14 PERFORMANCE CHECK

14.0 PERFOMANCE CHECK

14.1 Introduction, definitions and step-by-step guide

Operating turbines should frequently be checked if they perform as expected. There can be many reasons for poorer performance than expected when the project was designed. A major reason is that the model calculation had poor or wrong assumptions or the model did not handle the terrain well. But also operational issues like yaw errors, pitching problems, and unforeseen curtailments (e.g. grid), icing loss etc. could be the reason.

With the WindPRO PERFORMANCE CHECK module it is possible in an efficient way to analyze the performance and find reasons for under (or over) performance. Typically there will be a huge data amount, like 10 min values of numerous parameters from the SCADA system or turbine controller to look at. But also "just" monthly production and eventually availability figures can be efficient analyzed with the tool.

With the Performance Check module we have set up a flexible tool, which handles these typical situations:

- Monthly data with wind energy index correction gives the expected long term (future) production.
- Monthly data is analyzed against time varying PARK calculation aggregated monthly.
- Detailed (10 min., hourly etc.) data is analyzed against detailed time varying PARK calculation.
- Power curve validation based on detailed (10 min) wind speed, direction and power data.
- General X-Y graphs for identifying turbine control problems or data quality.

The first one requires a wind energy index, which can be downloaded from EMD Online data for some regions, established by the user by "copy paste", or generated by the comprehensive tool for wind energy index creation based on wind measurements, e.g. the free On-Line available MERRA or CFSR data sources or the more detailed purchase able EMD-ConWx data or data from other data providers like Vortex or 3TIER.

The last ones require time series of wind speed and direction, and preferable temperature and eventually pressure for air density correction. These data can come from a local measurement mast/Lidar/Sodar, from nacelle anemometer or from meso scale model data. In addition like RPM, pitch angle etc. can help identifying turbine operation problems.

Of importance is to state: The Performance check module has two major purposes:

- Helps to calibrate the model setup, so the expected long term production is calculated very accurate, which is very important if a project is going to be sold – the expected production simply decides the sales price!
- Analyze/identify turbine problems and/or model calculation problems – first issue might be correctable, second issue gives benefits in knowhow for future projects in development.

An important functionality in the performance check tool is the data filtering. No doubt that availability problems is the major reason for making it difficult to judge if like model calculations are right or wrong or if turbine performance is as it should be when in "normal operation". Therefore comprehensive filter options are a very important part of the tool.

14.1.1 Basic concept

The basic concept behind the module is:

Time varying production_power data + evt. availability, wind direction, RPM, pitch angle etc. are imported into EXISTING WTG object data. More time series can be imported to an object, e.g. both monthly and 10 min. values. Data can be aggregated from e.g. 10-min. values to hourly values. A comprehensive importer tool (Meteo object like) is available for this.

A PAIR tool secures that the imported data are put into the right turbine object, so e.g. comparison of calculated vs measured are performed for the right turbine object.

The data stored at the turbine object is chosen so data with a time resolution of one hour or higher (typically 10 min) is stored as power values (kW), while data at lower time resolution (typically monthly) is stored as production (kWh). This is the typical way data are available and gives access to an easy check if data seems reasonable.

There are two main “entries” to the tool:

1. **Monthly based** Wind Index Corrected (WCP) production and/or analyses against monthly aggregated PARK calculated productions.
2. **Detailed time series** data where PARK calculated vs measured and/or Power curve evaluation is performed.

Both can be run for the same park, but in two separate “sessions”. When starting the tool, the session “type” must be selected. More sessions of each type can be setup, meaning that like different data filtering is allocated to each session.

The wind energy index database must be mentioned as an important part of the basic concept. A comprehensive wind energy index database concept is developed. This handles as well “official” wind energy index’s as it has its own index calculator based on wind data. The wind data can be downloaded in METEO objects from the ONLINE data service, where like MERRA data or the EMD-ConWx data is some possible sources for creating own wind energy index’s.

14.1.2 Step-by-step guide

- ❑ Decide based on the detailedness of the data available which “type” op performance check to run.
- ❑ If check against model calculations is decided, setup and run a time varying PARK calculation (Must be based on “existing WTG objects”.)
- ❑ Arrange the measured production data etc. in ascii text files ready for import.
- ❑ Load PERFORMANCE CHECK module from left menu bar.
- ❑ Setup import filter for measured production data if data not already are loaded in existing WTG objects.
- ❑ Decide which existing WTG objects to include in analyze (assumed created in project).
- ❑ PAIR WTG ID’s from the import setup to existing turbine objects and load (import) the data.
- ❑ Utilize the analyzer and other tools to get “the idea” what might be wrong – or just to draw conclusions and print reports (WCP only) or copy data to excel for making the documentation of the findings.

14.2 Time varying PARK calculation (Optional)

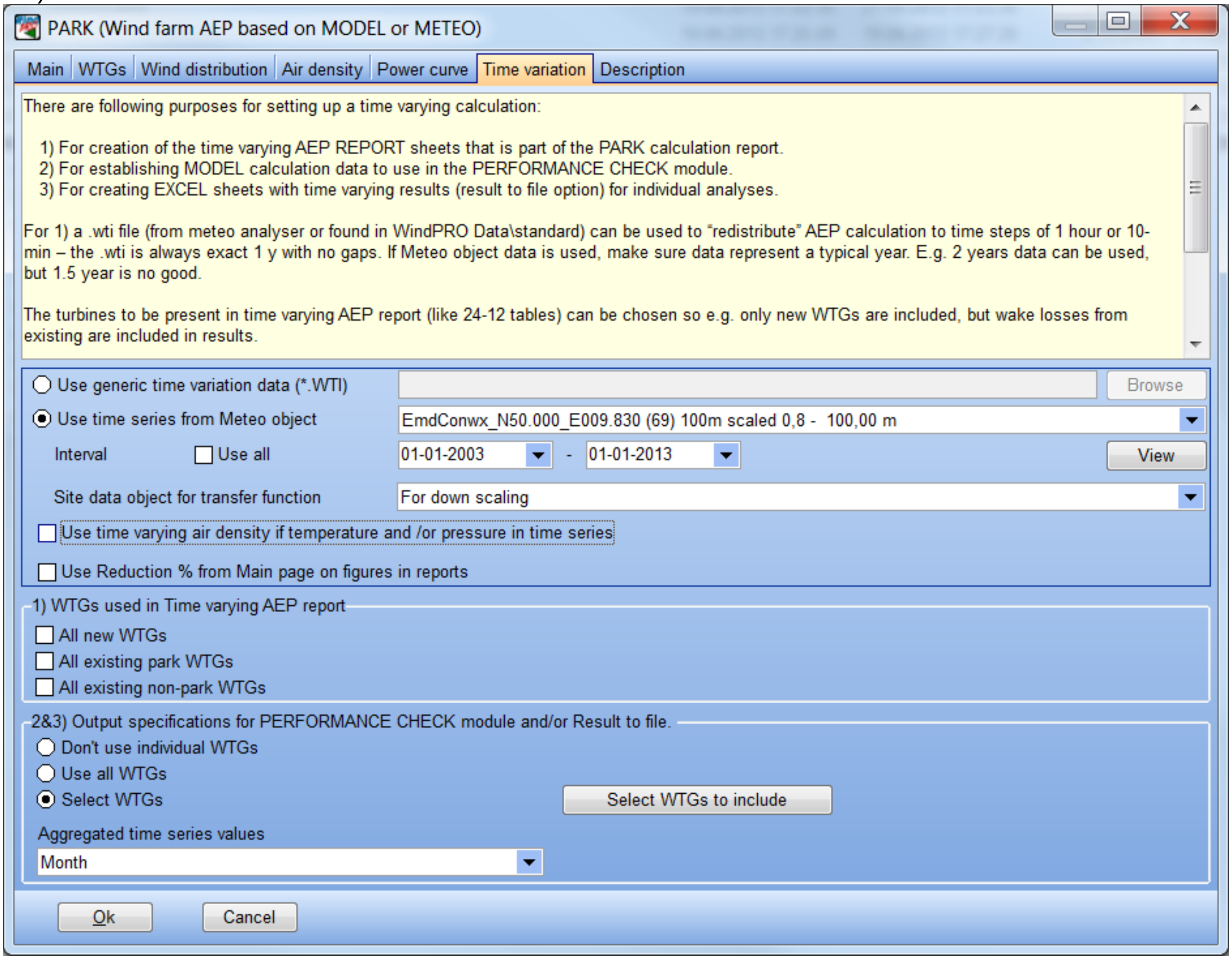
The time varying PARK calculation has to be introduces while this improves the use of the Performance check tool highly. Setting up a calculation model where in time variation is included offer the user the possibility to check if the model calculation performs well. The basic concept is a scaling by wind direction sector. The transfer function between the wind data source (met. Mast) and turbine position is calculated and used for each time stamp in the used wind data source.

14.2.1 Wind data etc.

As input for the time varying calculation wind speed and direction for a specific position (mast) can be used, or like meso scale model data can be used. But also nacelle anemometer wind data can be used, although these data has the problem that wake reductions are “included”, where the calculation model assumes the free wind speed is available. This can be handled by a quite comprehensive data cleaning where the wake reductions are “taken out”. This might also be needed if the met mast is located near the wind farm.

14.2.2 Calculation setup

The time varying calculation is set up in the park module by the following tab (appearing when checked at main tab):

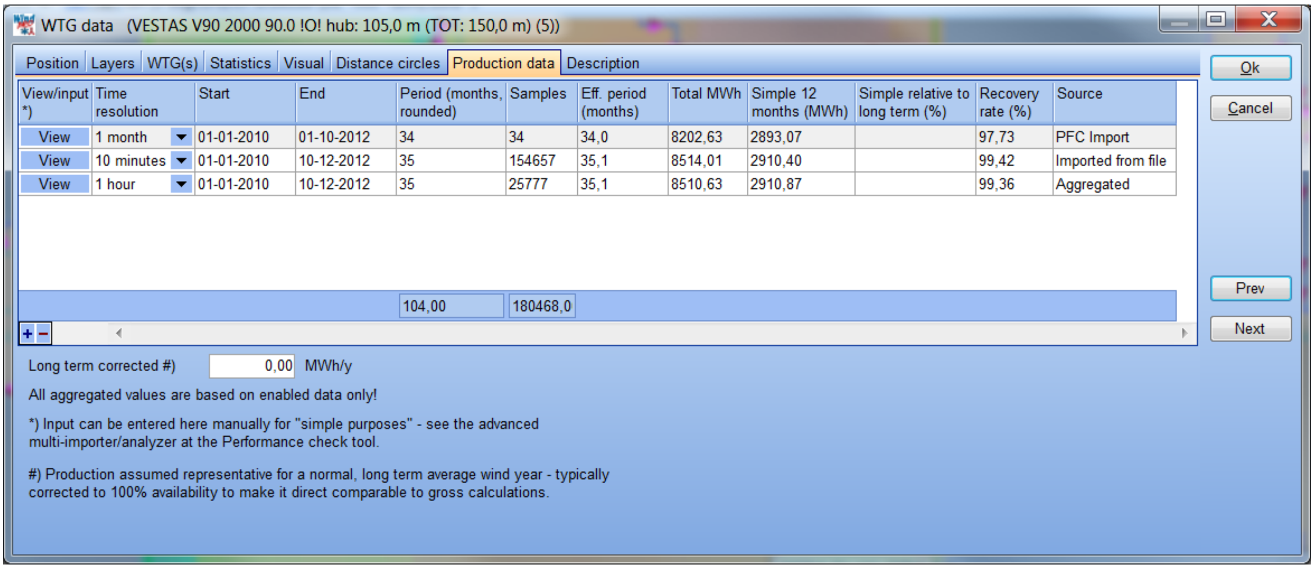


Here it can be decided which source is to be used for time varying calculation. For Performance check "use a Meteo object" always should be used. The site data object for transfer function decides how measurements are scaled from measurement position to turbine positions.
It is VERY important that the same wind statistic is selected in the site data object for energy calculation and for scaling. Otherwise some awkward scaling might be established.
BUT using a site data object specific for the transfer function can be a good idea. For example a site data object with a roughness rose can be used for downscaling meso scale data – meaning that it is possible to use a roughness rose for adjusting the meso scale data to local conditions or compensating for that the meso scale data are established based on a more "rough" terrain input than used in the micro scale model.
How to use this feature will be illustrated in an example later.

14.3 Data preparation and WTG object

The existing WTG object is the "center" of the performance check module. The data structure of this object is expanded to hold data in time domain. This can be as well production as any other parameter like wind speed, direction, pitch angle, rpm etc.

