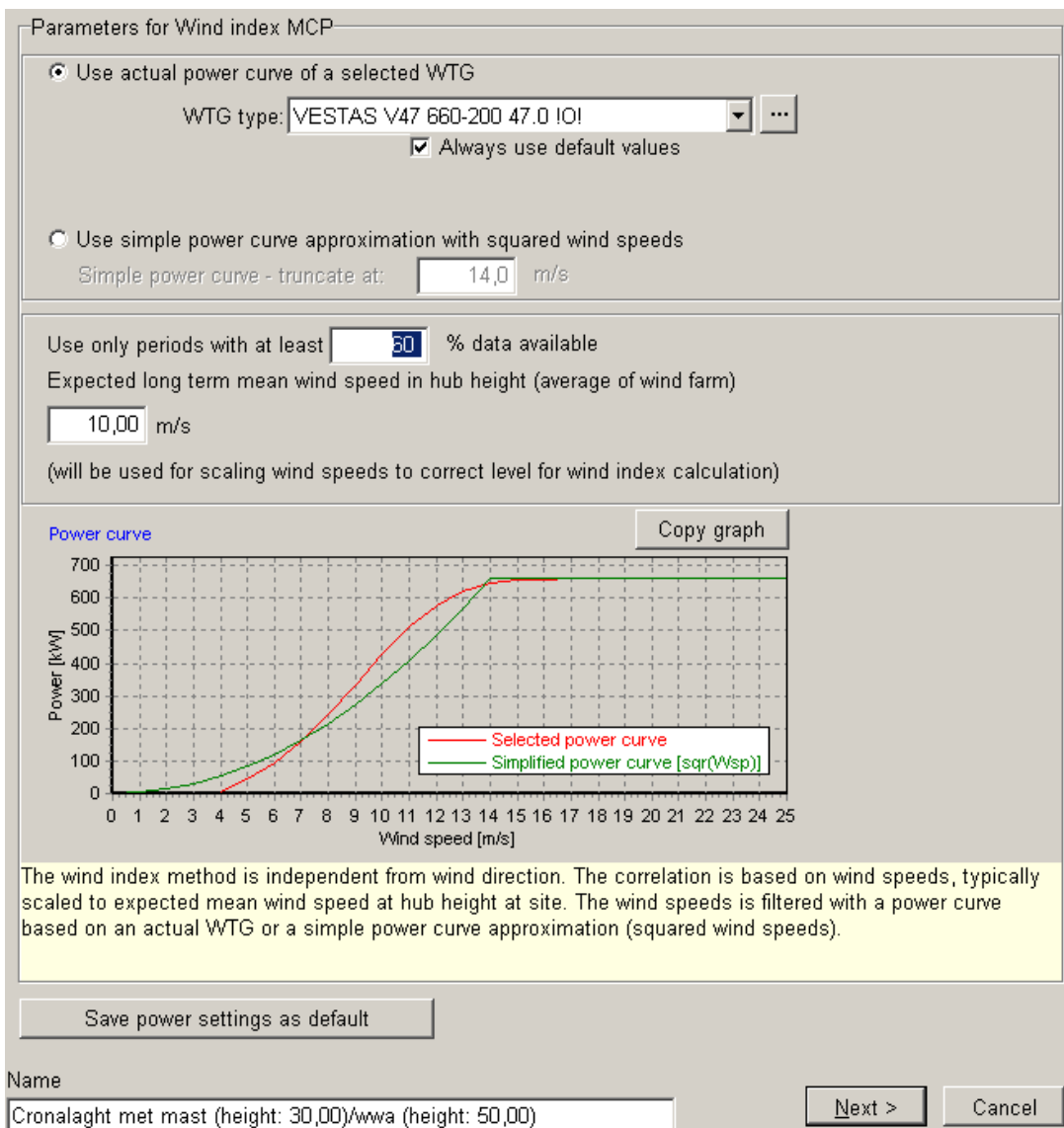
Page two gives the Weibull and frequency parameters for each sector for the data sets involved in the calculation. Also the resulting correction factors and the resulting long term corrected Weibull and frequency parameters are given.



The reports of the Weibull scale MCP

11.2.4.5 Wind index

The Wind index solver is started by pressing the Add Wind index button. The settings window appears.



Setup for wind index MCP calculation.

The measured wind speeds must be converted to power output values. This can be done in two ways:

Actual power curve

The power curve for the turbines involved in the project can be chosen in the WTG type field. This accesses the wind turbine catalogue and the mode of selection is identical to selecting turbines in the WTG property dialog box (chapter 2.5.2).

Simple power curve

As an alternative a simple power curve can be used by checking the Use simple power curve box. The simple power curve is the squared wind speed truncated at a wind speed given in the Truncate at field. The simple power curve is useful for projects where no specific turbine type has yet been chosen.

The graph compares simple and actual power curve. It can be copied or edited using the two buttons to the right.

Use only periods with at least ...

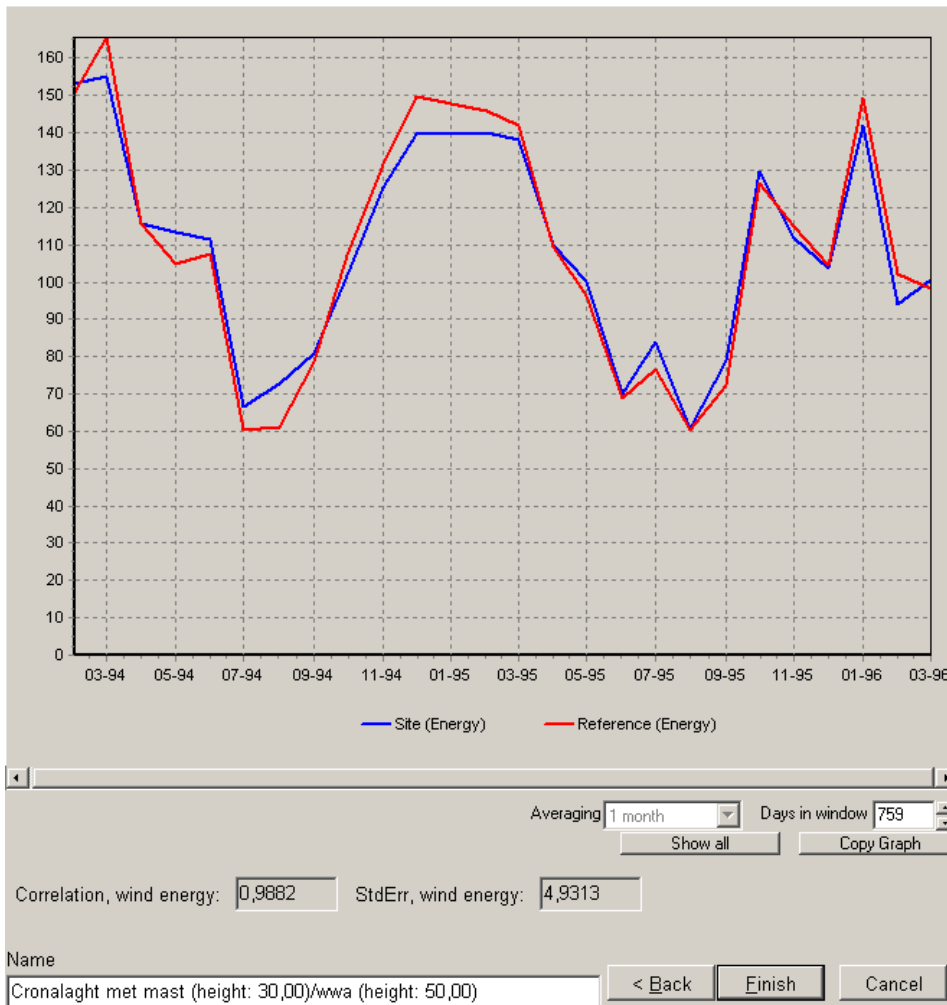
This option is used to exclude months, which are poorly represented in the concurrent and/or long term reference data sets. While such months does little harm to the actual correction the correlation parameters can be badly affected by months with only few data points. The data are excluded only from the visual presentation and calculation of correlation. All data, including months with few data, are included in the actual wind index correction.

Scaling

If the mean wind speed for the local data or reference data differs a lot from the expected wind speed at hub height at site, different parts of the power curves will be used and the correction factor will be wrong. The user must therefore enter expected approximate (+/- 0.5 m/s) long term mean wind speed at hub height – which might not be known at calculation time, and there might therefore be a need for a few iterations. It works in this way: The Long term reference is first scaled to the wind speed entered. Then for the concurrent part of the reference data the average wind speed is found. This is then used to scale the concurrent local data. As scaling compares to applying a shear factor to the data this is a valid modification of data.

Pressing Next compares the energy index of the concurrent period for local and reference data. The averaging can be changed but the correlation figures relate to the monthly averages like in the Correlation tab. A difference is that the concurrent reference data are normalized with the full reference, which is set to 100. The concurrent site data are normalized with the same value as the reference concurrent.

The better the graphs match the more successful the correction has been.

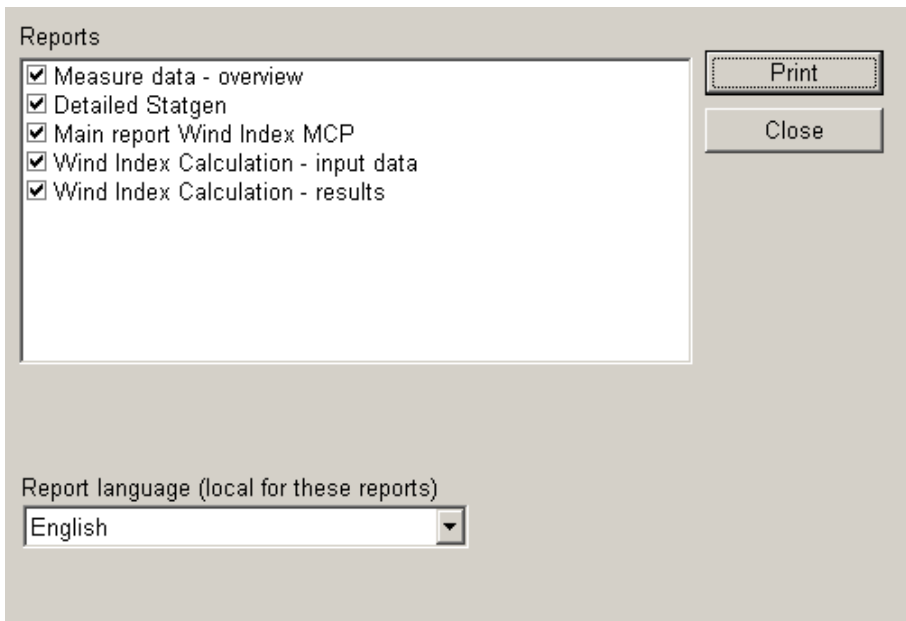


The wind index method only compares the wind energy level of the prediction based on reference data with the measured.

When pressing finish, WindPRO asks to continue to generate wind statistics (or just end with the meteo data). The wind statistic will be based on the entire long term corrected local data set, not just the concurrent part.

A result row is generated. Like with the Weibull scale method no correlation between measured and predicted is given. Instead the correlation and standard error is between concurrent site and reference data. A new parameter though is the Correction from Wind index. This is the correction factor, which will be applied to the production result when using the wind statistic generated from this calculation.

Wind index method Report

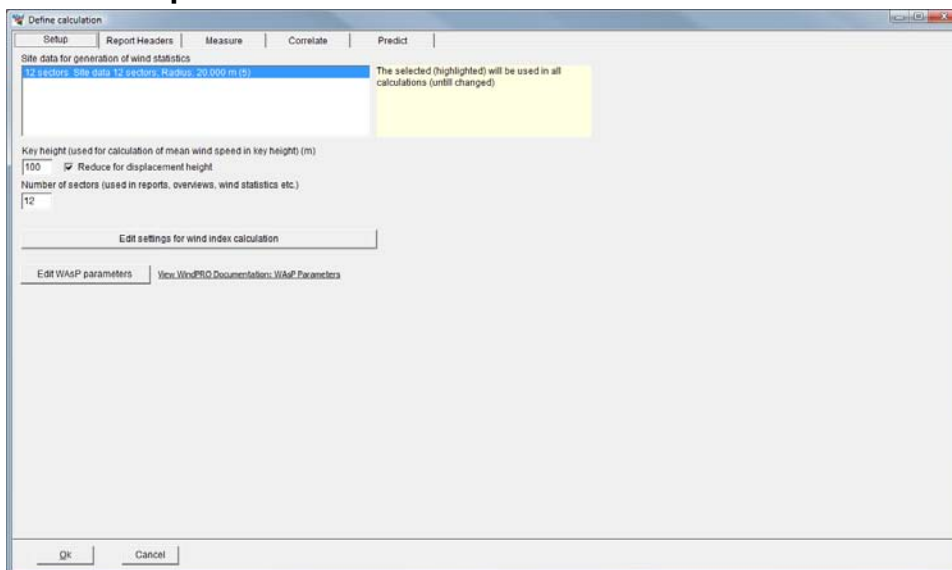


The reports from Wind index MCP

11.2.4.6 Report All

This report gives a summary of all the calculations done.

11.2.5 Setup



One of the important functionalities of the WindPRO MCP module is that it can generate a wind statistic from the generated long term corrected time series directly and thereby the “end result” needed for a typical WAsP PARK calculation. To generate the wind statistic a terrain description is needed. This is in WindPRO collected in a Site data object for STATGEN purpose.

The Site data object, which should be used, can be selected in this tab.

When wind index is calculated, either used in the Wind index MCP method or used as a “test option” in the other MCP methods, a few settings for wind index calculation is needed. See details described in 11.2.5.5 Wind index.

Use actual power curve of a selected WTG
 WTG type: ...
 Always use default values

Use simple power curve approximation with squared wind speeds
 Simple power curve - truncate at: m/s

Use only periods with at least % data available
 Expected long term mean wind speed in hub height (average of wind farm)
 m/s
 (will be used for scaling wind speeds to correct level for wind index calculation)

Power curve Copy graph

One of the evaluations compares wind energy level (wind index), where the wind speeds are filtered with a power curve based on an actual WTG or a simple power curve approximation (squared wind speeds).

The filter settings for calculating Wind energy index

11.2.6 Report Headers

In this tab sheet the headers and calculation name, which should be used in printouts, can be selected. The feature is described in further details in chapter 2.

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12.0 ENERGY - LOSS & UNCERTAINTY

12.1 Introduction, definitions and step-by-step guide

After calculating the expected AEP (Annual Energy Production) with the WindPRO PARK module, the next step to bring a wind farm project to a “Bankable” level is to estimate losses and uncertainties. Losses have the recent years become a more and more important part of the AEP estimate, partly because the losses typically are higher for modern wind farm projects, partly because the margin in AEP estimates has been lowered due to larger project sizes, and more tight budgets for wind farm projects. While wind farm investments have increased heavily, the need of knowing the uncertainties similarly has become of huge importance to get the projects financed.

With the WindPRO LOSS & UNCERTAINTY module the estimation of expected losses and uncertainties can be performed on a structured basis, with numerous tools for quantifying the individual components quite accurately.