14.3.1 Structure of the data – the existing WTG object



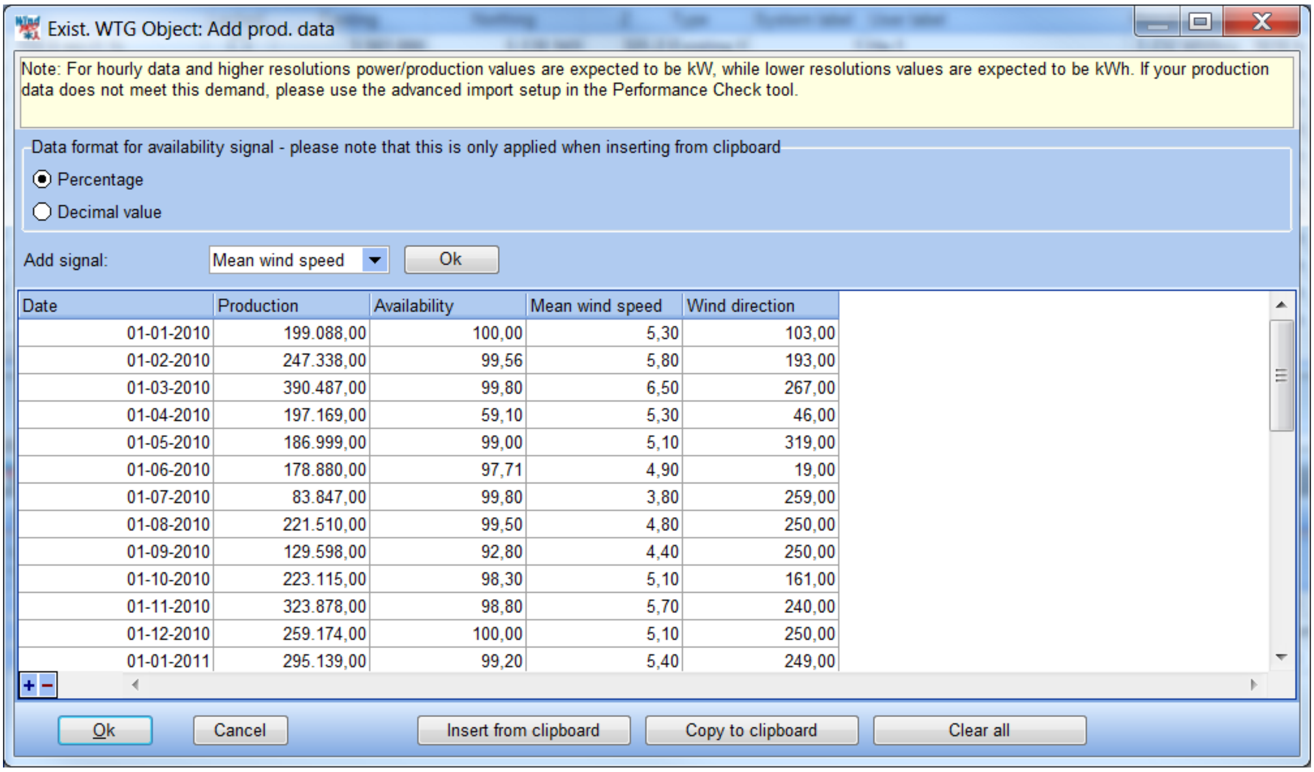
The existing WTG object has a tab “production data”.

Most important data are the production figures from the turbines. The basics are that with time resolution => 1 hour, it is power (kW) that is saved in the WTG objects. With time resolution <= 1 hour it is production (kWh) that is saved at each time stamp. (if 1 hour resolution, the value for kW = kWh). If data are available in other units, e.g. accumulated production (meter readings), this can be converted by the importer tool, see later.

In addition to power_production, any signal can be imported into the WTG objects. Most relevant is wind speed and direction, but also like RPM, pitch angle etc. can be relevant parameters for special analyses.

Within the WTG object tab it is as well possible to paste data into as import data from the performance check module.

Above is seen an overview of the data sets allocated to the object. The structure is that time series in different resolutions can be allocated, but only one series for a given time resolution. If there is a need for like two different sets of monthly data, there must be created a clone of the object.
The form can be used to evaluate the “rough” figures, like total MWh and simple 12 months MWh (average of all data scaled to a full year), to get a first impression of the production or to validate that the imported data is converted by the right unit and is plausible.

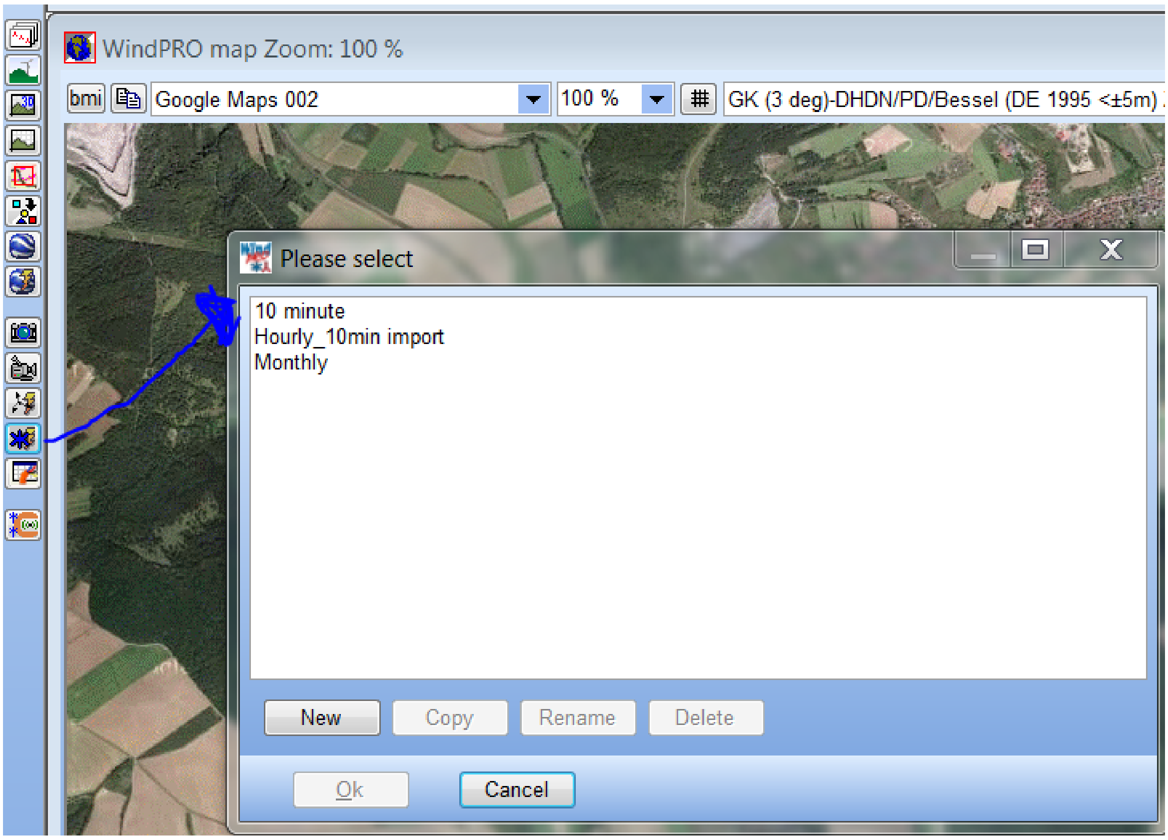


Here a view of a specific time series. Data can be inserted from clipboard. This is the "very simple" approach to get time varying data into the object. But having many turbines (or many data) it is handier to use the importer tool in the performance check module. The form can also be used to make manual editing of the data if there e.g. in import files are erroneous data.

14.3.2 Preparation of data for importer

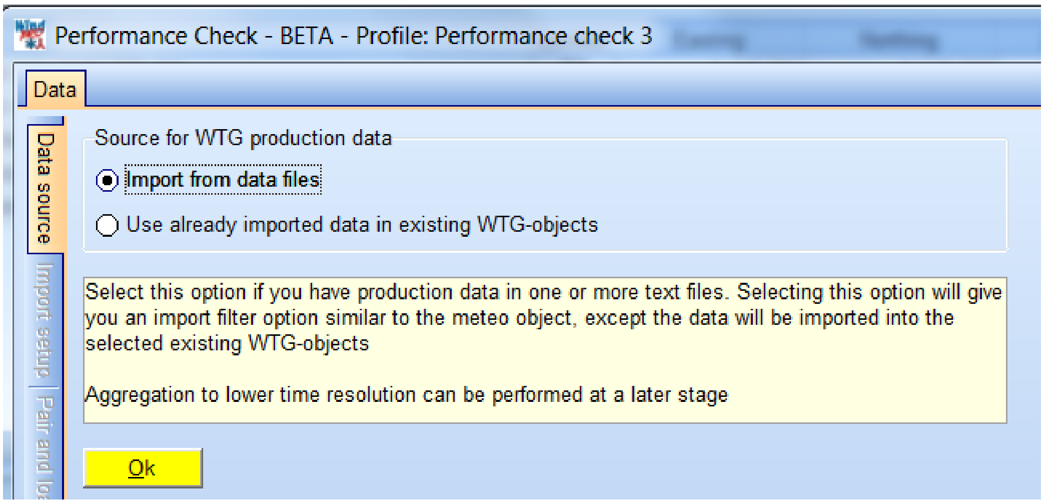
To use the Performance check importer to import the data to the existing WTG objects, some preparations of the data is needed. First of all, the data must be in ascii files. If they are in excel files, these must be saved as .txt or .csv or other text file formats.
Secondly, it is convenient to organize the files in an "import friendly" way. Basically the import tool is very flexible, but it requires well (equally) structured files. If data from many turbines are to be imported, it will be convenient, if turbine identification in the import files are similar to an ID in the existing WTG object (description or user label).
Basically the most important is that data files are organized so time stamp records appear row by row, with a "plain" time stamp column, preferable like dd-mm-yyyy hh:mm. Avoid like Dec-12 in time stamp column. Months by names will not work generally due to language differences.

14.4 PerfCheck; Start



Activate the Performance Check module from the left menu bar.

Start with creating a new “session”, or open a previous created. The naming is at indicated above typically related to the time resolution. Each time resolution is handled in its “own” session.



Starting a new session require to decide if new data are to be imported into the existing WTG objects, or already imported shall be used.

14.4.1 Monthly data based

A performance check session based on monthly data gives access to the wind index correction tool and the analyzer tool, where last mentioned needs that a time varying PARK calculation is performed with data aggregated on monthly level.

14.4.2 Detailed data based

A performance check session based on detailed data gives access to the power curve tool and the analyzer tool, where last mentioned needs that a time varying PARK calculation is performed with non-aggregated data – or aggregated to the level where measured data are available.

14.5 Data

At the data tab, import is handled, as well as pairing the import ID'd to turbine objects, and loading the data from files to the WTG objects. The time series can be reviewed, e.g. sorted etc. like in meteo object. There is a special functionality for time shift, while turbine production might sometimes appear in local time including daylight saving. This can be handled by the time shift functionality.

14.5.1 Data – Import setup

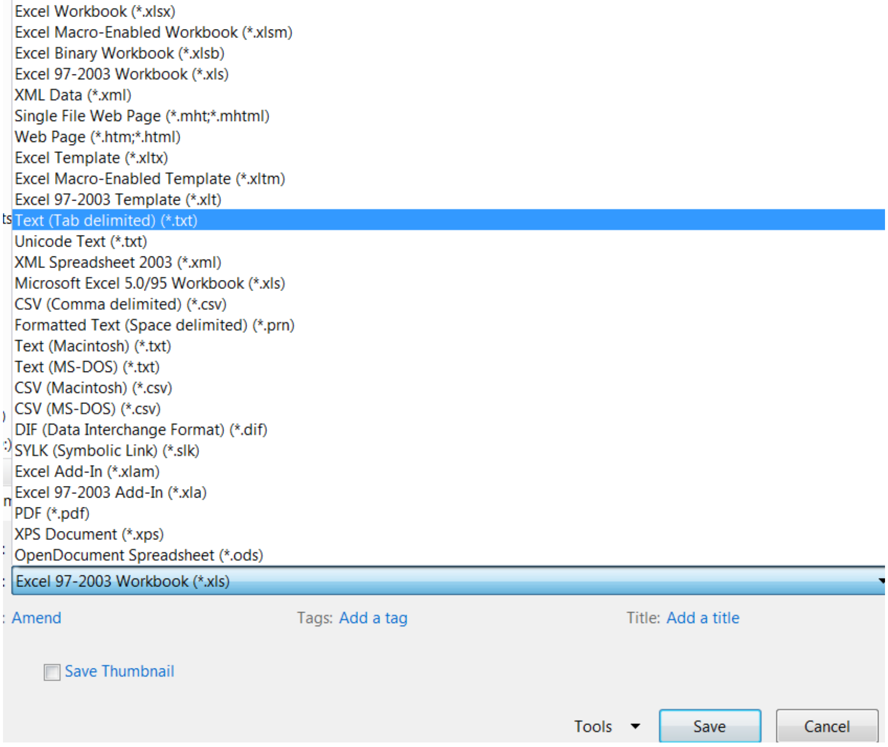
First the data files might need some preparation – e.g. if data are in Excel files.

Open in Excel to evaluate the data structure – copy header line + 2 first data lines and paste transposed to new sheet:

	A	B	C
1	PCTimeStamp	01-01-2011	01-01-2011 00:10
2	WEA04_Production LatestAverage Total Active Power Avg. (1)	-545	4950
3	WEA05_Production LatestAverage Total Active Power Avg. (2)	-557	3773
4	WEA06_Production LatestAverage Total Active Power Avg. (3)	-525	4186
5	WEA04_Ambient WindSpeed Avg. (4)	4	4,5
6	WEA05_Ambient WindSpeed Avg. (5)	4,1	4,5
7	WEA06_Ambient WindSpeed Avg. (6)	4,3	4,8
8	WEA04_Ambient WindDir Absolute Avg. (7)	250	248,4
9	WEA05_Ambient WindDir Absolute Avg. (8)	268,4	266,2
10	WEA06_Ambient WindDir Absolute Avg. (9)	293,3	290,9
11	WEA04_Blades PitchAngle Avg. (10)	23,9	-0,6
12	WEA05_Blades PitchAngle Avg. (11)	24	11,6
13	WEA06_Blades PitchAngle Avg. (12)	24	5,1
14	WEA04_Blades PitchAngle Max. (13)	19	-2,3
15	WEA05_Blades PitchAngle Max. (14)	24	-2,4
16	WEA06_Blades PitchAngle Max. (15)	24	-2,4
17	WEA04_Blades PitchAngle Min. (16)	24,1	17,6
18	WEA05_Blades PitchAngle Min. (17)	24	24
19	WEA06_Blades PitchAngle Min. (18)	24,1	25,6
20	WEA04_System Logs First Active Alarm No (19)	0	0
21	WEA05_System Logs First Active Alarm No (20)	0	0
22	WEA06_System Logs First Active Alarm No (21)	0	0
23	WEA04_Nacelle Temp. Avg. (22)	13	12
24	WEA05_Nacelle Temp. Avg. (23)	12	12
25	WEA06_Nacelle Temp. Avg. (24)	13	13
26	WEA04_Generator RPM Avg. (25)	295	1207
27	WEA05_Generator RPM Avg. (26)	278	635
28	WEA06_Generator RPM Avg. (27)	284	847
29	WEA04_Rotor RPM Avg. (28)	2,6	10,6
30	WEA05_Rotor RPM Avg. (29)	2,4	5,5
31	WEA06_Rotor RPM Avg. (30)	2,5	7,4

This looks OK – there is a unique WTG identifier in each column, and the date format is dd-mm-yyyy hh:mm. Where hour:min is 00:00 Excel typical do not show the hour, but this is ok. What is NOT ok is if the date-time format not is "straight numbers" – in such case convert to numbers in Excel before saving. (E.g. if month are by "name" like "Jan", there will be problems identifying).

Data must be converted to .txt files. Chose Save as:

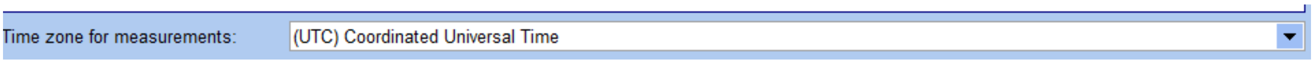


Use the Text Tab delimited, this is the most “safe” – but if data already are in like .CSV files, no conversion is needed (if date-time format is ok).

Doing this operation often or having really many files, there are tools for batch conversion of Excel to .txt for purchase.

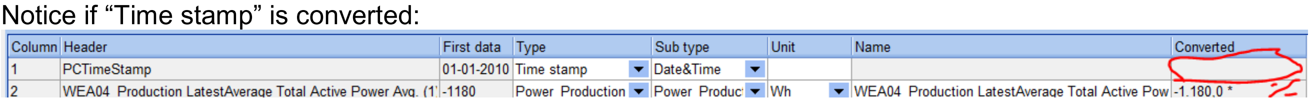
Start performance check session – name it: 10min - import

Add the files to the importer – run Auto detect. This might identify some of the signals, but typically some manual selection will be needed.

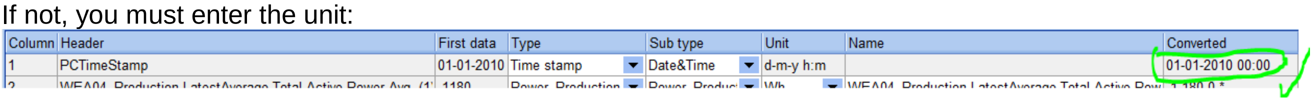


Remember to set the time zone – some Scada data will be delivered in UTC time, other in local time zone. You might later become aware of a time shift between calculations and measurements when viewing the time series, the wrong time zone in import might explain.

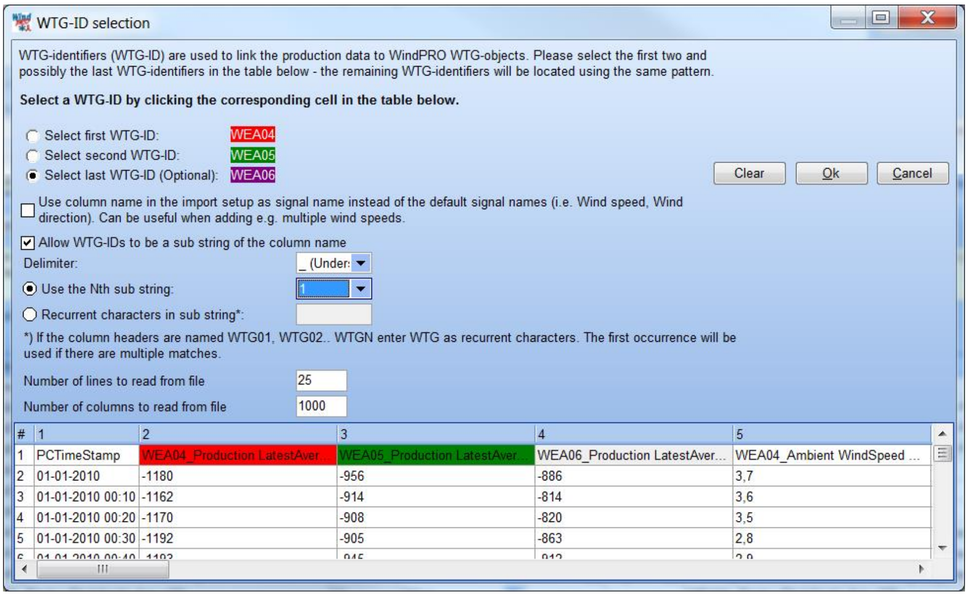
Notice if “Time stamp” is converted:



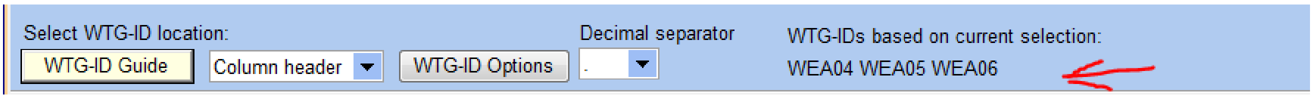
If not, you must enter the unit:



Run the WTG-ID Guide (just answer a few questions), and you will get this guide:

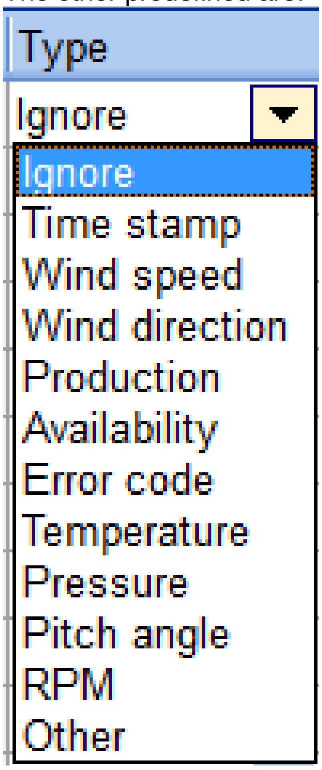


You simply point out the columns with fist and second WT-ID (optionally the last).
Then choose the delimiter, here "_" (underscore)
Decide which sub string (in case of more under scores, there will be more choices, but here with only one, there will be 1 or 2 (part of text before or after underscore).
That's it, and by OK the WTG ID's are found.

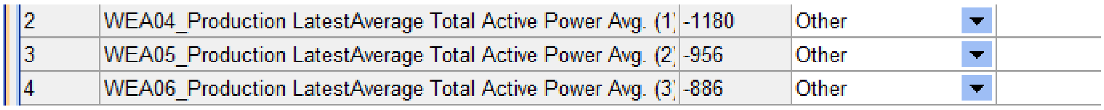


It's seen here if you were successful.

Now find the signals to include in import. The "must" fields are:
Time stamp
Production
The other predefined are:



Other can always be used for user defined signals.



Now select the 3 power columns, simply by mouse drag or “Shift – click” like in Windows Explorer.

Apply the correct type-units (must be known – or can easy be redone if it turn out to be wrong).
Choose thee Pitch angle and RPM in addition to wind speed and direction, which might be auto detected.
Set all other signals to “ignore”. (Multi select to do this in one operation).

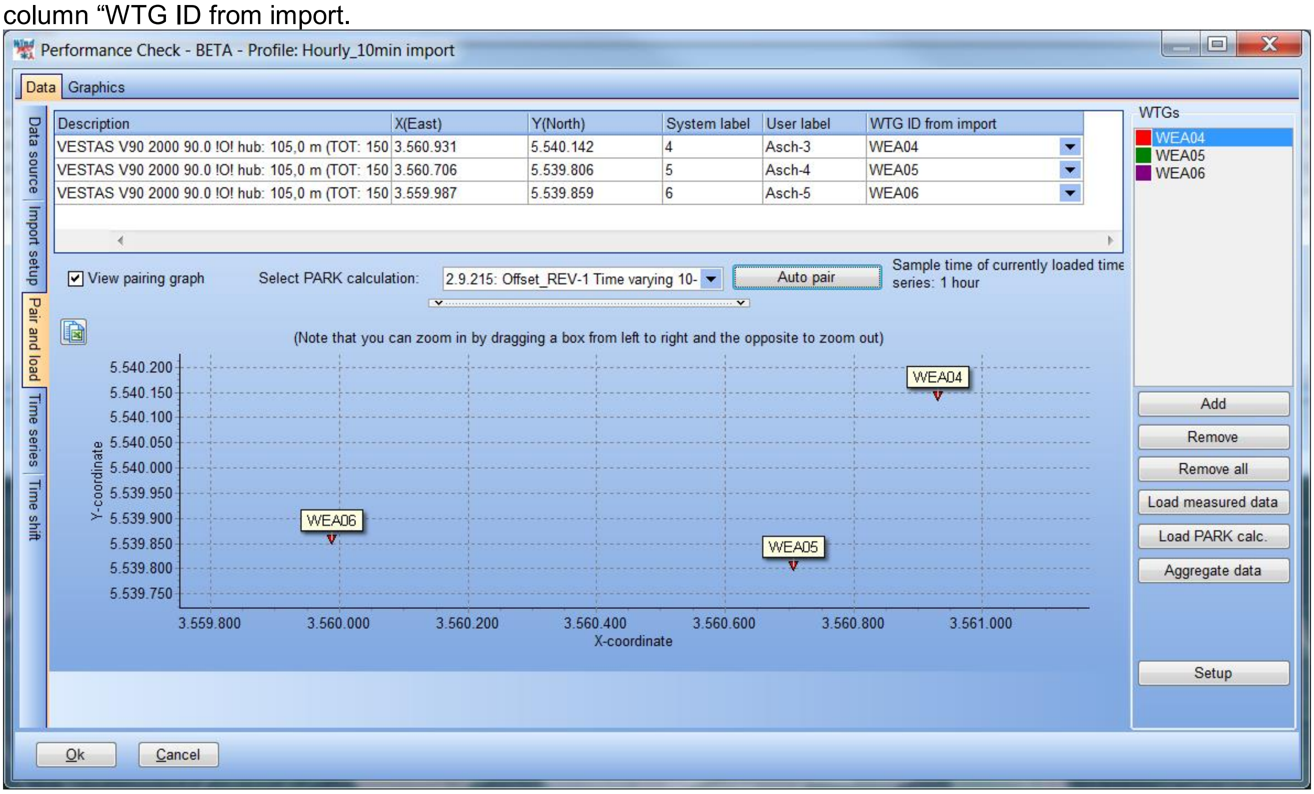
You are now ready for importing!

Check the data in time series view. Here you will see if everything seems to be imported correct.
Go to graphics:
Check the data in the Time series view. Do everything look ok?

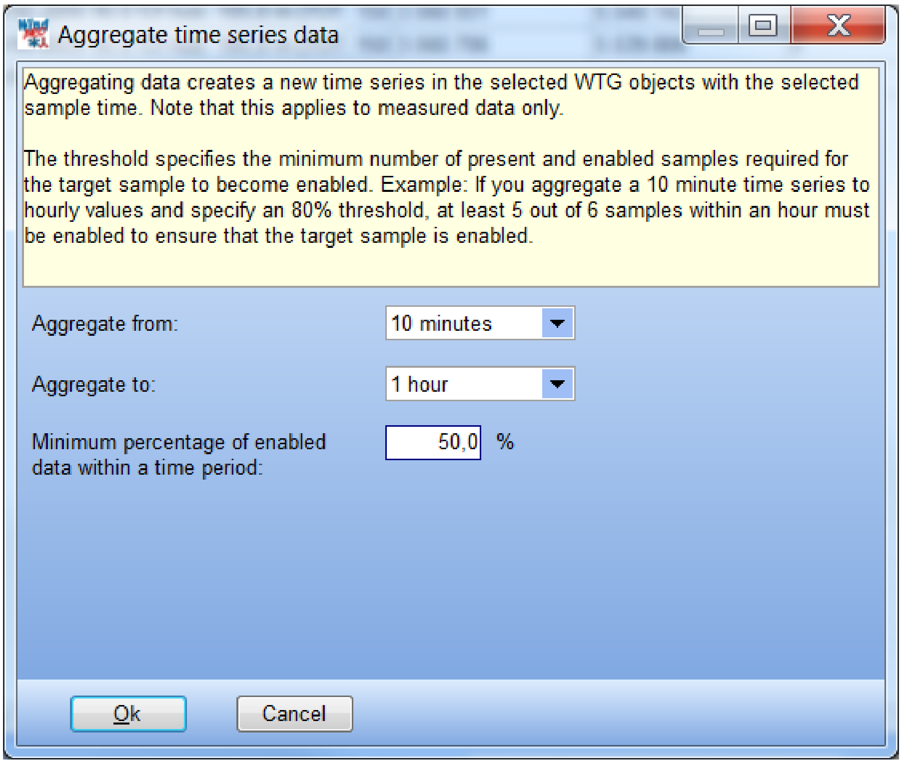
14.5.2 Data - Pair and load

First you must add the existing WTG objects that is part of your analyze. These can freely be selected based on layers.