Besides losses and uncertainties, the module also offers a Bias correction part. A Bias is a “known issue”, like model problems (e.g. RIX correction) or wind speed measurement errors, which have not been corrected in the calculation basis.

12.1.1 Basic definitions

The basic concept behind the module is:

Calculated GROSS AEP
 +/- BIAS correction
 - LOSSES
 = NET AEP (expected sold energy production) = P50

The expected NET AEP is also named the P50 value, which is the expected outcome of the project. There is a probability of 50% that the outcome will be more than P50 and a probability of 50% that the outcome will be less. This can also be named the “central estimate”. The uncertainty must be judged/calculated to find out how accurate the estimate is, and thereby the risk of getting a lower outcome than expected.

Including the uncertainty the AEP estimate is assumed to follow a normal distribution. All uncertainty components are assumed independent and, thus, combined as standard deviations, i.e. the square root of summed squares of individual contributions. The individual uncertainty components, judged or calculated, shall be given as 1 std dev (Standard Deviation or simply σ).

If the std dev (hereafter σ) is 10%, this means that the production at a given AEP exceedance level (PXX) for a calculated result can be calculated using the inverse normal distribution as:

P84 = P50 – 1 x Uncertainty (= P50 - 10%, for $\sigma=10\%$ as above)
 P90 = P50 – 1,28 x Uncertainty (= P50 - 12,8%, for $\sigma=10\%$ as above)

Below are listed additional coverage factors for other typical exceedance levels (e.g. 75%), all based on the normal distribution.

Prob. (%)	Coverage factor
50	(0,00)
75	0,67
84 *)	1,00
90	1,28

95	1,64
99	2,33

*) For P84,00 the coverage factor is not exactly 1,00 but 0,99. The coverage factor 1,00 corresponds to P84,13 which we round off to P84 here for convenience.

A special component in the uncertainty evaluation is the year-to-year variability of the wind, which can be included in the calculations. The variability describes how much the annual average wind speed varies from year-to-year for the region. This figure can be calculated in the MCP module based on long term data series, or it can be found in different research projects.

The expected probability of exceedance is calculated for 1, 5 10, 20 years with the variability for the time span in question included in the uncertainty. Contrary to the other uncertainties the variability depends on how many years the forecast covers, referred to as "expected lifetime". This can be of importance for judgment of the risk of the investment.

12.1.2 Understanding the uncertainty concept (Probability of exceedance)

The uncertainty concept is well illustrated by the figure below.

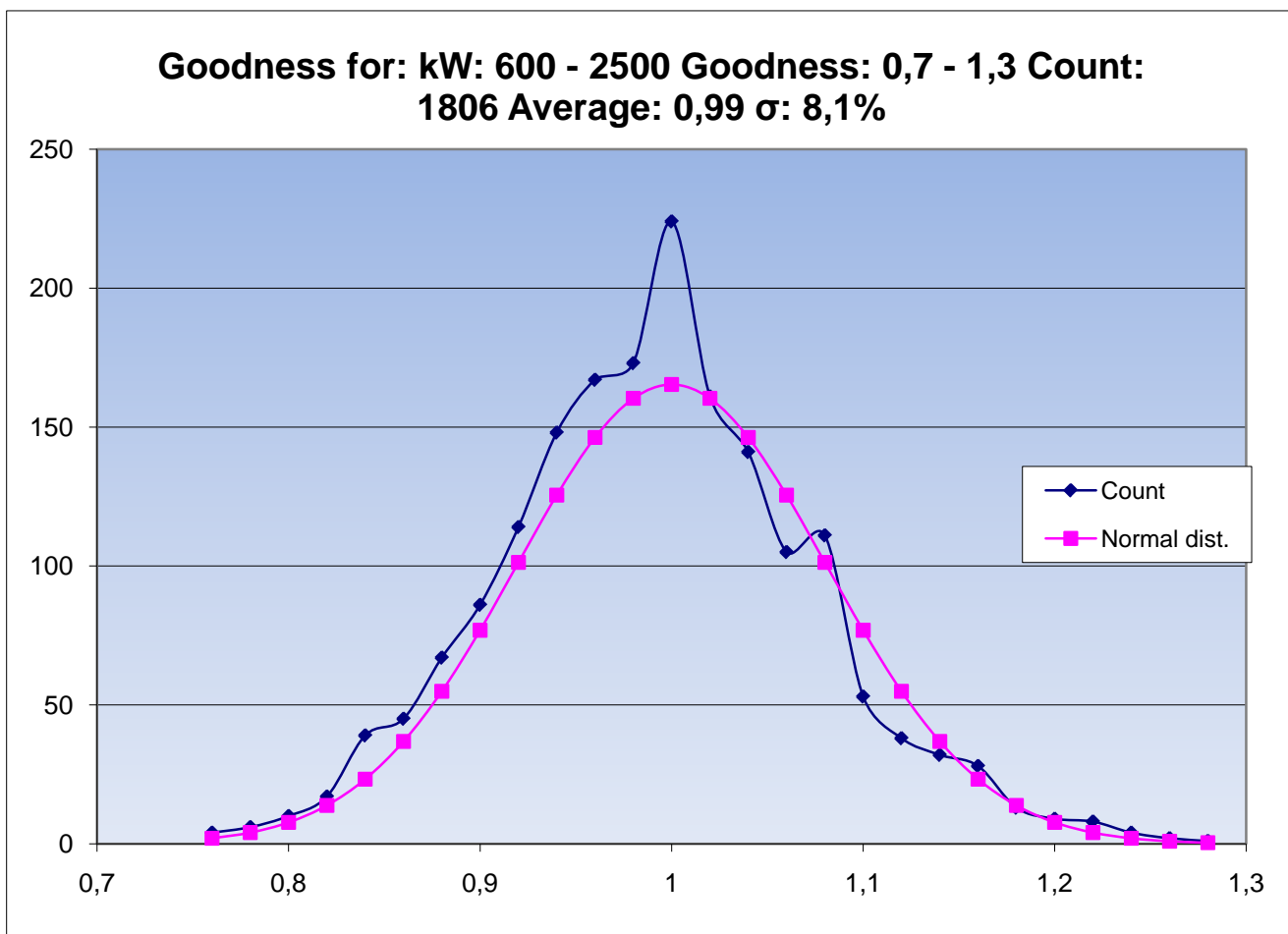


Figure 1 Based on calculations of 1806 wind turbines in Denmark, the count of goodness factor (Actual/calculated AEP corrected with wind energy index) for each turbine shows that the actual results are close to a normal distribution with a σ of 8,1%. In other words the uncertainty for these calculations is 8,1%.

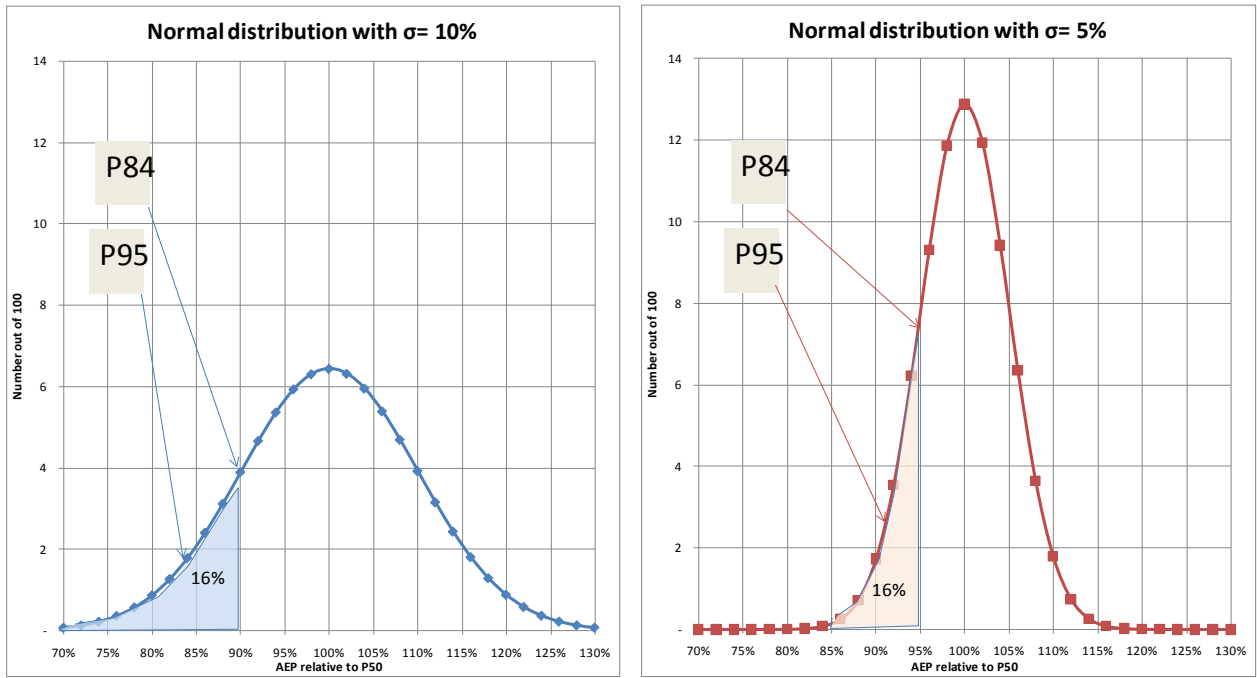


Figure 2 The Normal distribution is defined so that roughly 2/3 (more precisely 68,3%) of all events will be within +/- 1σ and around 32% is outside. In the one tail (e.g. below -1σ), there is around 16%, so there is 16% probability that the estimate will be below 1σ subtracted from P50, or 84% probability that it will be above (exceed). In other words, the P84 is the value where 84 out of 100 realizations will result in an outcome better than P84. For P95, there is only 5% probability to get an outcome poorer than this exceedance level which is found by subtracting the σ multiplied by 1,64 from the P50. So for σ=10%, the P95 value in the left graph where 5% would be “in the shaded area” (P95), would be found 16,4% below 100%, i.e. at 83,6% on the x-axis. Similarly, if σ=5%, 5% x 1,64 = 8,2%, so P95 is found at AEP of 100%-8,2% = 91,8% of the P50 on the x-axis.

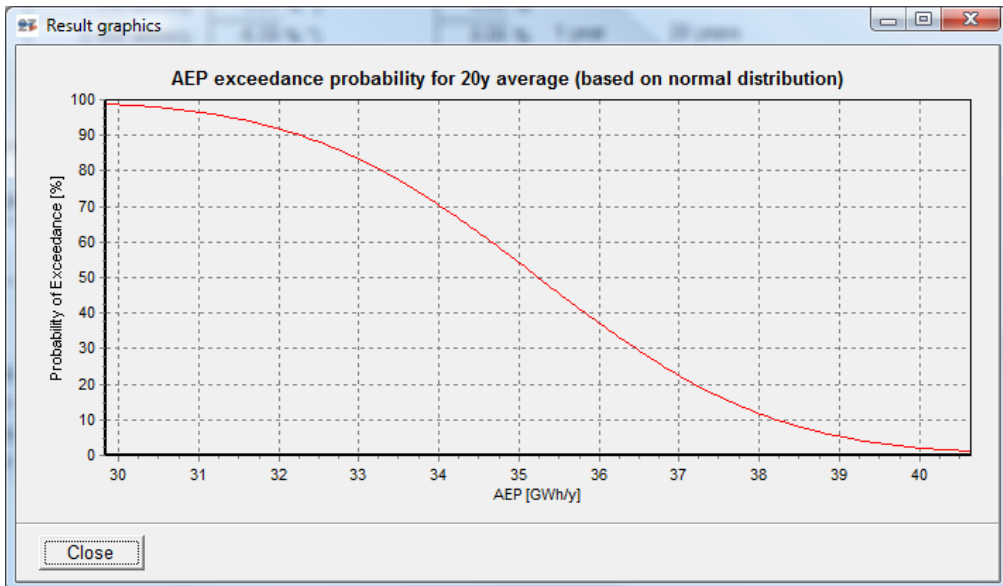


Figure 3 The probability of exceedance will normally be shown as a cumulative graph showing the probability of exceedance on the y-axis and the corresponding AEP PXX values on the x-axis.

12.1.3 What is included in GROSS value?

The module follows the DNV (Det Norske Veritas) definition as presented at AWEA 2008:

Included in GROSS calculation:

- roughness effects
- topographic effects
- obstacle effects
- air density correction
- (long term correction)
- (wind data correction)

Last two should be included, but it is up to the user to decide what is included. If e.g. a post calibration show that the wind data has been offset, it can be decided to redo PARK calculations with updated wind data or it can be decided to include the offset as a Bias correction of the GROSS.

NOT included in GROSS calculation:

- Wake losses (The PARK result includes wake losses, but these are “taken out” in the loss module so the “real Gross” based on the DNV definition is used as basis for all loss reductions.
- Other losses like availability, grid losses etc., see complete list below.
- Model issues like RIX correction or known power curve bias, will should be included as Bias, not as Losses, because these are considered “known issues” and should thereby be treated as corrections to the calculation results applied before the loss evaluation.

The structure of the module set demands to the user keeping track of what has already been compensated in the PARK AEP calculation, and what should be added in the loss, bias and uncertainty evaluation. The only “automized” issue is that the wake losses are taken out of the WindPRO PARK AEP calculation (the size of the wake loss is automatically filled in), so the LOSS & UNCERTAINTY module starts from the non wake loss added wind farm AEP calculation result.

The module has these features:

1. All Bias, loss and uncertainty components can be judged by the user and entered manually.
2. Some of the components can be calculated by the software based on different data sources, typically wind data time series.

The wind data time series are used to divide the expected AEP in time steps, to enable calculation of time, wind speed or wind direction dependent losses. But also links to other WindPRO calculations like SHADOW can be used to give an accurate estimate of AEP loss due to flicker stop, or a PARK RIX calculation can be used to perform a RIX bias correction.

12.1.4 Loss definitions

The loss definitions in the module follow the below definitions (in *italic* the EMD modifications). Note we have switched group 1 and 2 relative to the original paper so Wake effects occur first and availability second.

*Paper, AWEA 2008: Standard Loss Definitions for Wind Resource / Energy Assessments
Prepared by Steve Jones of Global Energy Concepts (DNV)*

Standard Loss Category	Recommended Subcategories	Comments
1. Wake Effects	Wake effects, all WTGs	Losses within the turbines which are the subject of the energy assessment. Helimax currently includes wake losses in the gross yield. Losses on the turbines which are the subject of the energy assessment, from identified turbines that are not the subject of the energy assessment, which either already operate or which are expected to operate the entire useful life of the facility being studied. <i>If the PARK calculation includes existing turbines (which it should), the wake losses from as well internal as external wake effects are included in the wake loss calculation, therefore the EMD has brought the two groups from original document into one.</i>
1. Wake Effects	Future wake effects	Losses due to additional development in the vicinity of the turbines being studied, but which would occur after commissioning of the turbines being studied.