If you have defined the existing WTG objects so the WTG ID from import files are part of the description or user label, the “auto pair” feature will work. This should always be arranged so if you have many turbines in your import. By few turbines, the manual pairing can be done, simply by selection in the drop down boxes in column “WTG ID from import.



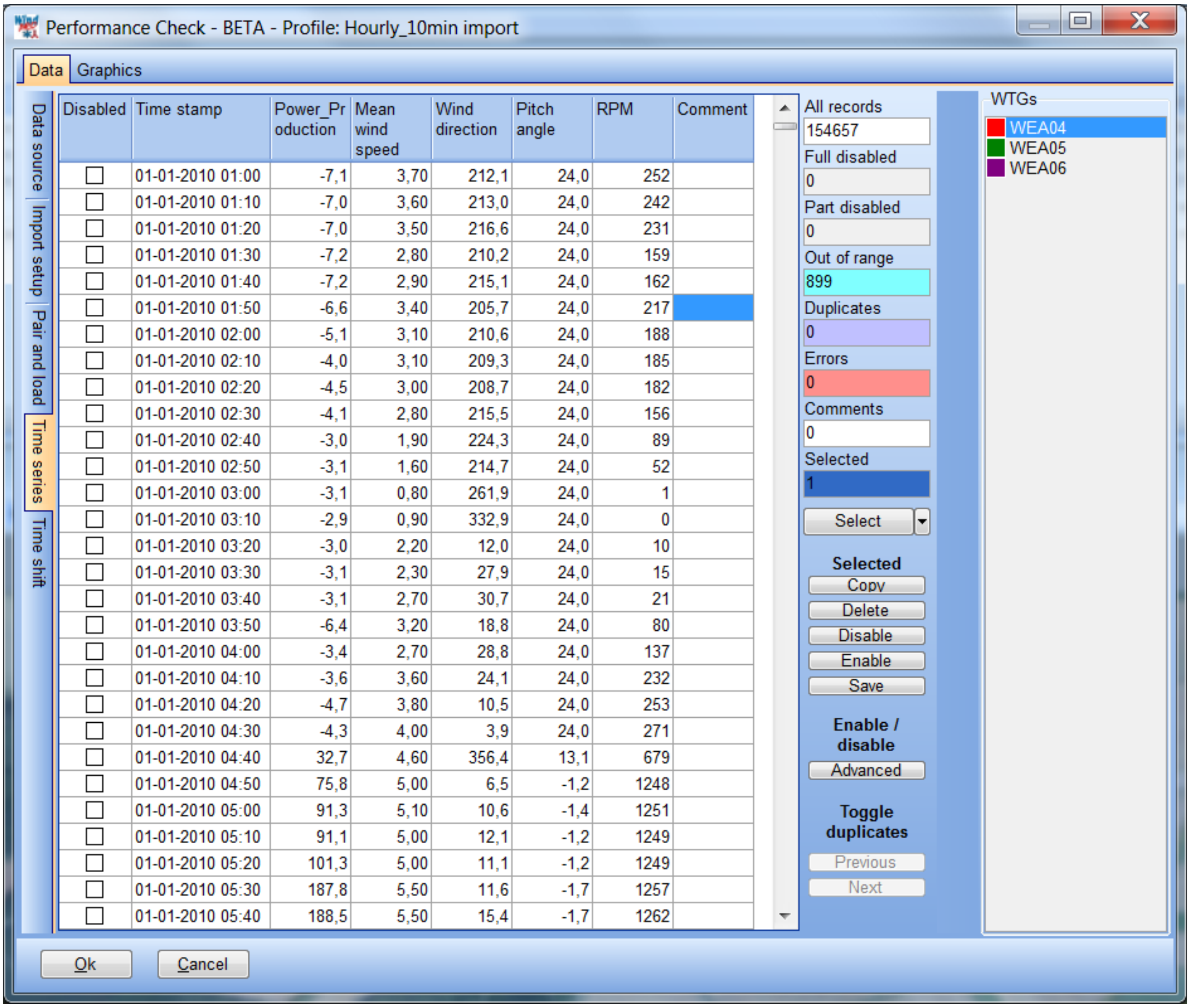
When paired, the button “Load measured data” will transfer the data from the import files to the WTG objects.
If having a time varying park calculation **based on same time resolution**, this can be selected and model calculations can be compared to measurements on time stamp level.
If calculations e.g. are based on hourly wind data and your import is 10 min. data, you can use the “Aggregate data” button to establish hourly measurements. This will add an extra data series in the WTG objects.



The aggregate form – note it has to be decided how many samples that must be present within a time step, to establish the value.

14.5.3 Data - Time series

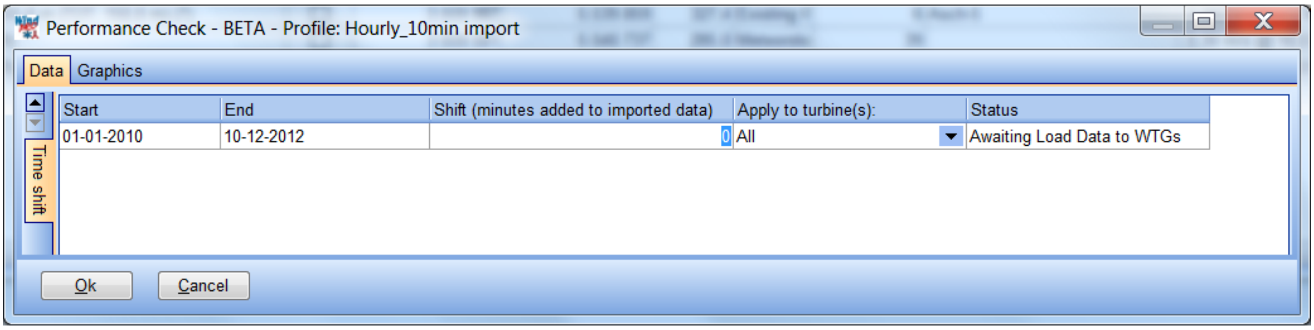
Here you can inspect your data and perform some "basic manipulations", please refer to Meteo object manual for details. The tools behind this are similar to the ones in Meteo object.



Time series view. Data can e.g. be sorted by clicking in the top columns.

14.5.4 Data - Time shift

With the time shift tab, general or individual time shifts can be applied. This can help fix data errors or it can e.g. fix if the measured data are in daylight saving time and the calculations to compare to are not.



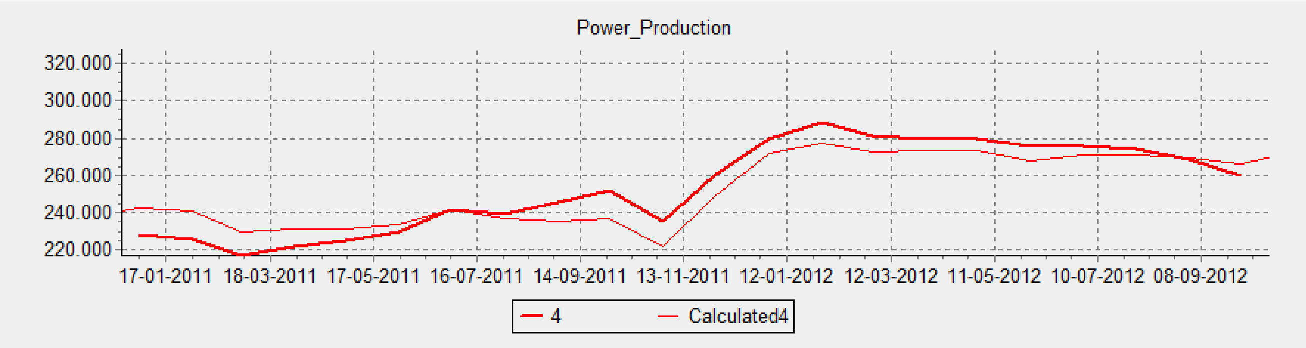
You can flexible add as many lines as needed and thereby perform individual time shifts to specific turbines or periods. The status column keep track on if the time shift operation has been performed. First by “Load measured data” the time shift is applied.

14.6 Graphics – Monthly time resolution

Very often the data basis for evaluation of the performance of operating wind farms is just on monthly basis. This is also quite good, while the data amount is reasonable in size and there are well established methods for performing performance check on monthly basis, like the wind energy index method. As well monthly as higher time resolution data can be loaded as described in previous chapters, either pasted into the existing WTG objects, or by using the import from file option within the Performance Check module.
Monthly data can be with or without grid losses.
With monthly data it is possible "just" to calculate expected long term production (wind energy index corrected), but it is also possible to compare with model calculations based on time varying PARK calculations, where results are aggregated on monthly level.

14.6.1 Time series

An illustration of monthly data, where a time varying PARK calculation is performed from 2001-12, but where measured production only is available 2009-12. Note also the measured monthly availability is part of the data set. Looking at the time series data it is important to notice that these always will be unfiltered.



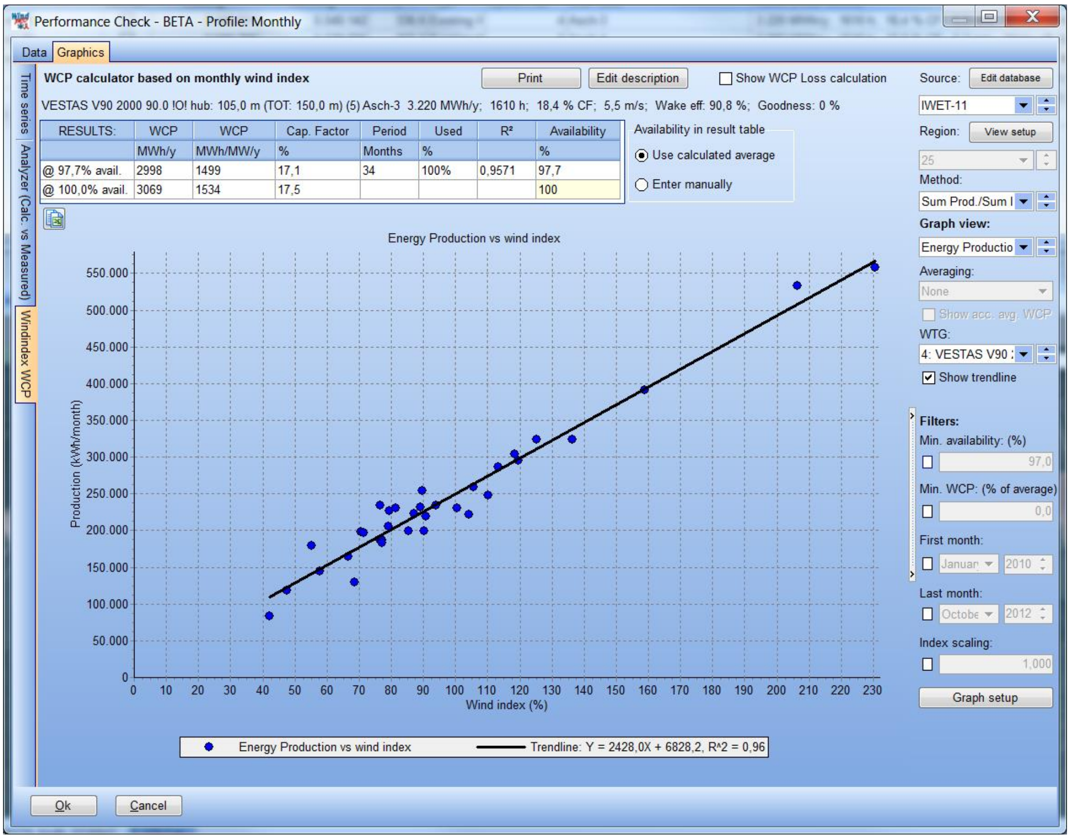
Looking at the 12 month moving average often can give an idea about the development in performance, like here where there seem to be a clear trend of improved performance in time.

14.6.2 WCP calculator/analyzer

The WCP calculator has many refinements. But the basic concept is simple: Based on monthly production and monthly wind energy indexes, the Wind Index Corrected production is calculated. There are two basic concepts for performing this calculation:

The sum method: The sum of productions is divided with the sum of index's (for non-filtered months).
The regression method: A linear regression line is established for production vs index, and the production for index 100% is found.

We have performed numerous analyses with the two different methods, and we can't in general say which is the best – they both have advantages. If data quality is good and a long period of data is available, the results will be almost identical. It's when having shorter data periods and/or poor correlation, the two methods can differ.

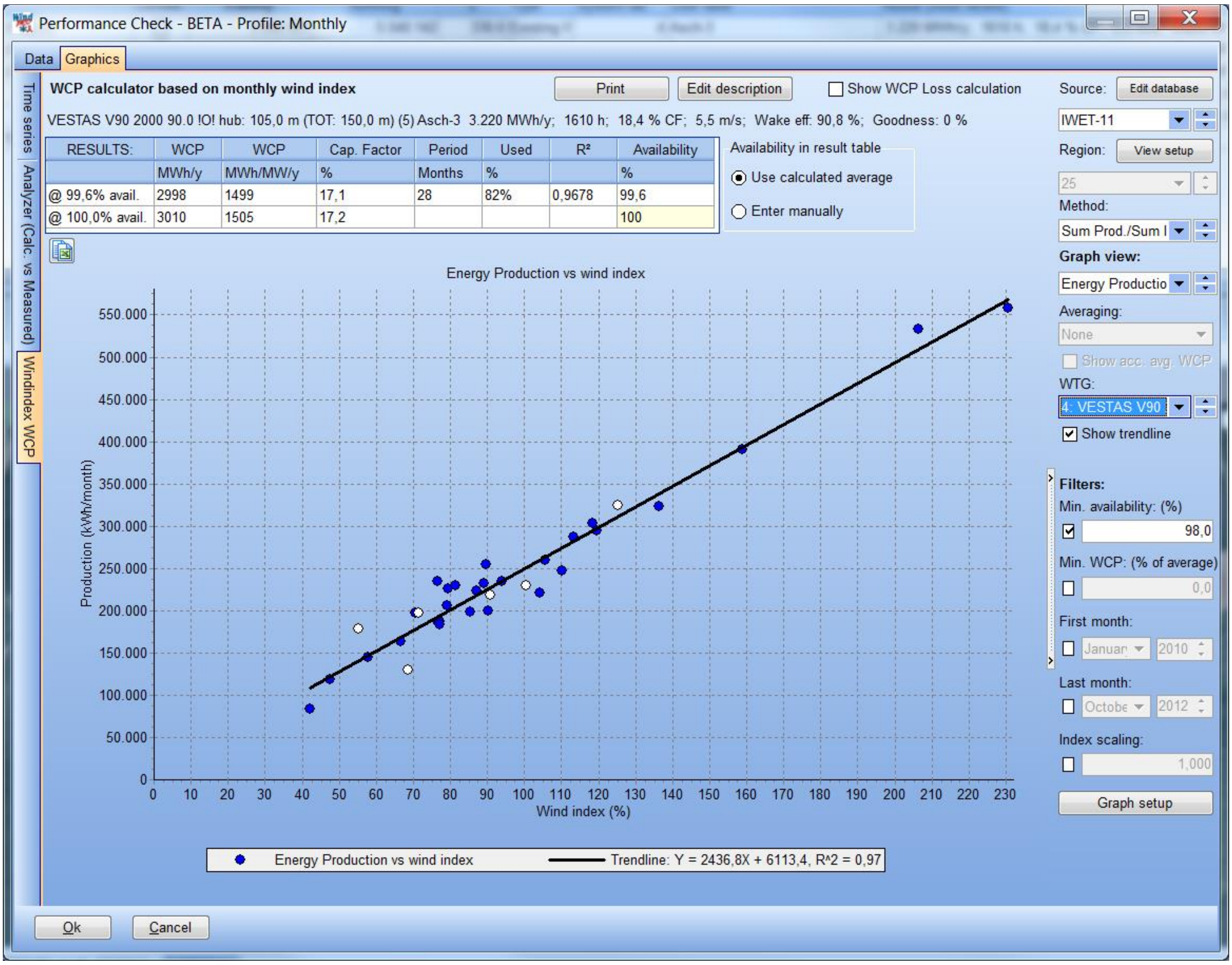


The "controller" for WCP calculation.

RESULTS:	WCP	WCP	Cap. Factor	Period	Used	R²	Availability
	MWh/y	MWh/MW/y	%	Months	%		%
@ 97,7% avail.	2998	1499	17,1	34	100%	0,9571	97,7
@ 100,0% avail.	3069	1534	17,5				100

Availability in result table
◉ Use calculated average
○ Enter manually

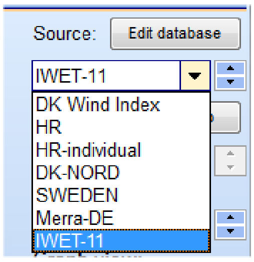
This is where results are seen. Here where availability data are included, the software calculates the average availability and scale based on this to a 100% (or user specified) availability. This can be some uncertain, while the availability typically are measured in time, not production. It is therefore recommended to filter months with low availability.
If availability data not are included (or judged to be of bad quality), it is possible to enter manually. This will often be a judgment, how much availability loss there are included in the monthly data. Printing the loss reports (see later) sometimes can help with this judgment.



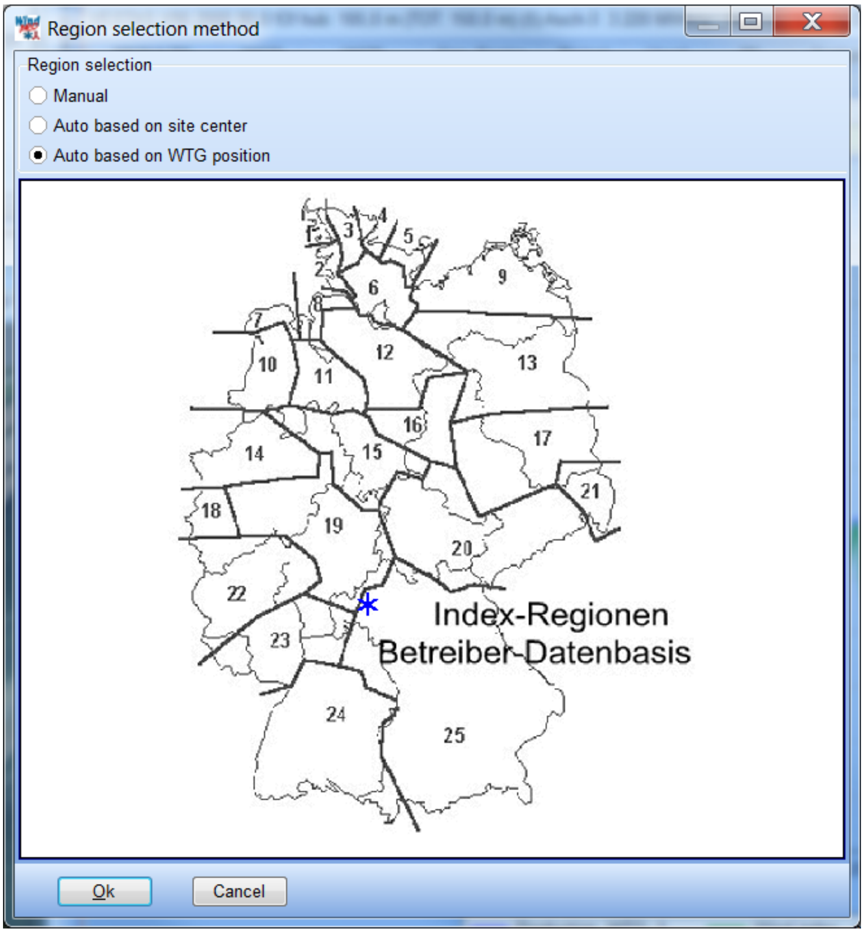
Here is filtered so months with less than 98% availability are excluded in the calculation. This reduces result from 3069 to 3010 MWh (2%) as 100% availability result. Last one is probably more correct, while the low availability in this case seem to be in periods with less wind – in other cases it might be reverse.
It is also possible to filter outliers by the “Min. WCP (% of average)”.
Filters can also be based on period, which e.g. can take out the startup month(s) where some poorer performance often can be seen.
Finally the “Index scaling” can be used if it is known (or assumed) the index has a bias.
Numerous different graph views can be shown, these will be presented in the WCP report chapter.

14.6.3 Wind energy index database

A central part of the WCP calculation is the Wind Energy Index.
For some countries, there are “official” wind energy index’es, like DK and DE, for other it is possible to establish index’es based on wind data, typical Model wind data, like Merra, CFSR, EMD-ConWx or other.

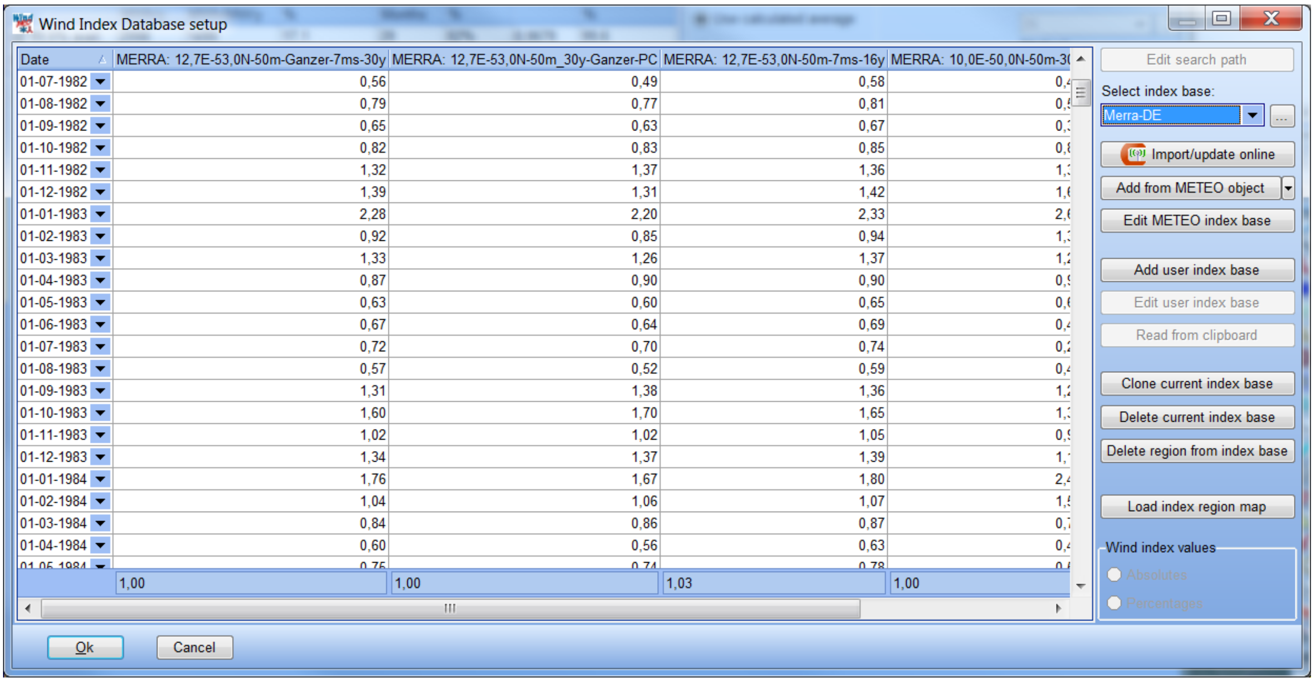


In the upper right corner the wind index databases are controlled. Here is a drop down box where the user established index databases are seen. Having the “official” DE og DK index databases, a map can be shown for index selection:



It is seen where the project is located at the index region map, and it is possible to test the neighboring regions by setting the selection to manual and choose the index region. NOTE: The German IWET index is NOT included in the software, the user must paste the data from Excel sheet with the index to the database, but the map is available at EMD online server.

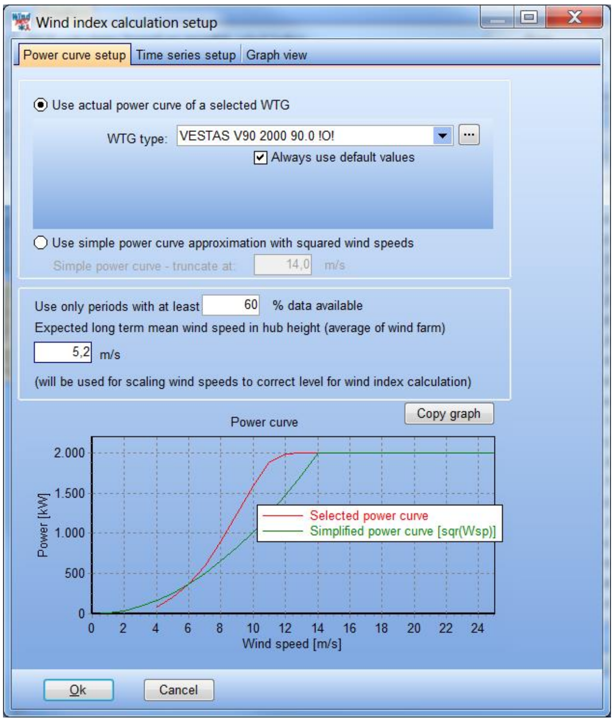
From the “Edit database” a new tool appear:

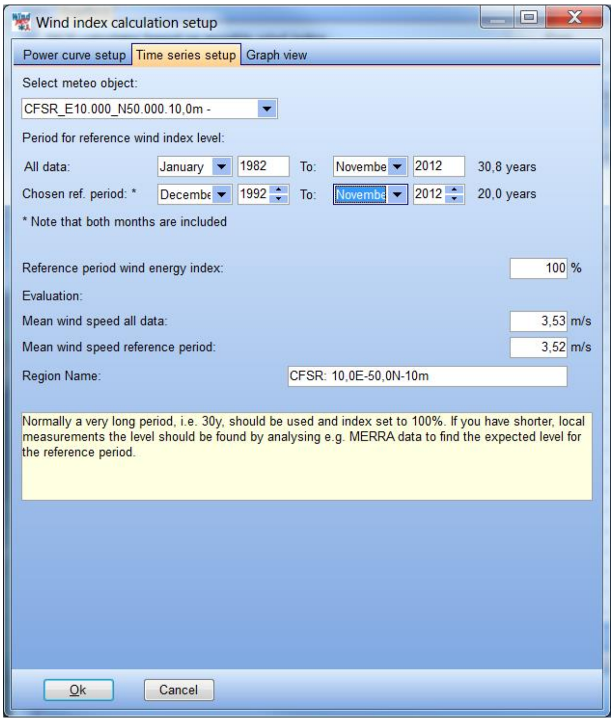


Here it is possible to:

- Import/update online (only DK-index so far)
- Add an index base based on Meteo object(s)
- Add a new index to an already established Meteo object based index database
- Add user index database, in which data can be pasted from clipboard (from Excel).