Standard Loss Category	Recommended Subcategories	Comments
2. Availability	Turbine	GEC further divides this into routine maintenance, faults, minor components, and major components. AWS Truewind uses a separate factor (Availability Correlation with High Wind Events) that could be buried into this number or categorized with "7. Other" below.
2. Availability	Balance of plant (<i>Substation</i>)	Losses due to downtime in components between the turbine main breaker to and including project substation transformer and project-specific transmission line.
2. Availability	Grid	Losses due to downtime of power grid external to the wind power facility.
2. Availability	Other	Other availability losses not accounted for above or in other categories below.
3. Turbine performance	Power curve (can be part of Bias)	Losses due to the turbine not producing to its reference power curve (even with new blades and wind flow within test specifications).
3. Turbine performance	High wind hysteresis	Losses due to shutdown between high-wind cutout and subsequent cut back in.
3. Turbine performance	Wind flow	Losses due to turbulence, off-yaw axis winds, inclined flow, high shear, etc. These represent losses due to differences between turbine power curve test conditions and actual conditions at the site.
3. Turbine performance	Other	Other turbine performance losses not accounted for above.
4. Electrical	Electrical losses	Losses to the point of revenue metering, including, as applicable, transformers, collection wiring, substation, transmission.
4. Electrical	Facility consumption	Losses due to parasitic consumption (heaters, transformer no-load losses, etc.) within the facility. This factor is not intended to cover facility power purchase costs, but does include the reduction of sold energy due to consumption "behind the meter."
5. Environmental	Performance degradation not due to icing	Losses due to blade degradation over time (which typically gets worse over time, but may be repaired from time to time), and blade soiling (which may be mitigated from time to time with precipitation or blade cleaning).
5. Environmental	Performance degradation due to icing	Losses due to temporary ice accumulation on blades, reducing their aerodynamic performance.
5. Environmental	Shutdown due to icing, lightning, hail, etc.	Losses due to turbine shutdowns (whether by the turbine controller, SCADA system, or by an operator) due to ice accumulation on blades, lightning, hail, and other similar events,
5. Environmental	High and low temperature	Losses due to ambient temperatures outside the turbine's operating range. (Faults due to overheating of components that occur when ambient conditions are within the turbine design envelope would be covered under turbine availability category above.)
5. Environmental	Site access and other force majeure events	Losses due to difficult site access due to, for example, snow, ice, or remote project location. Note that this environmental loss and some other environmental losses may be covered under the availability definition, above. However, these "environmental" losses are intended to cover factors outside the control of turbine manufacturers.
5. Environmental	Tree growth or felling	Losses due to growth of trees in the facility vicinity. This loss may be a gain in certain cases where trees are expected to be felled.
6. Curtailment	Wind sector management	Losses due to commanded shutdown of closely spaced turbines to reduce physical loads on the turbines.
6. Curtailment	Grid curtailment and ramp-rate	Losses due to limitations on the grid external to the wind power facility, both due to limitations on the amount of power delivered at a given time, as well as limitations on the rate of change of power deliveries.
6. Curtailment	Power purchase agreement curtailment	Losses due to the power purchaser electing to not take power generated by the facility.

Standard Loss Category	Recommended Subcategories	Comments
6. Curtailment	Environmental, Noise	Losses due to shutdowns or altered operations to reduce noise and shadow impacts, and for bird or bat mitigation. This would include use of a low-noise power curve vs. a standard one from time to time. <i>For Noise and flicker, there are in WindPRO access to detailed calculation options. Therefore EMD has expanded this with more groups, same for Birds and Bats, which can be set based on "free of choice" parameters like date interval, hour interval etc.</i>
6. Curtailment	Environmental, Flicker	
6. Curtailment	Environmental, Birds	
6. Curtailment	Environmental, Bats	
7. Other		This would cover anything that doesn't fit into the above six main categories.

12.1.5 Step-by-step guide

- ❑ Establish a PARK calculation (see Energy, Section 3.3.5), BUT note the following:
If more site data objects or turbine types are used, group these in separate layers before calculation.
If RIX Bias correction should be included, make the RIX calculation in PARK
If calculation of time dependent losses etc. makes sure you have a proper time series with required data. The WTI generator in Meteo analyzer tool may be used to establish this. Include temperature if high/low temperature shut down is expected. Include turbulence or gust if high wind hysteresis loss are expected.
- ❑ Start LOSS & UNCERTAINTY module
- ❑ Load PARK calculation
- ❑ You may attach a wind data time series from Meteo object or WTI file
- ❑ Input needed parameters in Bias, Loss and Uncertainty tab sheets
- ❑ Where "Edit" buttons are available, start detailed calculations – you might need to go back to "Main" to reselect the wind data to more a or less detailed series.
- ❑ When all inputs are established, review at "result" tab and start calculation for generating report by OK.

12.2 Basic data for calculations

A PARK calculation is the basis. From this all relevant data on AEP for each turbine, wake loss, elevation, hub height etc. are loaded. In addition sensitivity is calculated. The sensitivity defines the transfer from changes in wind speed to changes in AEP for each turbine by recalculation of the PARK with a small change in wind speed. It is worth to notice that if a RIX bias calculation is wanted, the PARK calculation loaded must hold a RIX calculation. Similarly, if a flicker stop loss calculation is wanted, there must be a shadow calculation for exactly the same wind farm configuration as in the loaded park calculation. For Noise loss calculation it must be noted that if the PARK calculation already includes turbines in noise reduced mode, no additional Noise loss should be entered. If it is a wish to present the loss due to noise in the loss calculation, the PARK calculation must be based on no noise reduced turbines, and the noise reduced modes must then be implemented in the loss module. We are aware of this is somewhat "tricky" and the handling of noise loss calculation will be improved further in the future. If for example the noise reduced mode only occurs during e.g. night hours, the Loss&Uncertainty module is very convenient to use, as the calculation setup allows limiting the noise reduced mode to specific hours or wind directions.

In addition following data can be used:

Climate data as time series: Either by link to a Meteo object time series or to a .WTI file (Wind Time variation file that can be established from the Meteo analyzer or selected from the WindPRO Data\Standards\ folder).

Power curve uncertainty can be specified detailed in the WTG catalogue and used from uncertainty module, but also simpler approaches for this calculation are available if no detailed data are available for the turbine.

Define Calculation

Main | WTGs | Model results | Bias | Losses | Uncertainty | Results | Description

Name: All MAST 4 based

Load data from wake calculation (PARK)

Main data from PARK calculation (including wake losses)

	Wind farm for loss calculation	Other existing WTGs in calculation	
Name	2.7.395: All MAST 4 based		
Number	6	0	
Rated power	9,0	0,0	MW
Capacity factor	44,4	0,0	%
Annual yield	34.998,3	0,0	MWh/y
Specific yield	3.888,7	0,0	MWh/MW
Mean wind speed	8,4	0,0	m/s (at hub height)
Sensitivity	1,4	0,0	% AEP/% mean wind speed

Use advanced loss calculation tools based on time variation data

Variation data

Data from meteo object (test if useable with VIEW before calculating) [View]

.WTI file, created from Meteo analyzer or selected from library [Browse]

C:\Users\per.EMD\Documents\WindPRO Data\PROJECTS\Honduras\410

(Look in folder WindPRO Data\Standards for generic data for some regions)

Assume constant power, no time variation, but some tools can be used

Lifetime

Expected life time of WTGs: 20 years

Ok Cancel

Figure 4 The “Main” tab where PARK calculation is loaded. If existing turbines are included in the PARK calculation, it can be decided if these shall be included in the loss & uncertainty evaluation. Further it is possible only to include the existing turbines if these are flagged “treat as PARK WTG” (property on existing WTG objects).

This tab shows the main results from the PARK calculation and the calculated sensitivity for propagation of changes in wind speed to changes in AEP (AEP%/ws%).

Checking the “Use advanced loss calculation tools...” gives access to add time varying data or to assume constant power. The last option is used if no time varying data are available, but the user still wants to calculate flicker or temperature loss assuming constant AEP in each time step.

The expected lifetime only influences the uncertainty contribution from the variability of the wind. All other calculations are based on annual averages. The uncertainty component coming from the year to year variability decreases with the number of years and will thereby be lower the longer the lifetime (part of the variability is averaged out).

12.2.1 Climate data

Several loss calculations are based on climate data including also temperature data. Of high importance is that the climate data represent a typical year. A time series averaged over several years will not hold the information of the dynamic behavior that is of high importance for the expected shut down situations of the wind turbines. However, calculations can be performed based on more than 1 year of data in a Meteo object.

In a Meteo object, a data set of one or more years of data can be established from more years of data by disabling data, so that one or more representative year(s) is enabled. If the data series merely holds a ½ year or 1½ year, the calculation will be seasonally biased. This should be avoided. But no matter how long (or short) period of data the Meteo object used hold, it is important to remark that the calculations always will assume these data long term representative and scale the calculations to annual values.

A specific way to establish exact 1 year of data prepared for such analysis is found in the Meteo analyzer. Here you can generate exactly 1 year of data with a specific temporal resolution (data can be down or up sampled) based on one or more time series in Meteo objects. See further details in the chapter on time varying data from Meteo analyzer.

12.2.2 Model results

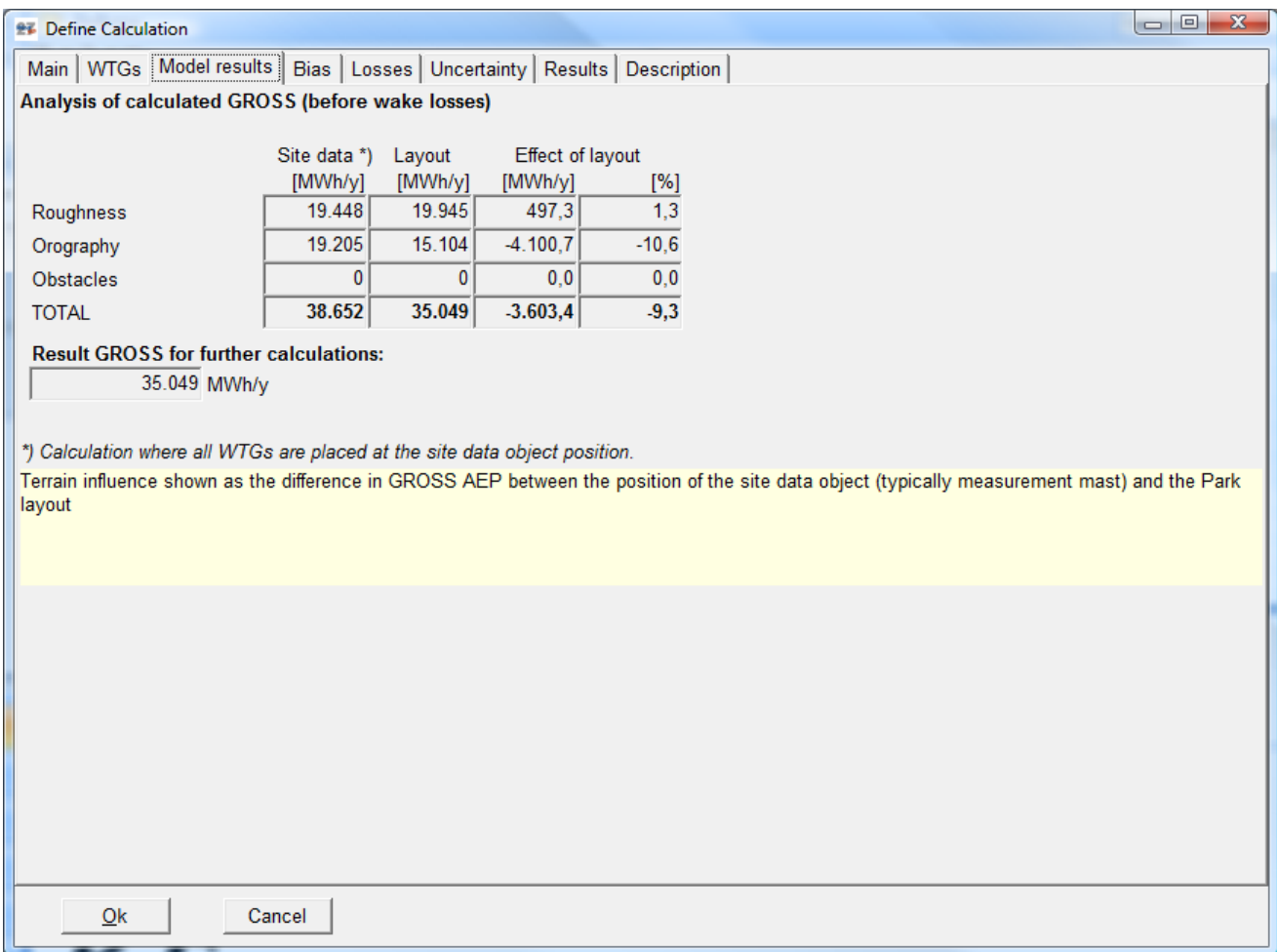


Figure 5 At the Model results sheet an evaluation of the effect of the layout is given.

The effect of the layout gives an idea of how large model corrections are applied. The software calculates the AEP if all turbines are positioned at the position(s) of the site data object(s) – if more than one site data objects, the turbines “belonging” to a specific site data object is moved to this object and calculated. This is compared to the actual calculation with the turbines at their “real positions” (the Layout). Thereby it can be seen how much the model transforms data based on roughness, orography and local obstacles. The higher the effect of the layout, the higher the risks are of errors in calculations if the model does not perform accurately. In other words, the more measurement masts the calculation is based on, the lower the effect of the layout, or the lower complexity of terrain/roughness, the lower the effect of the layout.

Note the results here are EXCLUDING wake losses; these are simply taken out of the calculation and transferred automatically to the LOSS sheet where belong according to the DNV standard definitions.

12.2.3 General concept for input of data in bias, loss and uncertainty sheets

In general there can only be entered one value for a loss/bias/uncertainty to represent the entire wind farm. But if a calculation module is available (i.e. an “Edit” tickbox), values can be entered in a more flexible way:

- Individually for each turbine
- For all turbines on a specific layer (in Maps&Objects)
- For all turbines

This means that if there is a need for specific data on half of the turbines and other values on the other half, it would be a very good idea to place these two groups in different layers in the project setup. A lot of individual input can then be avoided. An example could be if a wind farm is established with 2 or 3 different wind turbine types or if e.g. one group is more exposed (on a ridge) than another group and therefore needs a lower cut out wind speed value.

Input of data for an individual turbine or for all turbines in a layer is simply selected by clicking with the mouse on the individual turbine or on the specific layer. The input will then be assigned to the selected turbine or group.

12.3 Bias

Bias is a correction for “known issues”, like e.g. the RIX (Ruggednes IndeX) modifications of wind speeds in complex terrain introduced by RISØ, or e.g. power curve correction, where those are known to be too pessimistic or optimistic based on experience or evaluation by the HP method. Also wind measurements can have a known bias. For example specific anemometers are known to have a systematic error, or post calibration could show an error, in both cases it is more convenient to include these corrections as biases than by reanalyzing all the wind data behind the calculations. It is important is that bias corrections only are included once, either in the data basis of the PARK calculation or as a bias in the LOSS & UNCERTAINTY module. An advantage by having bias corrections in the LOSS & UNCERTAINTY module is that it will be clearly documented, and easy to change if new information appears at a later stage.