And there are different options for editing the index databases.

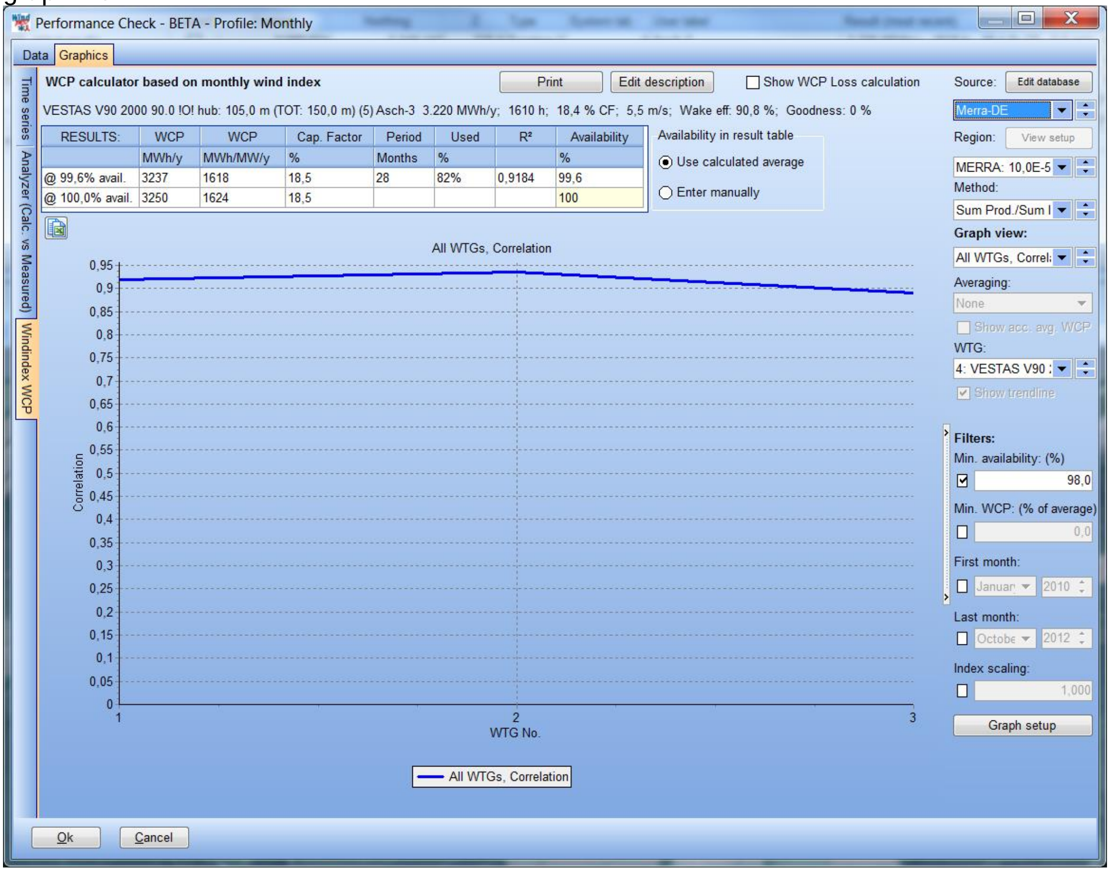




When adding from Meteo object, it is possible to use a specific power curve or a simplified (like in MCP tool). And of high importance, to scale the wind speed to a specific average before index's are calculated. The recommended value is the expected mean hub height wind speed for the turbine project, where the index shall be used. Then the dynamic behavior of the index reflects the production variations best possible.

It is possible to select the period used as reference within the time series available. Like selection of recent 20 y as shown above. The period can be given an index level, typically 100%, but if shorter local measurements are to be used, a suitable value can be found from other index data. The index can be named.

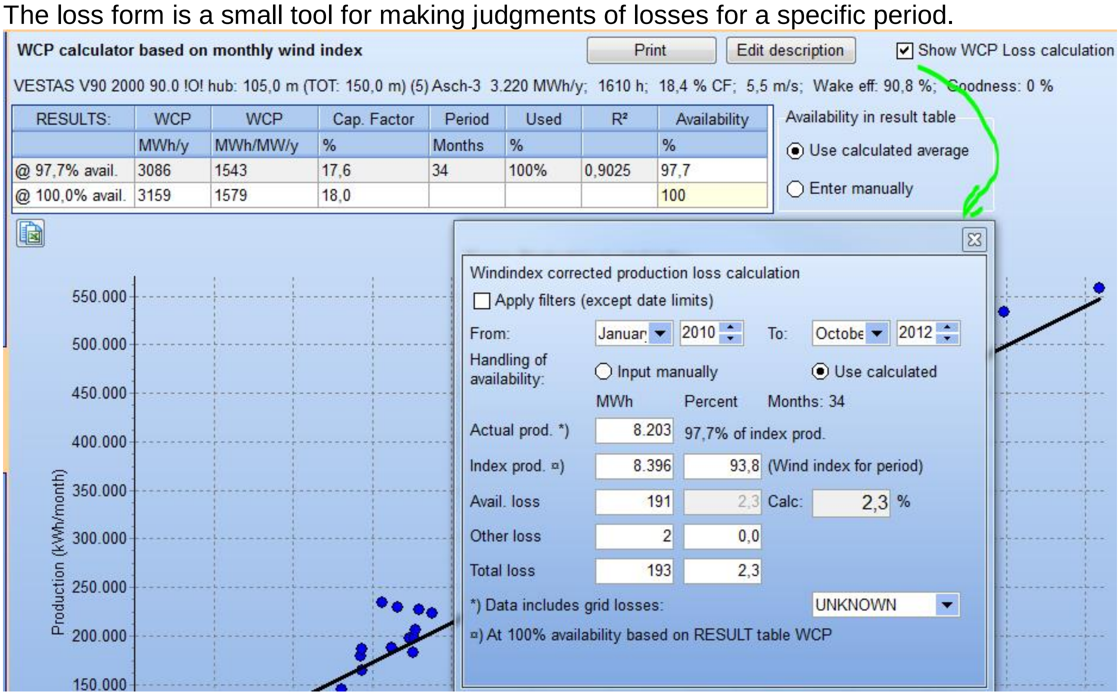
Checking the index:
A quality indicator of the index generated is the correlation. This can be viewed for all turbines in the following graph view:



Another very important quality parameter is the long term consistency and level. This can be hard to check, while there is no unique guideline for this. Slowly varying wind climate as seen in Northern Europe is a huge challenge – what is the correct long term reference period? Several papers on this issue can be found.

14.6.4 WCP – loss form

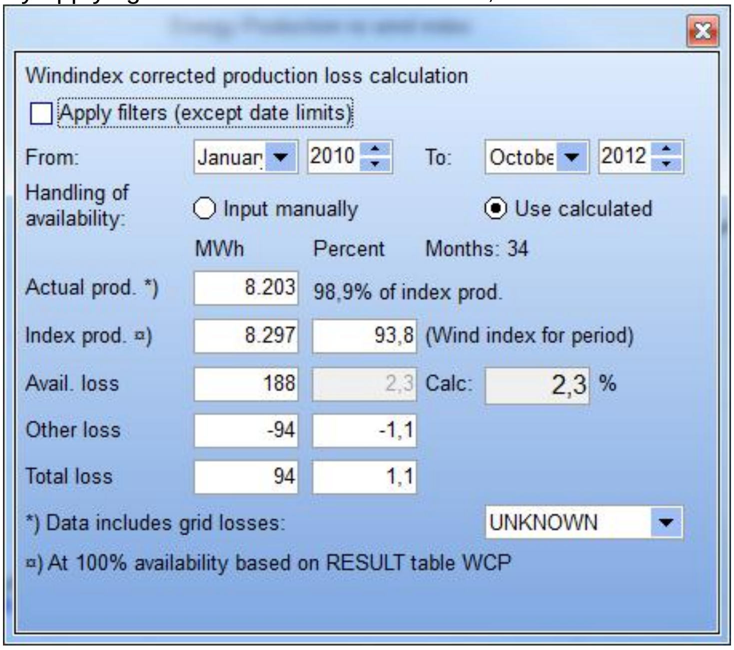
The loss form is a small tool for making judgments of losses for a specific period.



The loss form is designed like this:
Taking all data period, no filters applied, the actual production will be availability x index production
The index production is WCP @ 100% availability x index for the period x months/12.
The difference between the index production and the actual production is assumed to be the total loss. (Although not including grid loss).
In the form shown above, all loss is assumed availability loss.

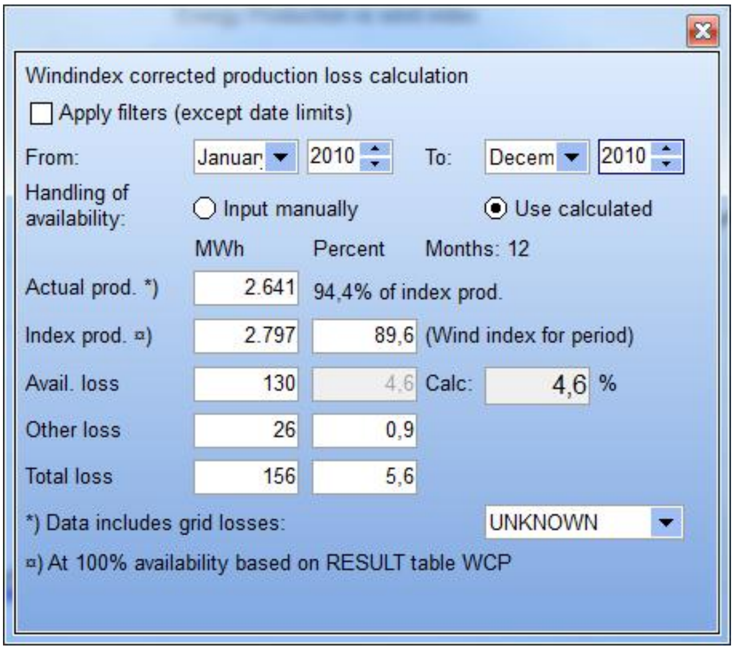
The form can be used to judge losses for a specific period – and if availability loss is assumed correct based on the imported availability data (or established as entered user input), losses due to other reasons can be identified roughly.

By applying filters in the WCP calculation, other results will be seen:



Using only data with > 98% availability, the calculated WCP is reduced and thereby the index production. Therefore the Total loss will be lower, and we get a negative "other loss". While a negative loss not is "real", it is important to know how to interpret this. We simply estimate the WCP based on a limited part of the data, where availability is high. While this give lower WCP than by including the months with low availability, we can conclude that the low availability months has a lower availability, than the reduction in production in this case. The stand still time has been mainly in weak wind periods. We therefore gear too much up including the low availability months. We can also conclude (or assume – we cannot be certain due to many uncertainties) that the real availability production loss then is closer to 1.1% than first assumed 2.3% for the 34 months of operation.

Finally we can look at a specific period, for example 2010:



Here the “simple calculated” (from time-avail.loss) availability loss is 4.6%, while the Total loss sum up to 5.6%. This can be explained by stand still periods mainly are in high wind periods in 2010. But it also just could tell that the turbine performance were poorer in 2010 than the next two years for some other reasons – or that the wind energy index not is accurate enough to make the calculation correct.

With several possible explanations, here for the poorer performance 2010, one can ask what can this be used for? First of all it is quick and easy to draw out figures and e.g. test different index sources. Then more different results can be produced based on different index sources. If these all point towards the same direction, like “poor performance in 2010 relative to later”, it is probably true, and it could be relevant to dive deeper. Especially if it was the last year of operation that had poorer performance, it would be very important to find the reason to avoid that future years continue with under performance.

Note the “apply filters” in the loss form can be used to take a look ONLY at the non filtered months in the period.

The information xx.x% of index production tell how well the performance were in the specific period relative to the period, the WCP calculation were based on.

If data includes grid losses or not can be set in the drop down box. This is just an info field. If grid losses are included (data from sales metering used), the WCP is the expected annual sale. If data from turbine controller is used, the WCP will typically be higher and assumed grid loss must be subtracted from WCP to get expected annual energy sale.

14.6.5 WCP - reports

When having established the settings giving “comfortable results”, reports can be printed.

There are 3 report pages from the WCP tool:

1. Main – assumptions and results including graphics
2. Losses – Loss tables and graphics giving “rough” loss estimates
3. Prognosis – Expected monthly productions incl. probability of exceedance based on user specifications

Performance Check - Wind index - production prognosis

WTG: 1: Asch-3

Calculation of wind index corrected production (WCP) for:

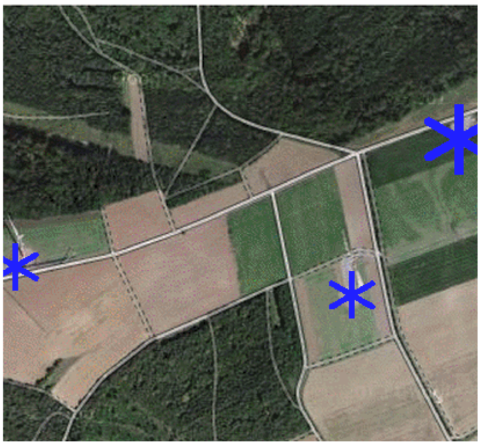
Turbine: VESTAS V90 2000 90.0 !O!
ID: 1: Asch-3
WTG properties: 2000 kW, Rotor: 90,0 m, Hub: 105,0 m
Coordinates: GK (3 deg)-DHDN/PD/Bessel (DE 1995 <±5m) Zone: 3 East: 3.560.931 North: 5.540.142

Assumptions:

Wind index source:	IWET-11	Region:	25
Wind index reference period from: (both incl.)	01-01-2000	Data to:	01-12-2012
Data from: (both incl.)	01-01-2010	Data to:	01-10-2012
Wind index in selected period:	96,5%		
Wind index calculation method:	Sum Prod./Sum Index		

Filter settings:

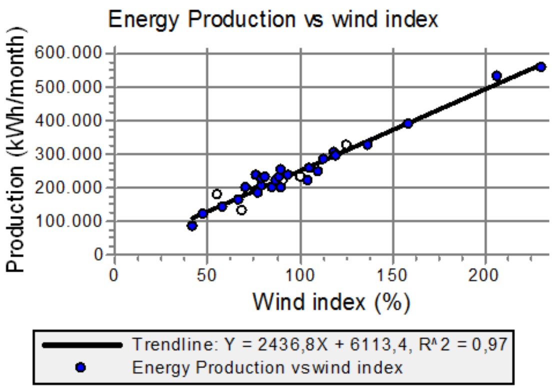
Minimum availability:	98,0%		
Min. WCP of average:	*<Not selected>*		
Data from:	*<Not selected>*	Data to:	*<Not selected>*
Total months (years):	34 (3)		
Filtered months (years):	6 (0)		
Used months (years):	28 (2)	Percent:	82,4 %

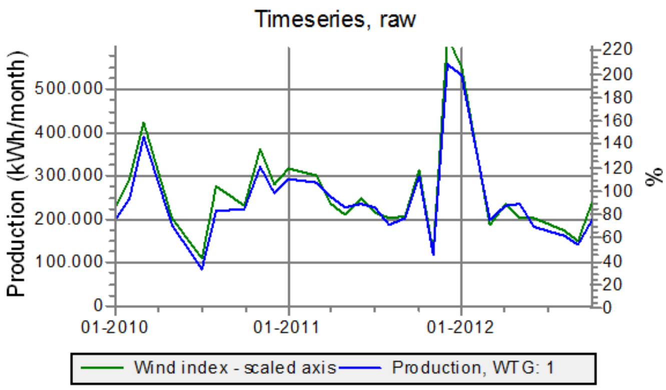

Scale: 15.000

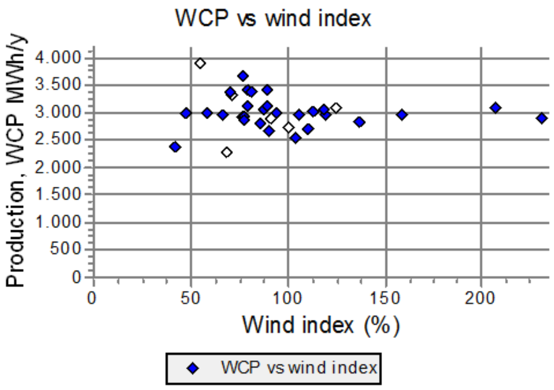
Results:

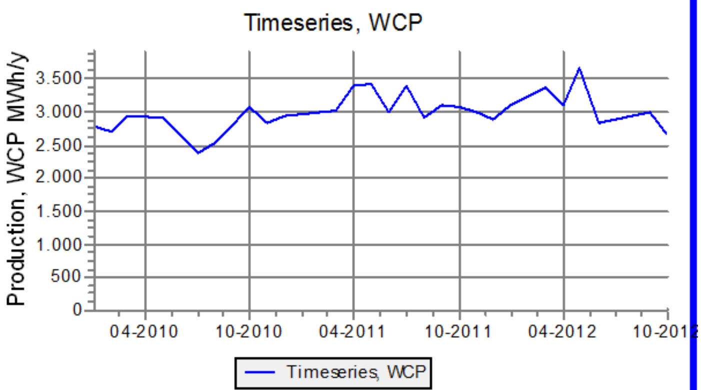
	MWh/y	MWh/MW/y	Cap. factor
Calculated WCP at 99,6 % avail *)	2998	1499	17,1 %
Calculated WCP at 100,0 % avail #)	3010	1505	17,2 %
Correlation (R^2)	0,97	Grid loss incl.:	Unknown

*) Calculated as average of used
#) Decided presentation value (e.g. 100% or estimated future avail.)









The main page, where the results from the WCP tool is presented.

14.6.6 Analyzer

xxx

14.7 Graphics – Detailed time resolution

With data of detailed time resolution is meant more detailed than 1 month. It would typically be daily, hourly or 10 min data. These data typically will come from Scada systems or turbine controllers. This mean typically that grid loss not is included in data. These data are especially well suited for checking details in the model calculations, partly while data can be aggregated by wind direction. And for power curve validation, where data should have a preferable resolution of 10 min.

14.7.1 Time series

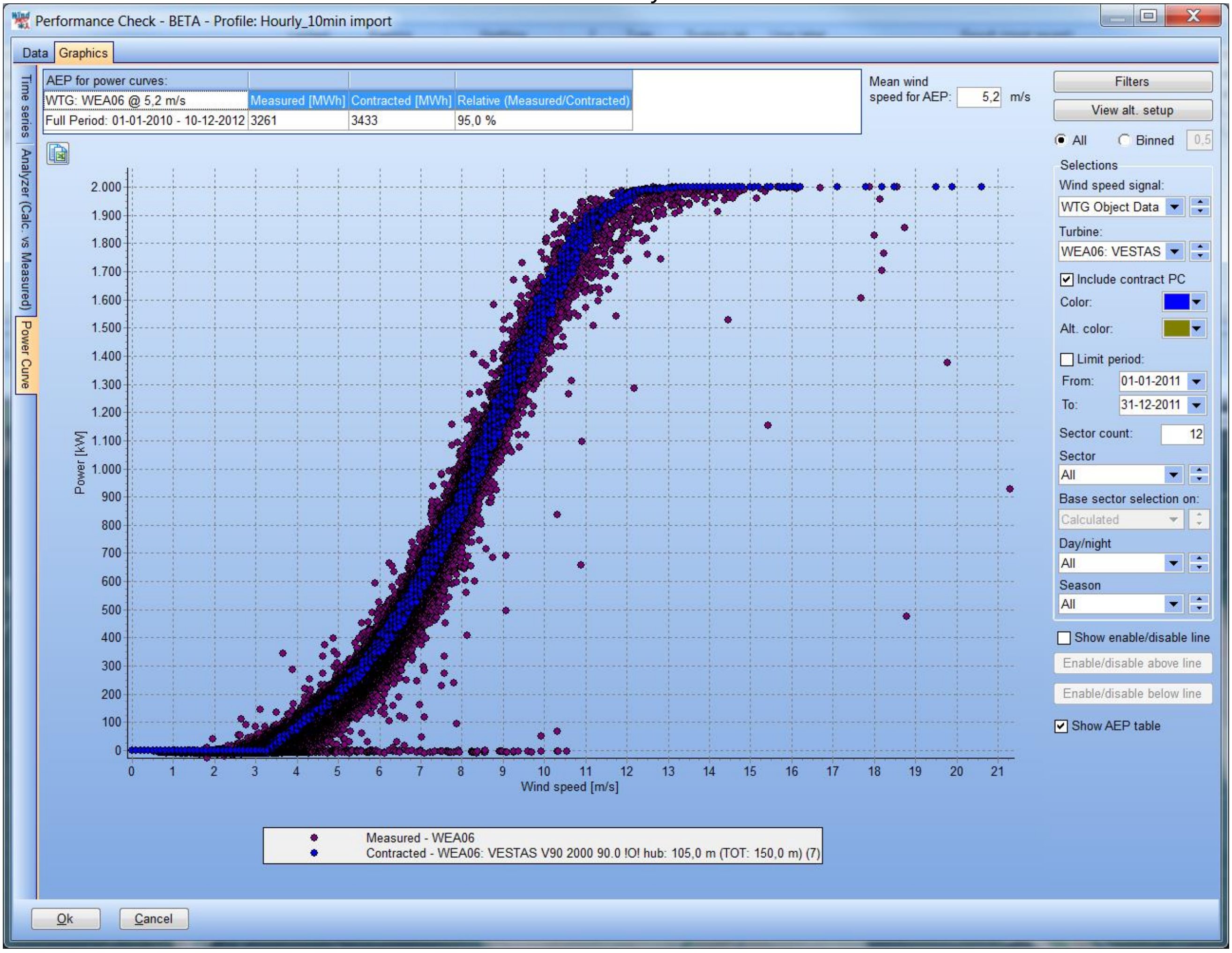
Inspecting time series give the possibility to screen the data quality on a very detailed level. It is especially interesting if a time varying PARK calculation is included.

Example on time variation. When both measured and calculated data are shown, the thick line is used for measured, thin for calculated. Example show measured directions are very different. This will often be seen due to the often some primitive system logging the direction of the nacelle. Therefore a checkbox [ ] use only calculated direction is included.

Data evaluation based on different aggregations can be performed like in Meteo object.
ONE difference from using meteo object is that it should not be needed to disable data with poor performance. This is later handled by the FILTERS. Only directly wrong (erroneous) data should be disabled. The reason for this is we later will use the filters to identify by which conditions, underperformance seem to be a problem, and how large. If data are disabled, these are simply taken out of all future analyses.

14.7.2 Power curve

Of high importance to notice is that it cannot be expected to validate if the power curve is within specifications by manufacturer, unless a very precise measurement setup is arranged, See IEC 61400-12-1 standard. This is very rare to find within a commercial operating wind farm.
The power curve evaluation tool must more be expected to be used to find like changes in time, e.g. before and after a modification of the turbine and much more analyses.

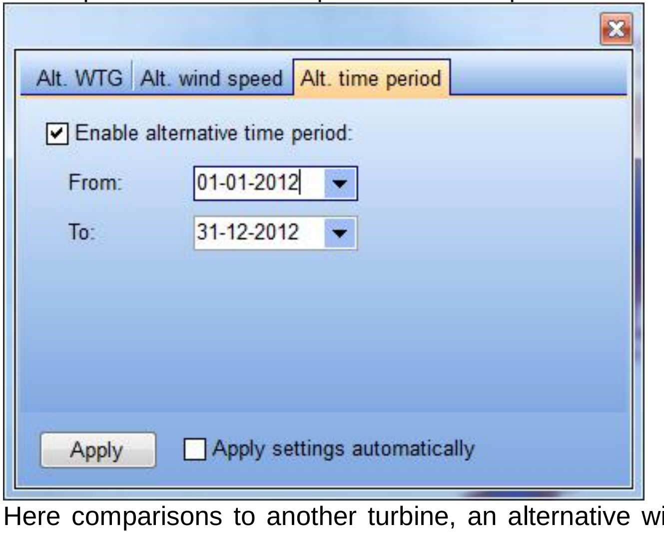


The basis selections are:
Wind speed signal; choosing the WTG object data, the wind speeds loaded into the turbine object is used. This will typical be the nacelle anemometer data, which are quite some influenced by the nacelle and rotor blades. But it is also possible to choose calculated wind speed (if a time varying PARK calculation model is loaded) or data from any meteo object. So there is a large freedom in selection and the user must judge what can be used for which specific analyses.
Turbine; any of the turbines in the Performance check session can be selected.
[ ] Include contract PC; makes it possible to view the power curve used in the time varying PARK calculation, which typically will be the power curve from Manufacturer. This will always be based on the calculated, wake reduced wind speed. The variation seen showing this is due to air density variations (assuming temperature and eventually pressure has been used in time varying PARK calculation). And an important issue here is that the contract power curve thereby always will be compared to measurements with THE SAME air density conditions.