A bias can be entered as a simple correction in percent either on wind speed or in percent on AEP. If entered as wind speed percentage, this quantity is converted to percent on AEP using the sensitivity $AEP\%/WS\%$ ($WS=Wind\ Speed$). The AEP percentage is then multiplied with calculated GROSS and added (or subtracted) to GROSS before loss subtraction. Remember that a bias can have a positive or negative value - so do remember the sign.

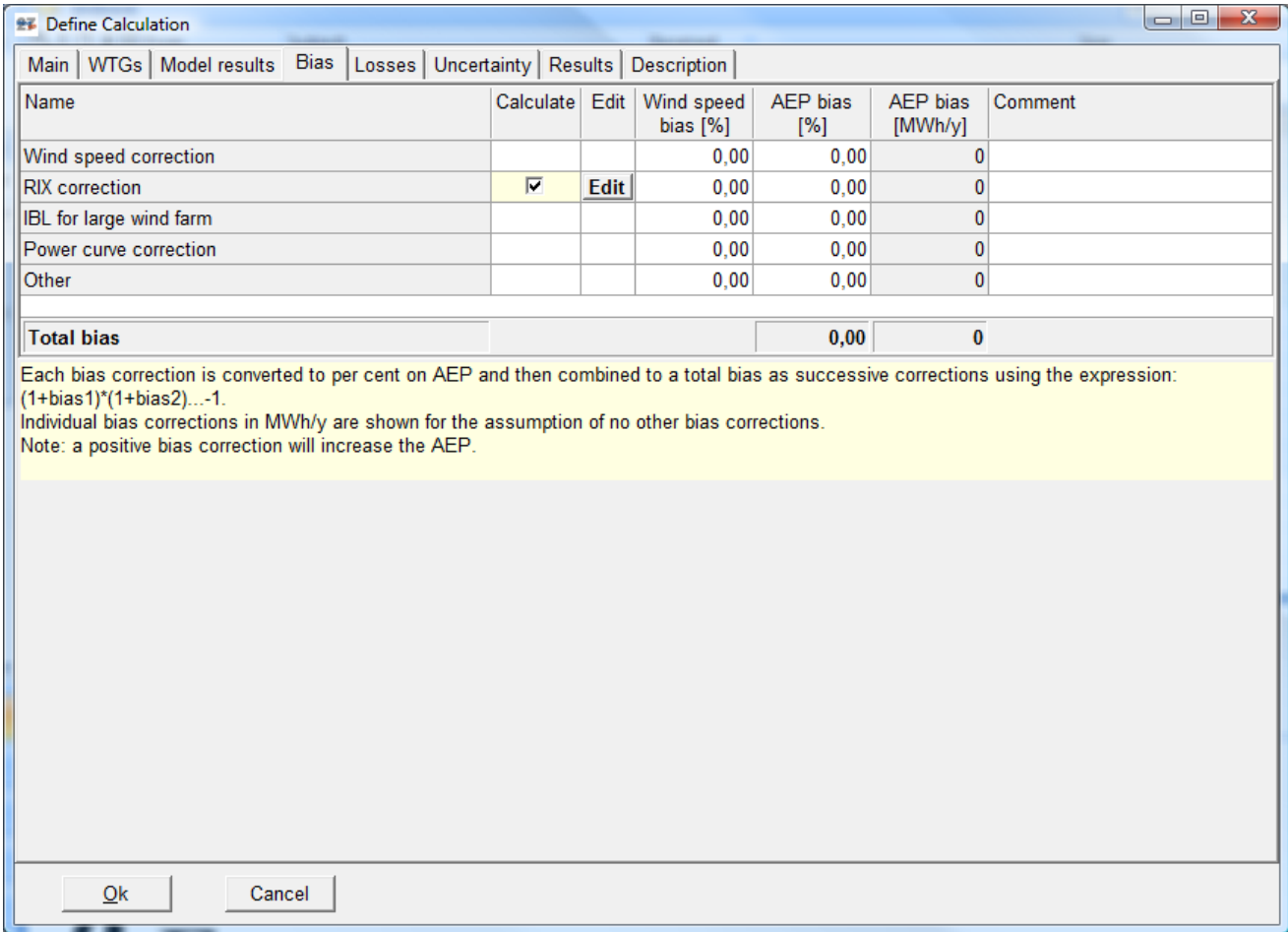


Figure 6 The input form for Bias. The RIX correction tick box is only available if the loaded PARK calculation includes a RIX calculation.

As seen above five different predefined bias input lines are available. If PARK calculation includes a RIX calculation, there will be a “calculate” tick box option for this (see next chapter for details).

12.3.1.1 Wind speed correction

If the wind data is known to have a bias, which has not already been corrected in the wind data used for the PARK calculation, the correction should be included here.

Wind data bias can have many reasons and is probably the most frequent reason for biased calculation results. But it can be very difficult to discover such a wind speed bias. The best method to avoid wind bias is to have more wind data sources for the site/region. Existing turbines with available production figures present near the site is also a valuable source of validation of the wind data level.

If local wind measurement equipment is used, the wind data correction can simply be due to known offset related to the equipment used. Often this will be corrected for at previous stage in calculations, if so it SHALL NOT be entered as a bias, the correction would then be double. But it is a good idea to write a comment if corrections are performed before PARK calculation, or if any validation of the wind speed level is made.

The correction can be entered as a modification on wind speed or AEP, remember to include the sign (- if it is a reduction) of the bias, because corrections can go in either directions.

12.3.1.2 RIX correction

For details, see 12.3.2. If a RIX correction proposal is made via another tool than WindPRO, or it just is a rough user estimate, the correction can be entered here. But it will then ONLY be as a common correction that will be the same for all turbines. So if RIX correction is issues always make a PARK calculation with RIX and use the correction calculation tool described in 12.3.2.

12.3.1.3 Model problems for very large wind farms

Very large wind farms might be over predicted due to the fact that the wind farm itself “drains” the area for energy in a way not included in wake loss calculation model. But it is still a research topic, which hopefully within few years will be solved. The problem is that some large wind farms seem clearly to indicate calculation problems (e.g. Zafarana, Egypt), while other wind farms like Horns Rev seems to be accurately calculated with the N.O.Jensen Wake loss Model. (Other wake loss models like e.g. the Ainsley model do not predict Horns Rev well and there has been made a correction to this model in the WindFarmer implementation). EMD is taking active part in the work of improving wake loss calculations for large wind farms and will hopefully during 2010 have revisions ready that can handle those more accurately. Until this is done, we leave an option in the Bias module to compensate for possible internal boundary layer effects by entering a Bias. But we cannot give any precise recommendations; we can only recommend reviewing research work done so far on the topic and decide possible reduction based on these.

12.3.1.4 Power curve correction

If it is known that a power curve is too optimistic or pessimistic, a simple correction should be entered here.

12.3.1.5 Other

Any other issues that the user knows is a bias in the calculation should be compensated here.

12.3.2 RIX correction calculation

For the RIX correction a calculation module is established. The main source for the implementation is: **EWEC06 paper:**

IMPROVING WASP PREDICTIONS IN (TOO) COMPLEX TERRAIN

By Niels G. Mortensen, Anthony J. Bowen and Ioannis Antoniou
Wind Energy Department, Risø National Laboratory

This paper describes why complex terrain with steepness > 30-40% violates the WASP model calculation method, and how calculation accuracy can be improved by applying the RIX correction method.

The screenshot shows a software dialog box titled "Rix-bias calculation". It is divided into several sections:

- Assumptions:** Includes input fields for "Based on radius" (3.500 m), "Based on terrain slope" (21,8 degrees), "Directional weighted" (40,0 %), and "Directional weighted" (False).
- Statistics:** Shows calculated values: "Minimum delta rix" (-7,4 %), "Maximum delta rix" (0,6 %), and "Average |delta rix|" (4,0 %).
- Formular used for correction:** Displays the formula $U_{corrected} = U_{calculated} / \text{Exp}(\alpha \times \text{DeltaRIX})$. The "Alfa" parameter is set to 1,0 (with a note: "From 0.7 - 1.5 recommended, depending on site *"). The "No RIX correction in the interval:" is set to -5,0 % - 5,0 %.
- Result:** Shows "Calculated Umean" (8,4 m/s) and "Corrected Umean" (8,7 m/s) with a "Change" of 3,4 %. Similarly, "Calculated AEP" (35.049 MWh) and "Corrected AEP" (36.979 MWh) with a "Change" of 5,5 %.
- Show detailed results:** Includes buttons for "Table", "Wind speed graphic", and "AEP graphic".
- At the bottom are "Calculate", "Ok", and "Cancel" buttons.

Figure 7 Input of details for the RIX correction calculation and main results.

The basic formula is: $U_m = U_p \times \exp(-\alpha \times \Delta RIX)$, where U_p is the predicted wind speed using WAsP and U_m (measured) is the corrected wind speed. The parameter α is found empirically (e.g. via cross prediction tool in Meteo analyzer in WindPRO) and ΔRIX is calculated by WindPRO in a park calculation based on the elevation data at the site. The key issue is to estimate the α value and to decide the radius and slope threshold for the ΔRIX calculation. Given these the RIX correction is simple math.. The calculation tool finds the appropriate (given α and ΔRIX) correction of the wind speed at each WTG position and converts this to an AEP modification based on the AEP%/ws% sensitivity for each WTG position. The calculated modification will be stored individually on each WTG.

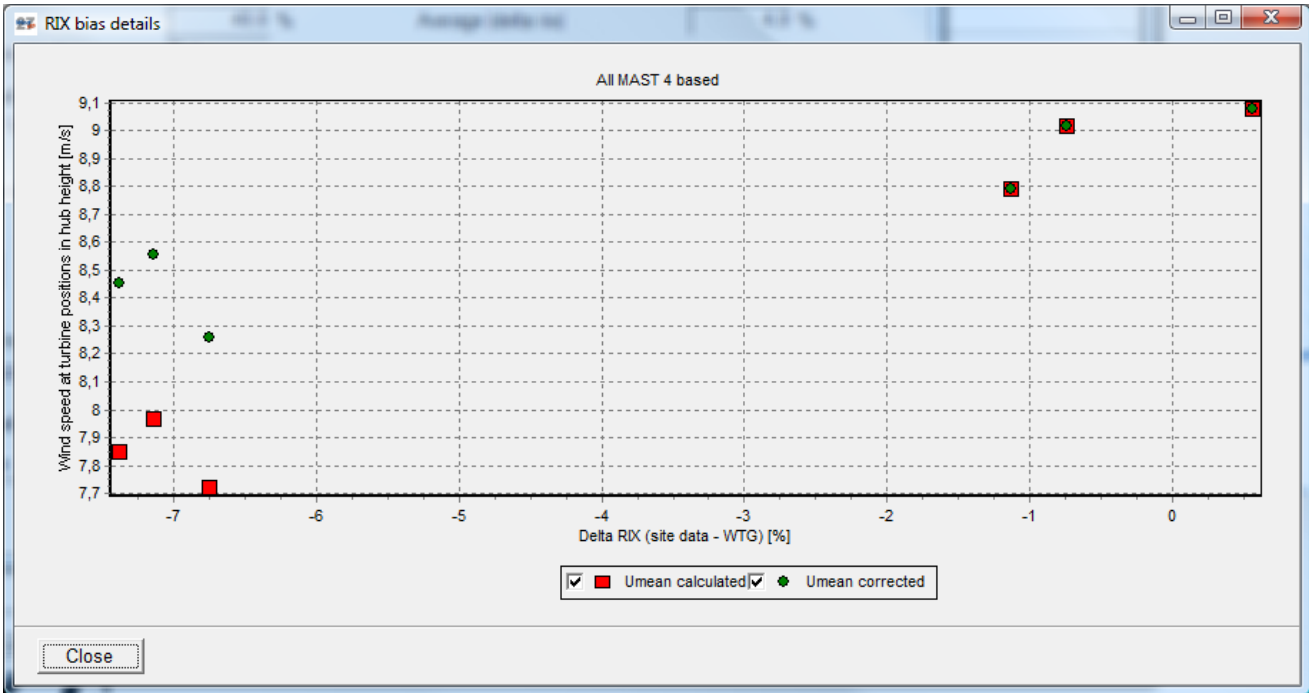


Figure 8 The Wind speed correction graphic illustrates how turbines with low D-RIX values compared to site data object position (met. mast) are corrected to higher wind speed. Similar turbines with higher D-RIX values would be corrected downwards.

12.4 Loss

Loss is the AEP that should be produced based on the available wind and the turbine power curve, but never reach the “sales metering”. Partly due to physical losses such as grid losses, partly due to wake losses, where turbines takes wind from each other and partly due to reductions in turbine operation, e.g. due to shut down at low temperatures or availability losses when out of order.

The seven loss main groups defined by DNV are listed in the Intro chapter. Here is how the general calculation runs.

For each turbine a given loss component is converted to efficiency, i.e. a 3% loss is converted to $100\% - 3\% = 97\%$ efficiency. This is done turbine by turbine. The efficiencies from each component are then multiplied and a resulting efficiency found. This is multiplied with the GROSS AEP after Bias correction, if any. Then the NET AEP = P50 is the result of the loss reduction.

Define Calculation						
Main WTGs Model results Bias Losses Uncertainty Results Description						
Name	Calculate	Edit	Loss [%]	Loss [MWh/y]	Comment	
± Group : 1. Wake Effects (Loss = 0,15 %)						
± Group : 2. Availability (Loss = 3,00 %)						
± Group : 3. Turbine performance (Loss = 0,25 %)						
± Group : 4. Electrical (Loss = 2,00 %)						
- Group : 5. Environmental (Loss = 0,85 %)						
Performance degradation not due to icing			0,50	185	Rather dusty region, some loss assumed	
Performance degradation due to icing			0,00	0		
Shutdown due to icing, lightning, hail, etc.			0,00	0	No icing events assumed for this site	
High and low temperature	<input checked="" type="checkbox"/>	Edit	0,35	130	Based on manufacturer specifications	
Site access and other force majeure events			0,00	0		
Tree growth or felling			0,00	0	Trees are assumed kept in average as is	
Other			0,00	0		
± Group : 6. Curtailment (Loss = 0,26 %)						
± Group : 7. Other (Loss = 0,21 %)						
Total losses			6,56	2.425		
Losses due to difficult site access due to, for example, snow, ice, or remote project location. Note that this environmental loss and some other environmental losses may be covered under the availability definition, above. However, these "environmental" losses are intended to cover factors outside the control of turbine manufacturers.						
<input type="button" value="Ok"/> <input type="button" value="Cancel"/>						

Figure 9 The loss input screen holds seven main groups that can be expanded for input of the relevant loss estimates. Some input lines hold a "Calculate" option. When checked, the edit button opens a form for detailed calculation of the loss due to the specific component.

For the losses that can be calculated by the module, a more detailed description of calculation method follows. For all components a comment can be added. This is an important part of the loss evaluation. In the report all lines with comments will be shown, so the user can see the background for the evaluation even if no loss are assumed due to the specific component.

Besides what can be calculated, it is of high importance to emphasize that two loss components always should be included:

1. Turbine availability, typically 2-5%, depending on service arrangement and turbine quality.
2. Grid losses (can be calculated with eGRID module), will typically be 1-3% depending on distance to meter point, and if e.g. staff house consumption should be included. Note that the power curves used in PARK-calculation are measured at the low voltage side of the turbine transformer so the turbine transformer losses should always be included; this alone is round 1%.

12.4.1 High wind hysteresis

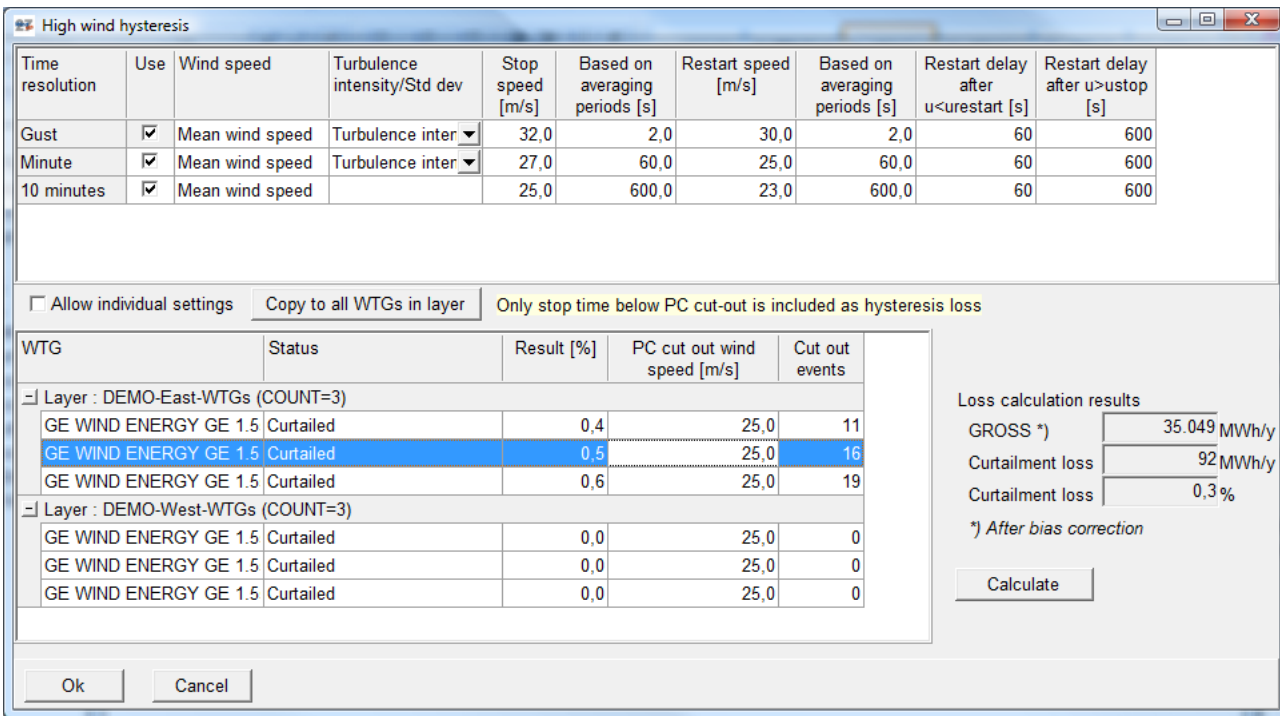


Figure 10 High wind hysteresis loss calculation.

High wind hysteresis loss is where the turbine is stopped below the cut out wind speed. All stop time above cut out wind speed (defined in power curve) are already corrected for in AEP calculation, but while the turbine sometimes stops before or restart after the wind speed is below cut out, losses in relation to AEP calculation are introduced. The setup of the stop/start procedure must be confirmed by the turbine manufacturer. This is individual from turbine type to turbine type, but is sometimes also set individually from site to site.

12.4.2 High and low temperature

AEP is calculated for each time step in the climate data time series based on a scaling of the wind speed to the calculated average wind speed for each turbine. The AEP results based on this method is then scaled so the annual sum equals the main calculation result.

Based on entered shut down threshold temperatures, the AEP calculated for each time step is summed for all time steps outside the temperature threshold values. The AEP loss sum is then converted to a loss percentage that is saved for each WTG.

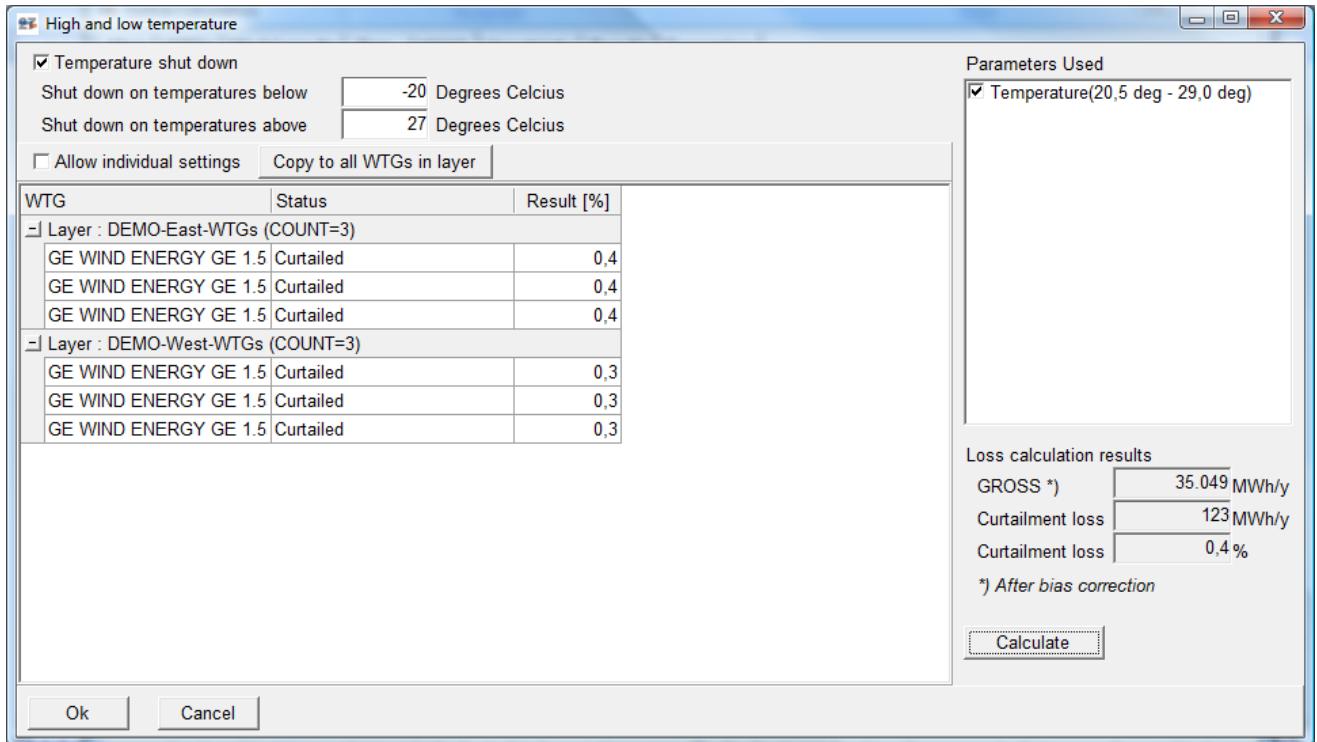


Figure 11 The loss due to high/low temperature is calculated.

In the example above it is seen that the time series with temperature vary in the range from 20,5 to 29,0 degrees. The setting for temperature shut down is below -20 and above +27 deg. C (this is set low just to illustrate the calculation). The loss is calculated to 0,4% based on an AEP calculation for each time step, where the time steps with temperatures outside operation range is summed and included as a loss. The loss calculation for each turbine is shown, in this example it is almost same for all turbines while only one time series can be handled. The differences for the two groups are due to different AEP characteristics.

12.4.4 Wind sector management

Wind sector management is stop of turbines when the wind comes from specific directions, to prevent damage of neighboring turbines due to wake added turbulence due to dense spacing. This is quite complicated to input, while it is individual from turbine to turbine. Above is seen an example where all turbines in the East group have the same settings. But to input this realistically, there must be an individual input for each turbine based on e.g. a WAsP Engineering calculation. By mouse click at one specific turbine (highlighting this), the settings in the field above will only relate to this specific turbine. For a large wind farm this work is quite troublesome. In a future version of the software tool, the sector management settings can be calculated by the software.

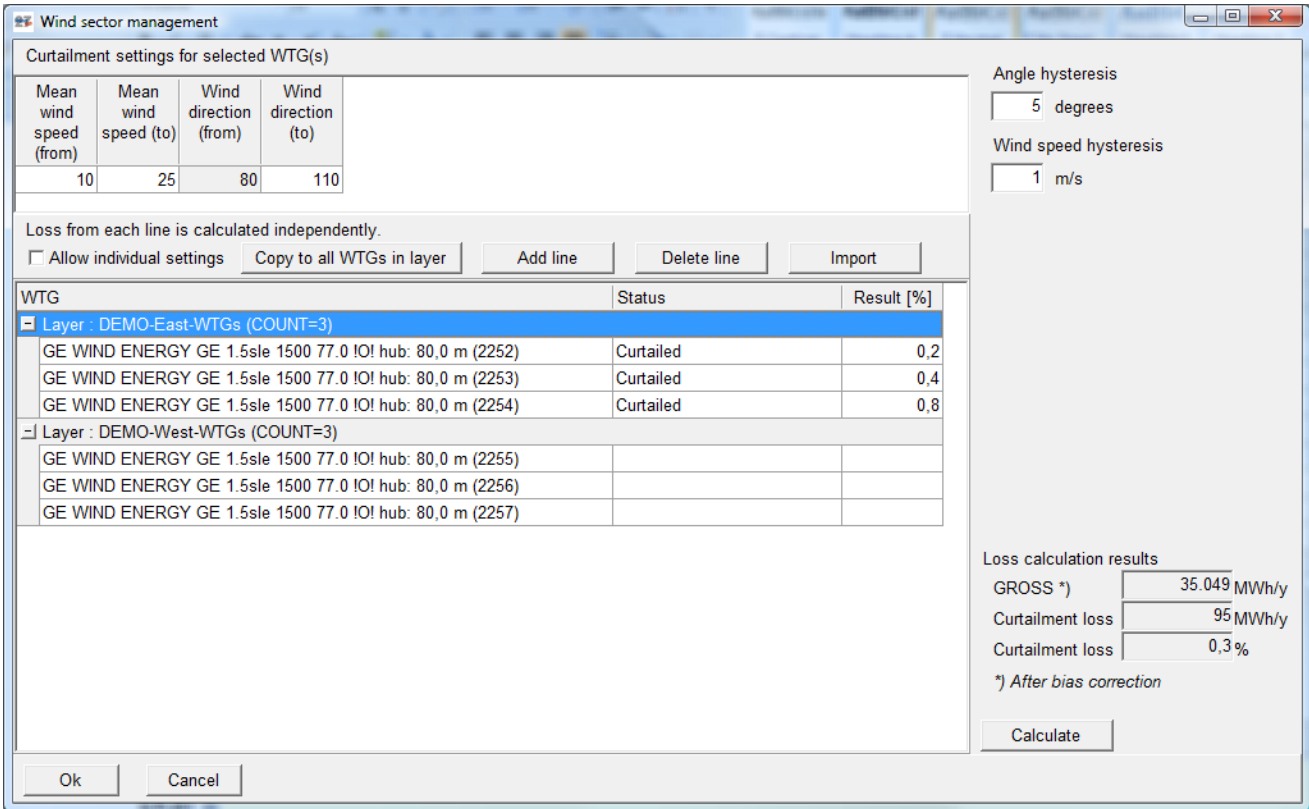


Figure 12 Wind sector management, one of the more complicated ones to input.

12.4.5 Noise

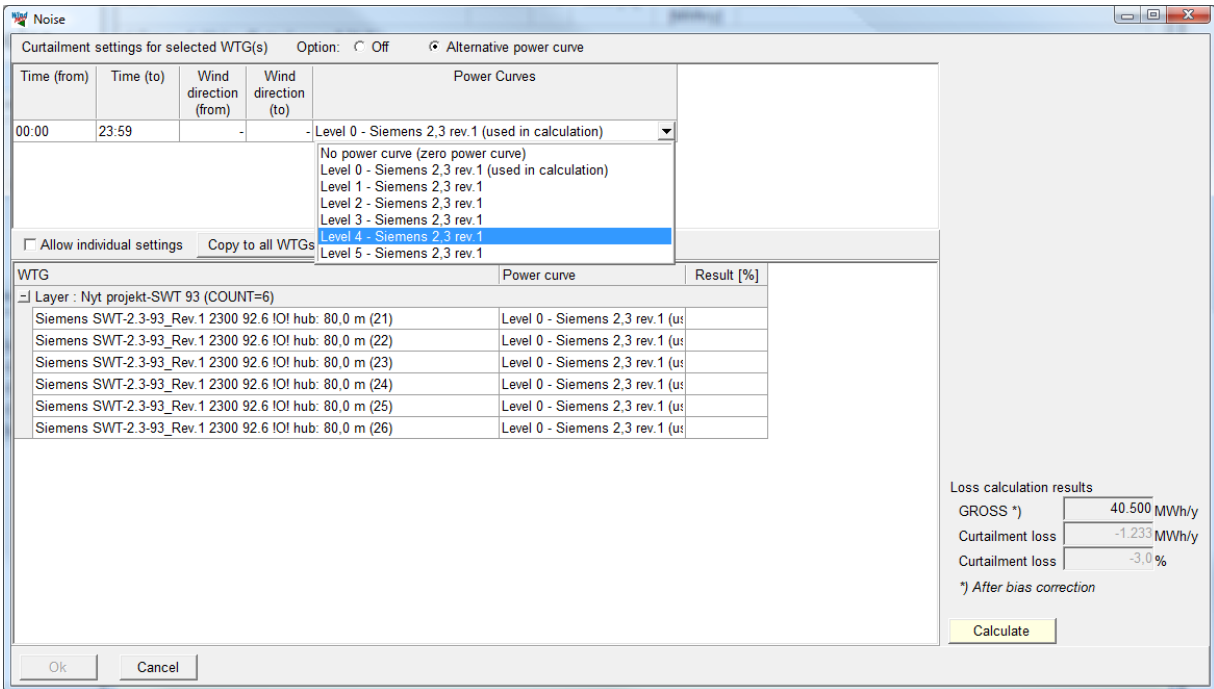


Figure 13 Input for noise loss.

Some turbines might run in noise reduced mode, maybe only within specific time of day, maybe only at certain wind directions (or combinations). Besides time and direction interval, the noise reduced power curve (or no power curve meaning full stop), can be selected. A tricky issue here is if the PARK calculation already is calculated with noise reduced power curves. In this case, there shall not be entered noise loss. So to include the noise reduced mode loss correctly, the PARK calculation must be without noise reduction, and the noise

reduced modes selected here. In future version, there will be an option to treat noise reduction the same way as wake reduction, meaning the software first takes out the effect of noise reduction, and transfers the loss, where it is automatically set up. This will also include L_{den} calculations, where different settings for day, evening and night will be required. Note in the power curve selection field, there will be information telling with which power curve each turbine has been calculated.

12.4.6 Flicker

SHADOW calculation

Select SHADOW calculation

Calendar stop (at all possible events – “worst case”)

Advanced stop (light sensors etc. included)

Reduce to: % AEP reduction relative to worst case

WTG	Status	Result [%]
+ Layer : DEMO-East-WTGs (COUNT=3)		
+ Layer : DEMO-West-WTGs (COUNT=3)		

Loss calculation results

GROSS *) MWh/y

Curtailment loss MWh/y

Curtailment loss %

*) After bias correction

Calculate

Ok Cancel

Figure 14 Setup of input for shadow flicker stops loss calculation.

Loss due to stop caused by flicker at neighbors is simple to performed. A Shadow calculation for exact the same wind farm layout as PARK calculation is based on, must be loaded. Then time step by time step it is checked if there is flicker at a neighbor and the loss due to stop within flicker time is calculated. The calculation is based on the turbine running in “calendar mode”, meaning all possible events of giving flicker is included (worst case calculation). If a more advanced flicker reduction mode is implemented, the stops will be less, and a simple reduction due to this can be entered – typically around 50%.

12.4.7 Other

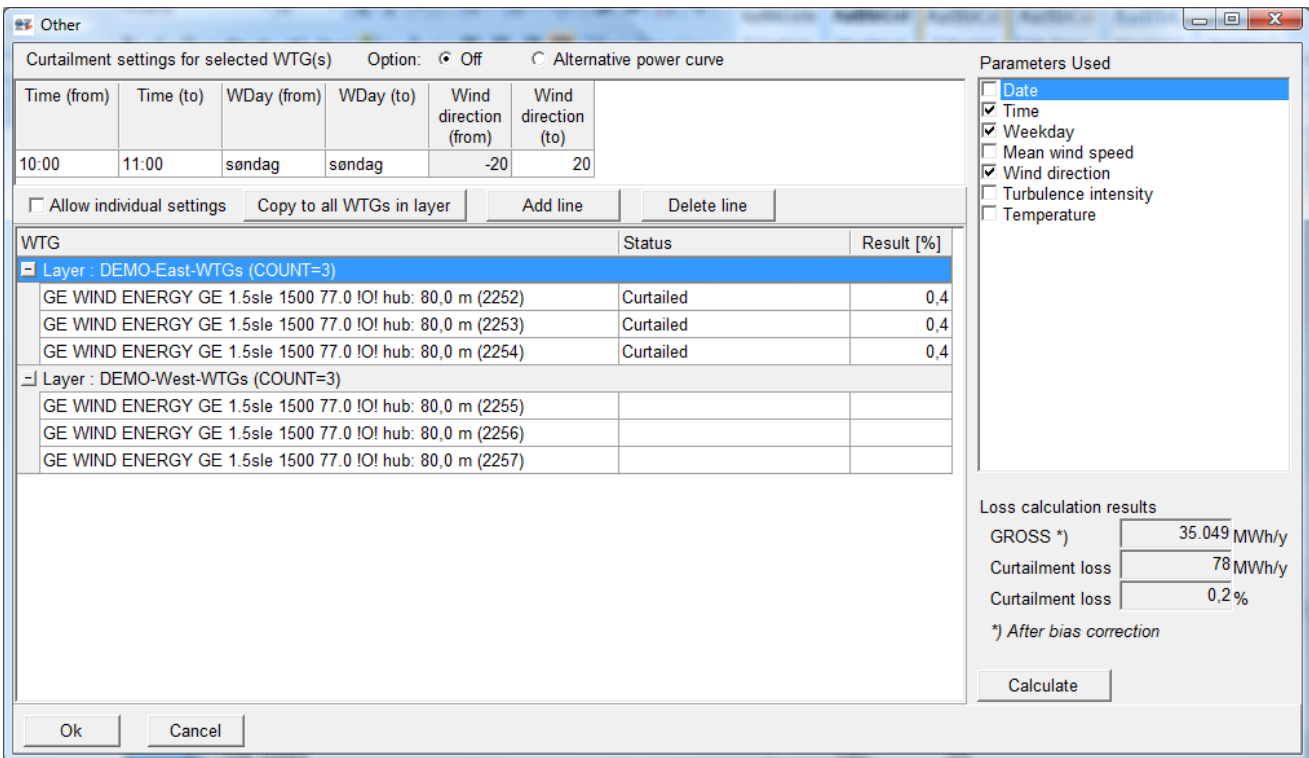


Figure 15 “Other” gives large flexibility for loss calculation depending on any parameter combination.

Using “Other” any parameters available in Meteo object or .WTI file can be used for setting up any parameter combination. In the example above, stop for the one group of turbines is every Sunday between 10:00 – 11:00 if wind direction is between -20 and 20. This could be when wind blowing towards the Church within church time.

12.5 Uncertainty

Uncertainties are grouped in 5 groups,

- A. Wind data
- B. Wind MODEL
- C. Power Conversion
- D. Bias
- E. Loss

Each of those groups must be judged, and as for bias and loss, some groups have calculation features which will be described in separate chapters. In later versions, more calculation features will be implemented.

Before going to the calculation features, the Wind data group will be explained, while this is one of the more important ones.

Define Calculation								
Main WTGs Model results Bias Loss Uncertainty Results Description								
Parameter	Calculate	Edit	Value	Unit	Std dev on Value [%]	Std dev on AEP [%]	Comment	
- A. Wind data (AEP std dev = 4,89 %)								
Wind measurement/Wind data				WS-%	3,00	3,46	Good quality equipment	
Long term correction				WS-%	3,00	3,46	Rather small ltc variations, long measuremen	
Other wind related				WS-%	0,00	0,00		
Year-to-year variability				WS-%	0,00	0,00		
Future climate				WS-%	0,00	0,00		
- B. Wind model (AEP std dev = 2,17 %)								
Vertical extrapolation	<input type="checkbox"/>			WS-%	1,59	1,83		
Horizontal extrapolation	<input checked="" type="checkbox"/>	Edit		WS-%	1,01	1,16		
Other wind model related				WS-%	0,00	0,00		
- C. Power conversion (AEP std dev = 0,34 %)								
Power curve uncertainty	<input type="checkbox"/>			AEP-%	0,34	0,34		
Metering uncertainty				AEP-%	0,00	0,00		
Other AEP related uncertainties				AEP-%	0,00	0,00		
- D. BIAS (AEP std dev = 0,00 %)								
RIX correction			1,78	AEP-%	0,00	0,00	All calculations based on M4	
- E. LOSS (AEP std dev = 0,00 %)								
Wake effects, all WTGs			-0,10	AEP-%	0,00	0,00		
Turbine availability			-3,00	AEP-%	0,00	0,00		
High wind hysteresis			-0,82	AEP-%	0,00	0,00		
Electrical losses			-2,00	AEP-%	0,00	0,00		
Performance degradation not due to icing			-0,50	AEP-%	0,00	0,00	Rather dusty region, some loss assumed	
Wind sector management			-0,27	AEP-%	0,00	0,00		
Other loss			-0,22	AEP-%	0,00	0,00		
Total uncertainty on AEP (1 year average)						5,36		
Each uncertainty contribution (std dev) is converted to a std dev on AEP and then combined to a total std dev assuming the individual contributions are independent and have Gaussian distributions (i.e. normal distributions). The mathematical expression used is: $(StdDev1^2 + StdDev2^2 + StdDev3^2 + \dots)^{0.5}$.								
<input type="button" value="Ok"/> <input type="button" value="Cancel"/>								

Figure 16 The five uncertainty groups A-E.

12.5.1 Wind data uncertainty

Wind data can be used in the PARK calculation in different ways:

- Measurements on site, typically along with a long term correction.
- A wind statistic for the region, possibly verified/calibrated based on performance from existing turbines in the region.
- A wind resource map, based on a model, like mesoscale model, CFD model or WAsP model – behind the wind resource map there will be wind data, that can be based several different sources.

To judge the quality of the wind data is probably the most essential part of the uncertainty evaluation. If turbines with longer operation period (>1y) exists in the region, a test calculation with the used wind data is one of the best ways to reduce uncertainty of the wind data basis. It is essential that the production from these turbines is properly long term corrected and cleaned for availability problems. If the actual cleaned production from those can be reproduced accurately, the uncertainty on the wind data can be assumed small.

If only local measurements are available, the uncertainty depends much on measurement equipment, mast configuration, sensor calibration and quality. Long term correction is normally a must, but here additional uncertainties are introduced, while the long term sources often are of poor quality, and might even be trended, if e.g. trees has grown up around the reference mast of if it is modeled data there might be trends due to changes in the data basis for the model. Such trends should NOT be considered just as an uncertainty, but should be corrected for up front or included as bias correction.

Even with high quality data, the wind measurement uncertainty should not be assumed lower than 2% on wind speed - an "upper limit" is difficult to give. If it is a low wind site, the wind speed uncertainty converted to AEP

uncertainty can be as high as 3 times the wind speed uncertainty, while it at a high wind site only will be 1,5 times the wind speed uncertainty.

A specific source of uncertainty is the position on the measurement mast. If the mast location is in a hilly environment, it is crucial that the position is correct, and that the elevation information around the mast is accurate. It is often seen that measurement masts are placed on a small hill top. If the elevation data are rough, the little hilltop is not included in the data and an error is introduced when cleaning the data based on orography. This is not an uncertainty but an error that must be handled by establishing the elevation data round the mast in a correct way. Photomontage tool should be used to verify that the elevation data round the mast is correctly established. If the mast position is uncertain, this should be included in uncertainty, for instance in "Other wind related".

Long term expectations might be the component within the wind data group with highest uncertainty. It is therefore important to understand how the composition of this part should be established.

In the input forms, there are 3 different input fields related to this topic:

- Long term correction
- Year-to-year variability
- Future climate

Long term correction

Here the uncertainty based on the facts used in the long term correction, typically performed with the MCP module shall be entered. This covers the uncertainty based on:

1. The length of the concurrent data period, the eventual seasonal bias and the resolution (time step of concurrent data)
2. The length of the long time data series (possible trends should be evaluated and if there seem to be trending, this is a very critical issue and usually other data should be found)
3. The correlation (how well the reference data correlate to the local measurements)
4. The accuracy of the method used for establishment of the transfer function and thereby the correction

The uncertainty is highly based on these issues. To give some rough judgments:

QUALITY LEVEL:	5	4	3	2	1
Length of local data series (years)	0,5	1	2	3	5
Uncertainty, AEP%	8	4	3	2	1
Length of long term reference (years)	3	5	10	20	30
Uncertainty, AEP%	12	8	6	4	2
Correlation, monthly basis (r-value)	0,6	0,7	0,8	0,9	1
Uncertainty, AEP%	15	10	6	4	2
Combined, Sqr sum of squares	18,8	12,3	7,8	4,9	2,2

The table above is just fiction, but it gives an idea of how it works. The "fictive values" are AEP uncertainties. Having the "typical good setup", Quality level 2; with 3y local measurements, 20y long term reference, correlation 0,9, an uncertainty of 5% is the result. At lowest quality level close to 20% on AEP must be expected. The table above can be used across the columns, in the sense of having e.g. quality level 2-3-4 for the 3 rows, will yield $\text{Sqrt}(2^2+6^2+10^2) = 11\%$. But still it is important to emphasize that this is an example made for illustration of how it could work, not scientifically based.

The very best way to estimate the uncertainty (and to reduce this) is to involve several long term data sources, where following can be found in EMD Online data: Synoptic stations, Airport data (Metar), NCAR data (and QSCAT for offshore) + more local meteorological masts. In addition use more methods (Regression, Matrix, Wind index) if data quality permits (NCAR data usually should be restricted to Wind index method). Based on the numerous results, the general tendency and scatter gives an indication of the level of the correction and its uncertainty. Obvious outliers should be omitted.

A typically uncertainty of Long term correction is between 1-3% on wind speed, but should not be lower than 3% on AEP.

Year-to-year variability

The figure entered here is decides how the 1,5,10, 20 year uncertainty is calculated. It tells how much the wind varies from year to year in the specific region. A typical value is **around 6% on wind speed**, but several sources are available at the Internet giving more specific regional variations. In the MCP module, the variability is calculated based on the long term reference used. The variability entered is used for the 1-year calculated uncertainty, while the 5 year then is the $\sigma_{1y}/\sqrt{5}$ etc. So the 20y variability uncertainty is the $\sigma_{1y}/\sqrt{20}$. E.g. for $\sigma_{1y} = 6\%$: $6\%/\sqrt{20} = 1,3\%$ (on wind speed, which converts to AEP% depending on wind speed level). It is important to be aware of that the variability tells about the fluctuations within few years, not the very long term variations seen in e.g. Northern Europe described by the NAO index (North Atlantic Oscillations). This is handled separately in the “future climate” input field.

Future climate

E.g. in Northern Europe, we have seen large variations during the 30 year 1980-2009 of modern turbine operation in Denmark. While 1986-95 (10y) were 8% above long term average measured in AEP, 1996-2006 (11y) were 5% below long term average. This illustrates well that 10 year for sure is too short a period to use as long term, and that there are climate variations that no one can predict. So far it seems that the variations in wind climate not are related direct to global warming etc. The slow variations have been seen for 150 years (eg. by the North Atlantic Oscillation); going up and down, but not trending towards more or less wind. Prediction the future 20y wind is a hard task that no one really can do. So to assume an uncertainty around 1-3% on wind speed due to future climatic variations seems appropriate – at least for Northern Europe – other parts in the world have similar variations, some has not. This should be studied region by region.

12.5.2 Model uncertainty

Vertical extrapolation

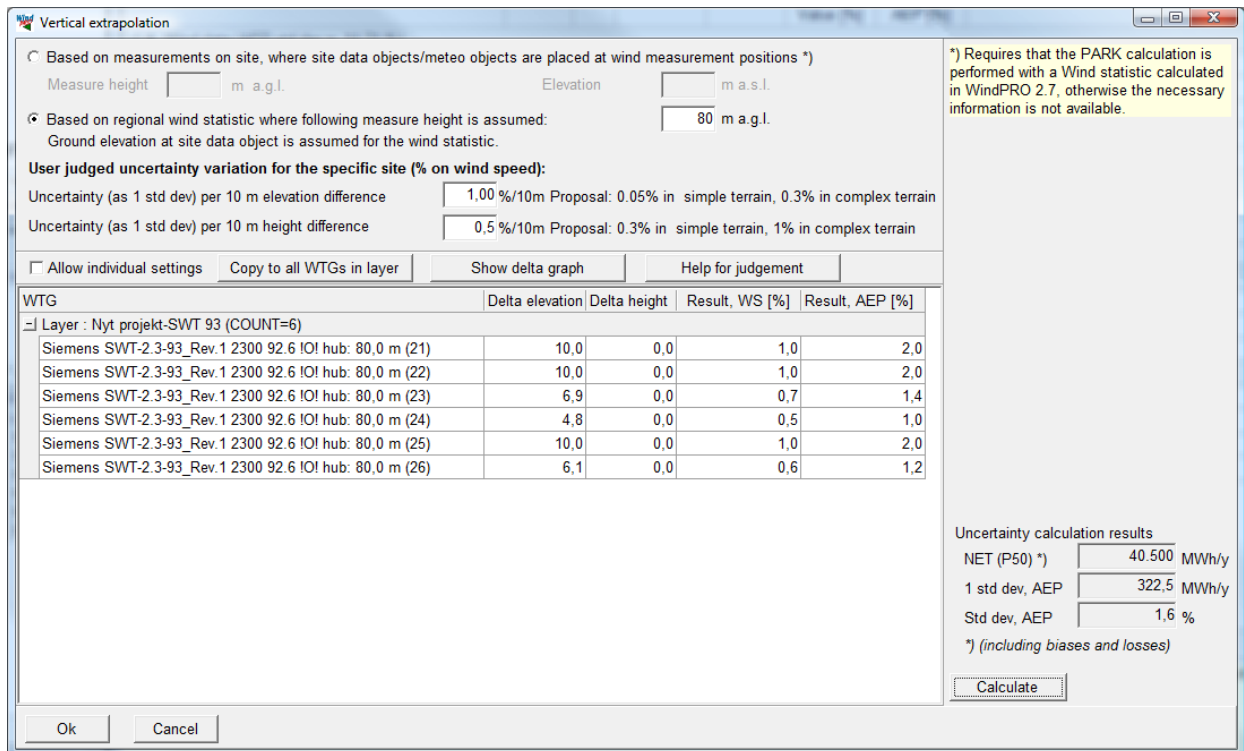


Figure 17 Input for vertical extrapolation uncertainty calculation.

The vertical extrapolation uncertainty is divided into the uncertainty due to elevation (above sea level) difference and difference between mast height and turbine height (above ground level). The proposals given for the uncertainty is based on different studies, but can be very site dependent. The best way to get a reasonable basis for the judgment is if there are more masts at the site, the cross prediction accuracy can give an idea on the uncertainty.

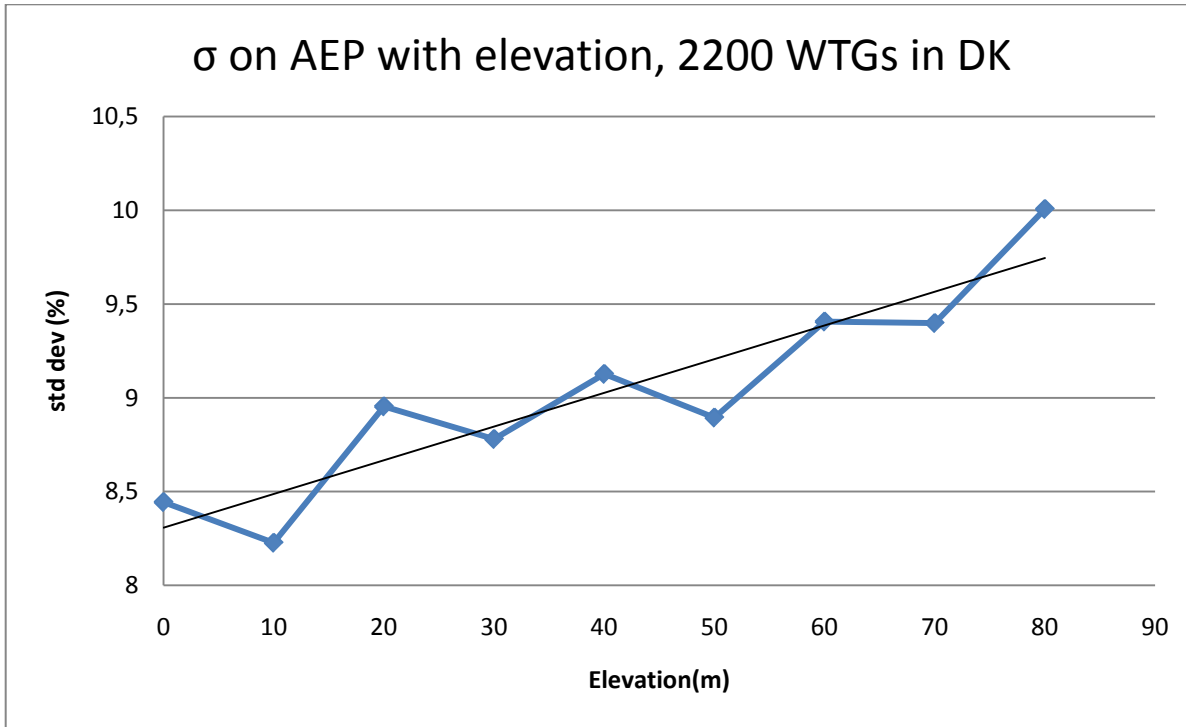


Figure 18 A large number of calculations in Denmark suggest a linear relationship between uncertainty and increased elevation in non-complex terrain.

For the DK example above it is important to emphasize that it is actually the absolute elevation that is shown. But in the Danish landscape the elevation difference is linked to the absolute elevation as the typical data basis is based at low elevation. Therefore, the figure indicates an increased uncertainty with increased elevation difference. Several other studies come up with similar findings. If the terrain is very complex, a RIX correction might have been performed. In this case the elevation difference uncertainty will be lowered.

The recommendations written in the input fields are intended to give an idea for input of uncertainty, but as terrain types vary very much from site to site, also the uncertainties vary similarly much. The best way is always to have more measurement mast at site and use the cross prediction tool in Meteo Analyzer to help give more precise indications of the uncertainty of the wind model.

Horizontal extrapolation

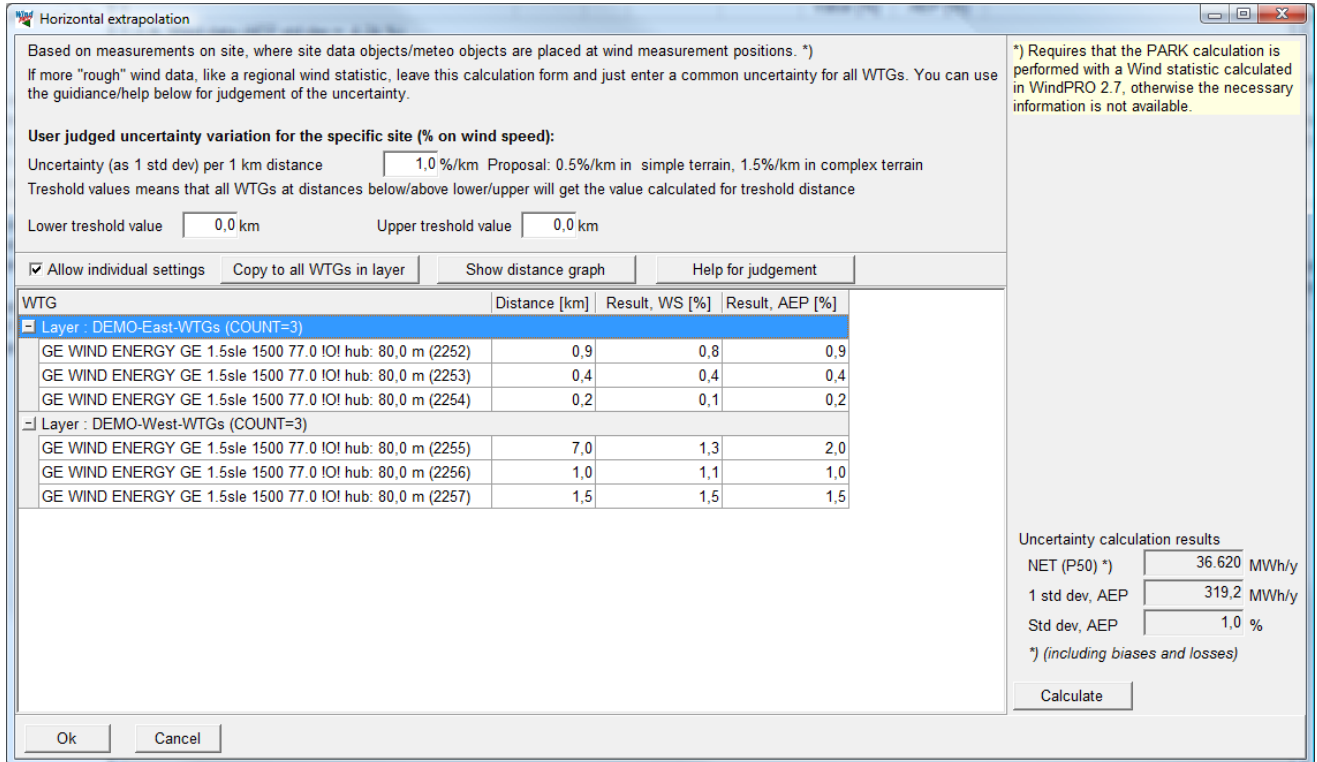


Figure 19 Input for horizontal extrapolation uncertainty calculation.

This calculation is similar to the vertical extrapolation. The critical issue is to judge the distance dependency of the uncertainty. An upper threshold value will normally be reasonable to use, while the uncertainty does not just continue to increase with distance. As for the vertical uncertainty, cross prediction based on more masts will be the best way to establish a basis for the judgments of uncertainty versus distance.

12.5.3 Power conversion uncertainty

Power curve uncertainty will often be found in the reports from power curve measurements. But please note that these will typically give very high uncertainty estimates, which might not be fair. Often power curves are measured on more turbines of the same type at different locations and the manufactures then perform their best judgments/averaging of more measurements to reduce their risk. This will reduce the uncertainty. A simple input can be given as illustrated above like a detailed input requiring input in the WTG Catalogue can be used. It is our hope to get the uncertainty included for the most power curves in future, but it will probably take some time before these are available – at least the structures are ready now.

Power curve uncertainty

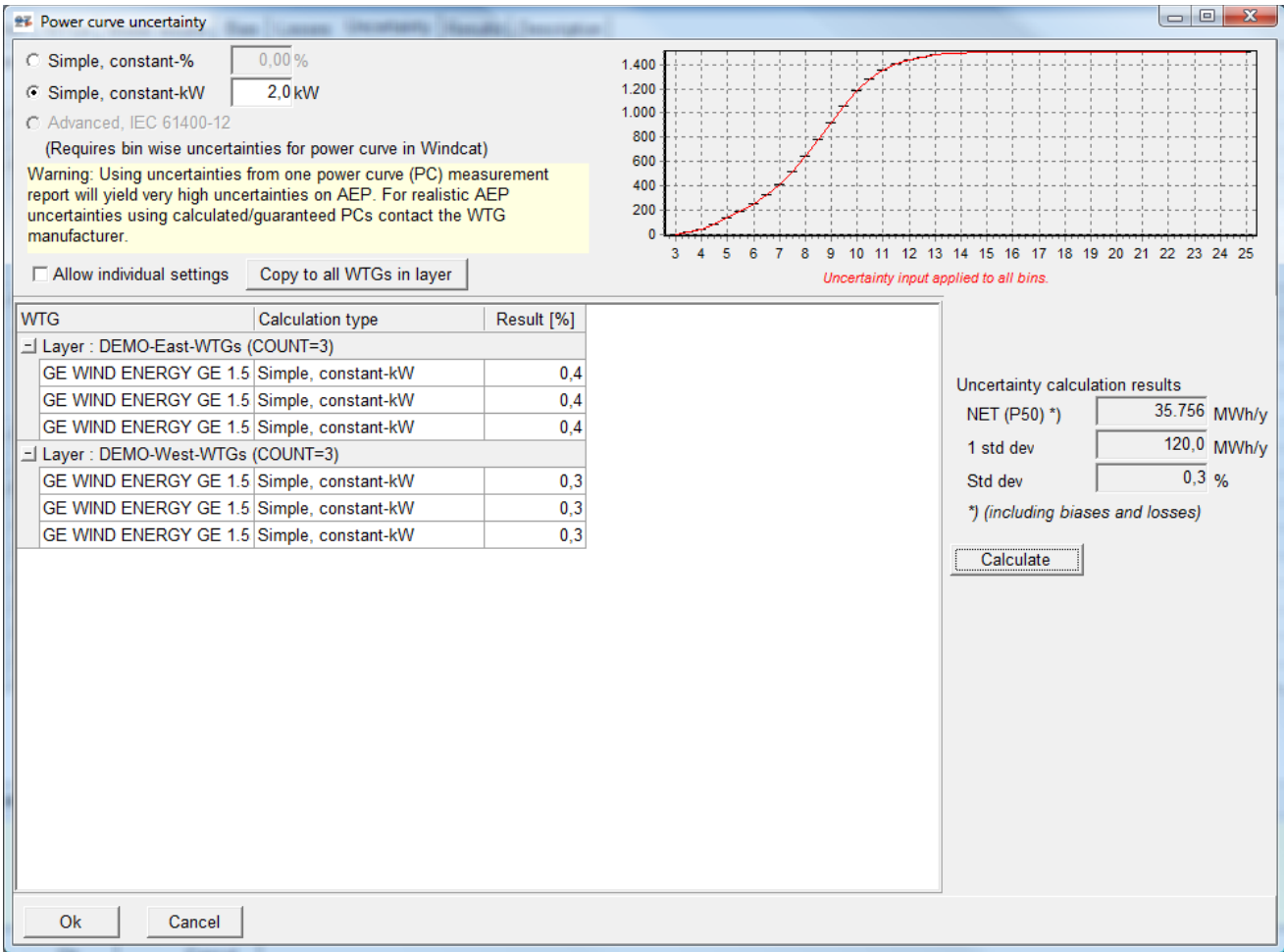


Figure 20 Input for power curve uncertainty calculation.

12.5.4 Bias uncertainty

For each bias component the user attributes a value, the uncertainty on this value can (and should) be set as well. Note that the entered uncertainty estimate is multiplied by the bias value, so if e.g. a bias is set to 5% with an uncertainty of 10% on that value, the resulting uncertainty is 0,5% on AEP resulting from that component.

12.5.5 Loss uncertainty

For each loss component included with a value, the uncertainty should also be set by the user. Note that the estimate is multiplied with the loss value-. A loss of e.g. 5% with an uncertainty of 10%, results in an uncertainty on AEP of 0,5% due to that loss component.

12.6 Results

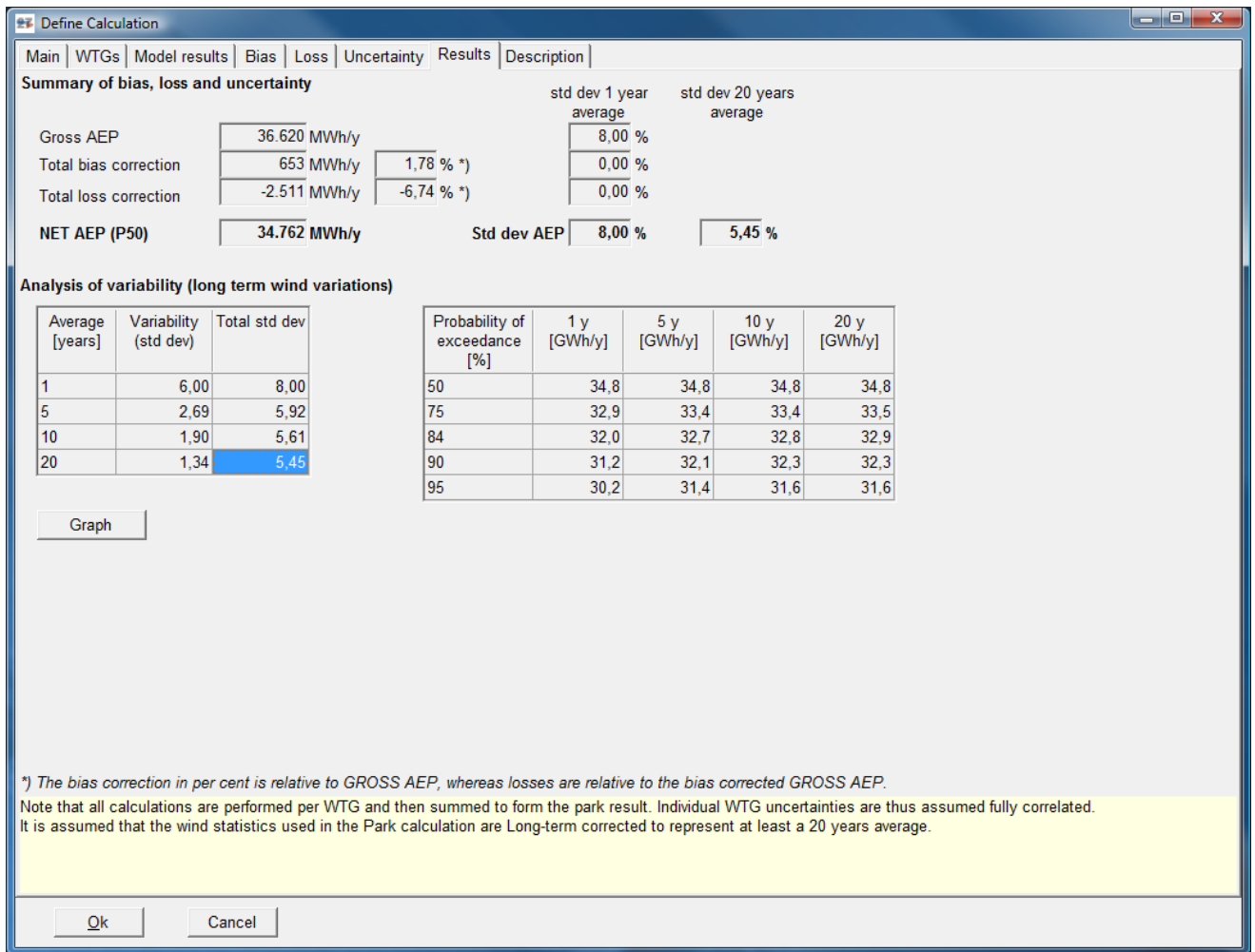


Figure 21 Evaluation of results.

On the Results sheet to the lower right presents results for 1, 5, 10 and 20 years of averaging (i.e. life time) and at several probability of exceedance values (50%, 75%, 84%, 90% and 95%).

12.7 Calculation and print

12.7.1 Main results

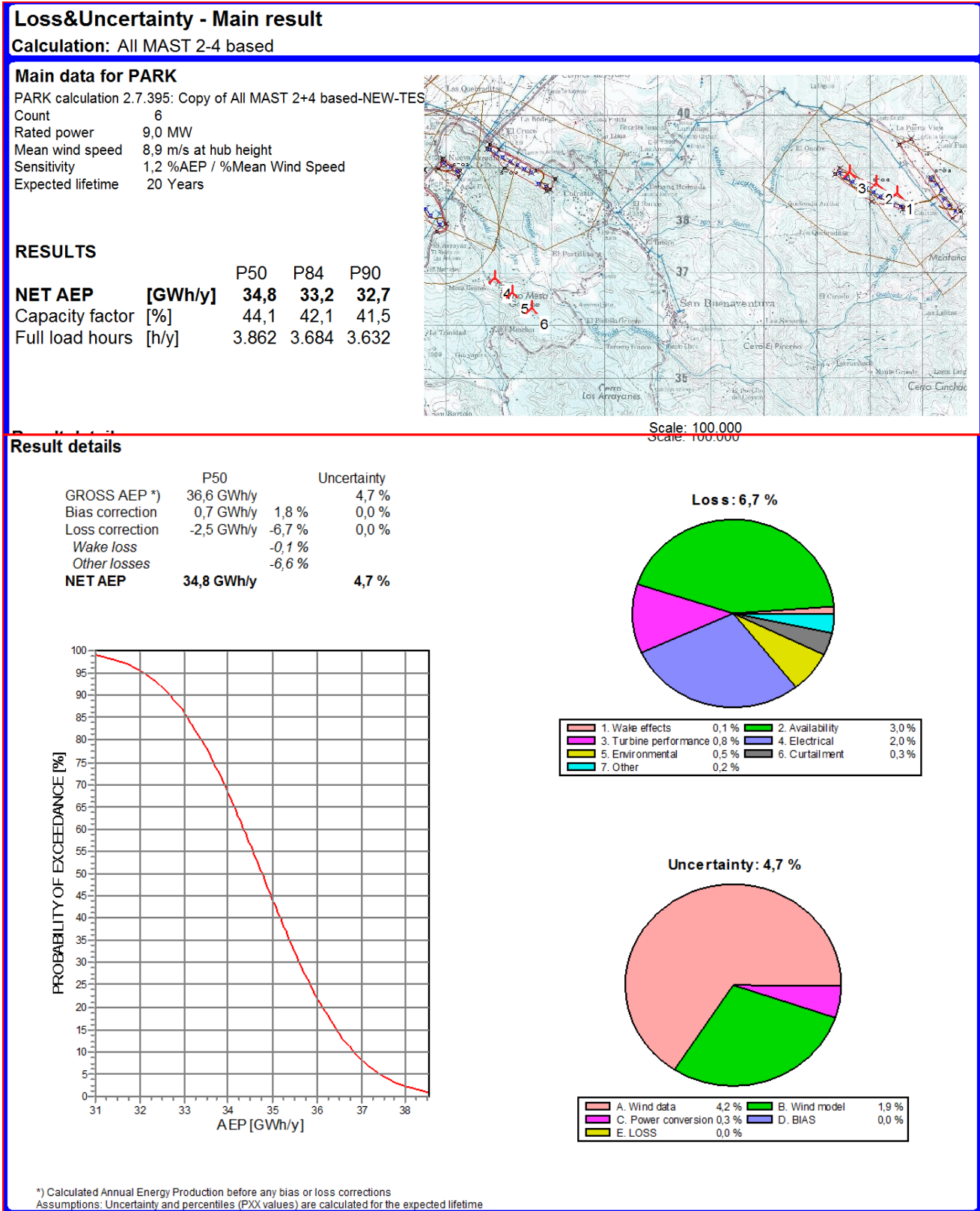


Figure 22 The printout of main result gives an overview of all results as a table and as graphics.

12.7.2 Assumptions and results

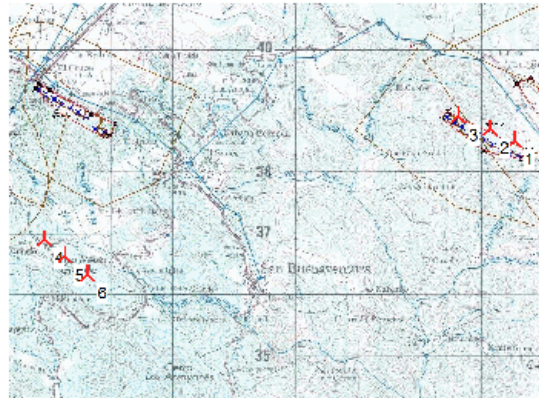
Loss&Uncertainty - Assumptions and results					
Calculation:All MAST 2-4 based					
ASSUMPTIONS					
BIAS					
	Method *)	Correction Wind speed [%]	AEP [%]	Uncertainty, std dev on AEP [%]	Comment
RIX correction	Calculation	4,2	1,8	0,0	All calculations based on M4
BIAS, total			1,8	0,0	
LOSS					
	Method *)	Loss AEP [%]	AEP [GWh/y]	Uncertainty, std dev on AEP [%]	Comment
1. Wake effects					
Wake effects, all WTGs	Calculation	0,1	0,0	0,0	
2. Availability					
Turbine availability	Estimate	3,0	1,1	0,0	
3. Turbine performance					
High wind hysteresis	Estimate	0,8	0,3	0,0	
4. Electrical					
Electrical losses	Estimate	2,0	0,7	0,0	
5. Environmental					
Performance degradation not due to icing	Estimate	0,5	0,2	0,0	Rather dusty region, some loss assumed
Shutdown due to icing, lightning, hail, etc	Estimate	0,0	0,0	0,0	No icing events assumed for this site
High and low temperature	Estimate	0,0	0,0	0,0	Based on manufacturer specifications
Tree growth or felling	Estimate	0,0	0,0	0,0	Trees are assumed kept in average as is
6. Curtailment					
Wind sector management	Estimate	0,3	0,1	0,0	
7. Other					
Other loss	Estimate	0,2	0,1	0,0	
LOSS, total		6,7	2,5	0,0	
UNCERTAINTY					
	Method *)	Std dev on wind speed [%]	on AEP [%]		Comment
A. Wind data					
Wind measurement/Wind data	Estimate	2,7	3,0		Good quality equipment
Long term correction	Estimate	2,7	3,0		Rather small ltc variations, long measurement peri
Other wind related					
Year-to-year variability	Estimate	6,0	7,0		
Future climate					
B. Wind model					
Vertical extrapolation	Estimate	1,4	1,8		
Horizontal extrapolation	Calculation	0,9	1,0		
Other wind model related					
C. Power conversion					
Power curve uncertainty	Estimate		0,3		
Metering uncertainty					
Other AEP related uncertainties					
D. BIAS, total uncertainty			0,0		
E. LOSS, total uncertainty			0,0		
UNCERTAINTY, total (1y average)			8,4		
UNCERTAINTY, total (20y average)			4,9		
VARIABILITY					
Years	Variability (std dev)	Total std dev			
1	6,95	8,4			
5	3,11	5,8			
10	2,20	5,1			
20	1,55	4,9			
Comment					
Wind measurement/Wind data Good quality equipment					
WindPRO is developed by EMD International A/S, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf: +45 90 35 44 44, Fax: +45 90 35 44 40, e-mail: windpro@emd.dk					

Figure 23 Second report page collect all input data on 1-2 pages. Also the detailed result matrix will be shown at the bottom of this page (not shown here).

12.7.3 WTG results

Loss&Uncertainty - WTG results

Calculation: All MAST 4 based



Scale: 100.000

Expected AEP per WTG including bias, loss and uncertainty evaluation

Description	Calculated GROSS*) [MWh/y]	Bias [%]	Loss [%]	20 years averaging			
				Unc. [%]	P50 [MWh/y]	P84 [MWh/y]	P90 [MWh/y]
Layer: DEMO-East-WTGs							
1 GE WIND ENERGY GE 1.5sle 1500 77.0 !O! hub: 80,0 m (2252)	6.062,3	5,5	6,8	6,6	5.964,1	5.573,3	5.460,5
2 GE WIND ENERGY GE 1.5sle 1500 77.0 !O! hub: 80,0 m (2253)	6.296,5	5,5	7,2	6,6	6.162,1	5.758,4	5.641,8
3 GE WIND ENERGY GE 1.5sle 1500 77.0 !O! hub: 80,0 m (2254)	6.561,3	5,5	7,6	6,6	6.396,2	5.977,1	5.856,1
Layer: DEMO-West-WTGs							
4 GE WIND ENERGY GE 1.5sle 1500 77.0 !O! hub: 80,0 m (2255)	5.576,5	5,5	5,8	6,6	5.541,9	5.178,8	5.074,0
5 GE WIND ENERGY GE 1.5sle 1500 77.0 !O! hub: 80,0 m (2256)	5.779,1	5,5	5,9	6,6	5.735,0	5.359,2	5.250,7
6 GE WIND ENERGY GE 1.5sle 1500 77.0 !O! hub: 80,0 m (2257)	5.480,5	5,5	5,9	6,6	5.442,0	5.085,4	4.982,5
PARK	35.756,1	5,5	6,6	6,6	35.240,7	32.931,7	32.265,1

*) NOTE: GROSS value is calculated as "free" turbine without wake losses or other losses.

Figure 24 This page show results turbine by turbine, thereby the needed details for projects sold turbine by turbine are available.

12.7.4 Detailed results

For each "calculation option" a separate report are available. These describe the calculation setup and partly the data basis. Only one sample is given below. These reports can be quite detailed.

17-11-2009 01:20/2.7.395

Loss&Uncertainty - High wind hysteresis, Detail

Calculation: All MAST 4 based

Shown losses is the energy content below powercurve cut-out where the WTG is stopped.

Note that all hysteresis losses in MWh are calculated for the full time series. The losses in per cent in the Main report are scaled to represent one year if the length of the data series deviates from a year.

WTG: GE WIND ENERGY GE 1.5sle 1500 77.0 !O! hub: 80,0 m (2252) in layer: DEMO-East-WTGs

Cut out time	Cut in time	Total duration [min]	Duration below PC cut out [min]	Hysteresis loss [MWh]
29-10-2008 01:02	29-10-2008 01:19	17	17	0,42
29-10-2008 03:52	29-10-2008 04:30	38	38	0,95
29-10-2008 05:53	29-10-2008 08:09	136	125	3,13
29-10-2008 08:37	29-10-2008 09:18	41	41	1,02
29-10-2008 09:36	29-10-2008 10:05	29	26	0,65
29-10-2008 19:16	29-10-2008 19:30	15	14	0,36
30-10-2008 00:33	30-10-2008 04:14	220	140	3,50
30-10-2008 05:36	30-10-2008 11:53	377	213	5,33
30-10-2008 23:25	31-10-2008 00:20	55	35	0,88
31-10-2008 02:49	31-10-2008 04:35	106	90	2,25
31-10-2008 04:55	31-10-2008 07:00	125	116	2,89
17-11-2008 03:36	17-11-2008 04:42	65	35	0,88
17-11-2008 21:42	18-11-2008 04:28	406	208	5,19
18-11-2008 07:59	18-11-2008 13:32	333	301	7,53
23-11-2008 00:38	23-11-2008 15:31	893	680	16,99
04-02-2009 17:02	06-02-2009 03:22	2059	1562	39,05
23-02-2009 06:46	23-02-2009 08:19	93	64	1,60
02-03-2009 10:25	02-03-2009 12:59	154	128	3,20

WTG: GE WIND ENERGY GE 1.5sle 1500 77.0 !O! hub: 80,0 m (2253) in layer: DEMO-East-WTGs

Cut out time	Cut in time	Total duration [min]	Duration below PC cut out [min]	Hysteresis loss [MWh]
29-10-2008 00:54	29-10-2008 01:24	30	28	0,70
29-10-2008 03:24	29-10-2008 05:28	124	105	2,62
29-10-2008 05:47	29-10-2008 10:09	261	212	5,29
29-10-2008 18:56	29-10-2008 19:34	38	29	0,73
30-10-2008 00:27	30-10-2008 04:19	232	102	2,55
30-10-2008 05:31	30-10-2008 11:56	386	175	4,37
30-10-2008 23:10	31-10-2008 02:22	192	134	3,36
31-10-2008 09:45	31-10-2008 09:07	222	222	5,61

Figure 25 High wind hysteresis loss is shown with a detailed list for each turbine, where as well number of expected stops as duration and losses can be seen.