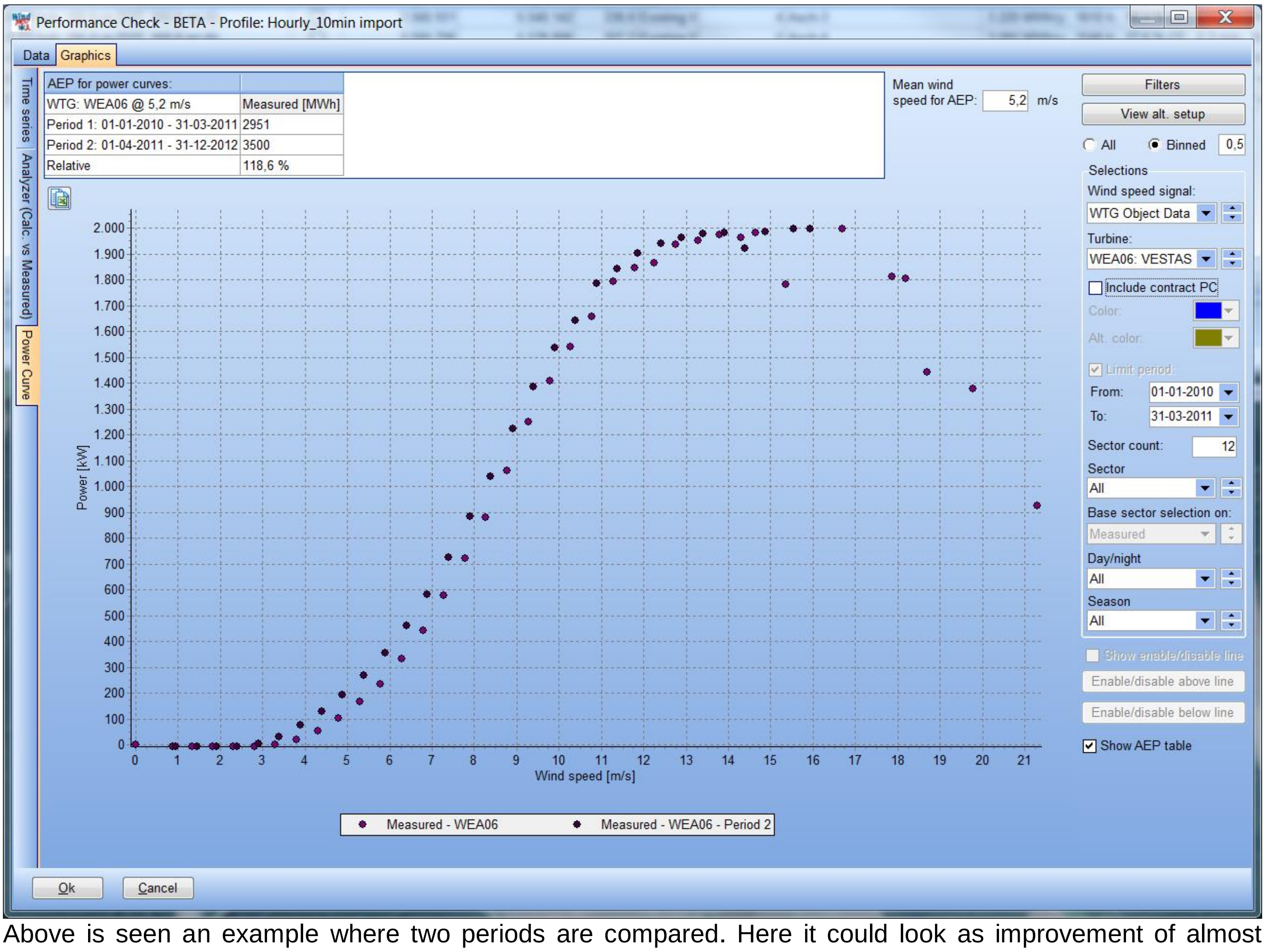
Comparing different power curves

A special feature is the AEP window, where the power curves seen is converted to an annual energy production at a given mean wind speed (Rayleigh distributed). This tells very exact how much the measured power curve deviates from e.g. the contract power curve or another time periods power curve. The ratio will also be shown. The calculation is based on a binned power curve with 0.5 m/s bin size, and the use of WindPRO's "normal" power curve extrapolation features. This mean e.g. that the power curve is extrapolated to the Cut out wind speed specified at the power curve in the WTG object, if too few data for creating this part, and then cut off.

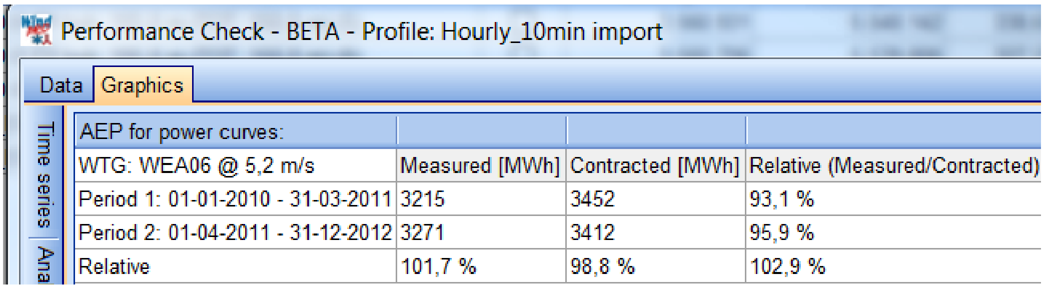
In a separate window, it is possible to set up an alternative to compare with.



Here comparisons to another turbine, an alternative wind speed signal or an alternative time period can be chosen.



Above is seen an example where two periods are compared. Here it could look as improvement of almost 20%, BUT, based on other analyses, it seem that there has been a modification in the nacelle anemometer calibration between the two periods – and it is not realistic that such large changes are seen.



AEP for power curves:			
WTG: WEA06 @ 5,2 m/s	Measured [MWh]	Contracted [MWh]	Relative (Measured/Contracted)
Period 1: 01-01-2010 - 31-03-2011	3215	3452	93,1 %
Period 2: 01-04-2011 - 31-12-2012	3271	3412	95,9 %
Relative	101,7 %	98,8 %	102,9 %

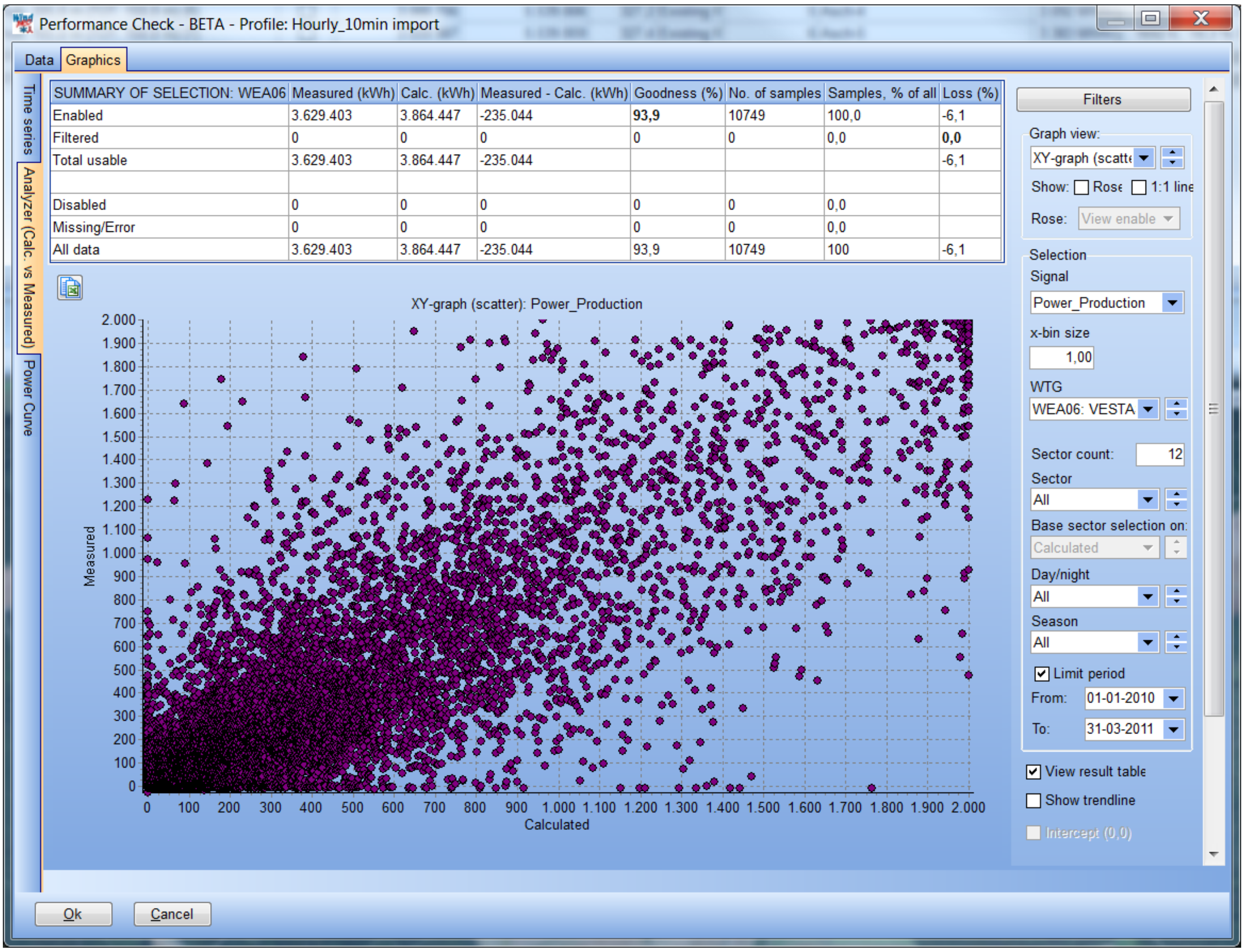
Same figures here seen based on calculated wind data, the improvement are now “only” 1.7%, but while the air density were higher in first period, 1.2% less were expected, thereby the resulting improvement is seen in third column to 2.9%. But note that no filters are applied, so a major explanation of the low measured/contracted is the availability problems.

For power curve evaluations, the filtering shall be handled carefully. If e.g. all power <=0 is taken out, the curve at the low wind speeds are “lifted”. Best option seems therefore to use the disable line to take out the poor performance data. (See explanation of the disable line in METEO object manual).

Filters and selections as described in previous are also available in the power curve analyze. Especially the selection of direction by sector important if having a real power curve measurement setup, where only sector with turbine downwind mast is useable for the power curve validation.

14.7.3 Analyzer

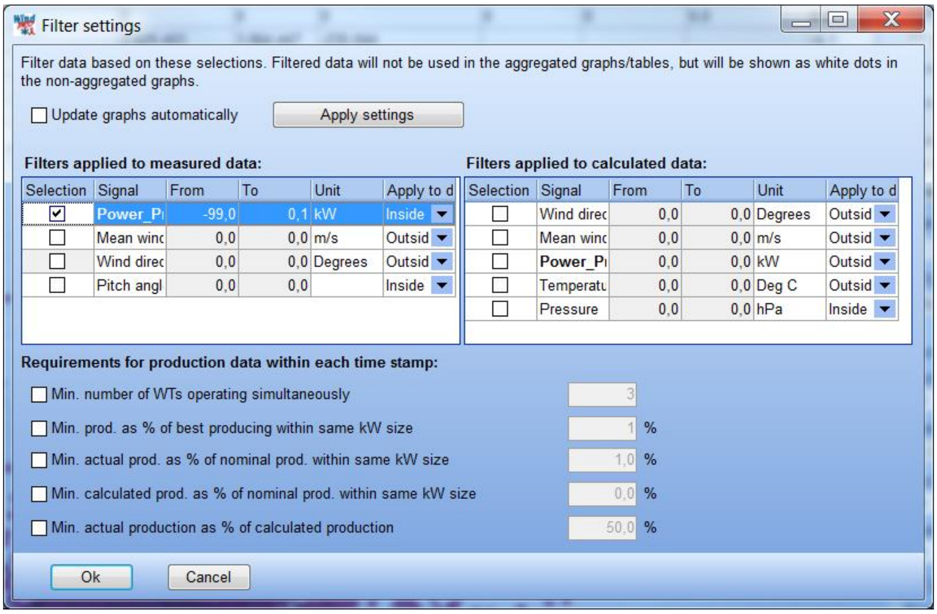
The analyzer is the place where the most comprehensive comparisons between measured and calculated data can be performed and where input for model calculation revisions can be identified.



SUMMARY OF SELECTION: WEA06	Measured (kWh)	Calc. (kWh)	Measured - Calc. (kWh)	Goodness (%)	No. of samples	Samples, % of all	Loss (%)
Enabled	3.629.403	3.864.447	-235.044	93,9	10749	100,0	-6,1
Filtered	0	0	0	0	0	0,0	0,0
Total usable	3.629.403	3.864.447	-235.044				-6,1
Disabled	0	0	0	0	0	0,0	
Missing/Error	0	0	0	0	0	0,0	
All data	3.629.403	3.864.447	-235.044	93,9	10749	100	-6,1

Here hourly measured versus calculated data is seen. Quite a huge scatter which much relates to the use of Meso scale data. These data often are shifted some in time, the storm comes a little before or after it appear in the real world. But by aggregating the data quite good correlations can be seen.

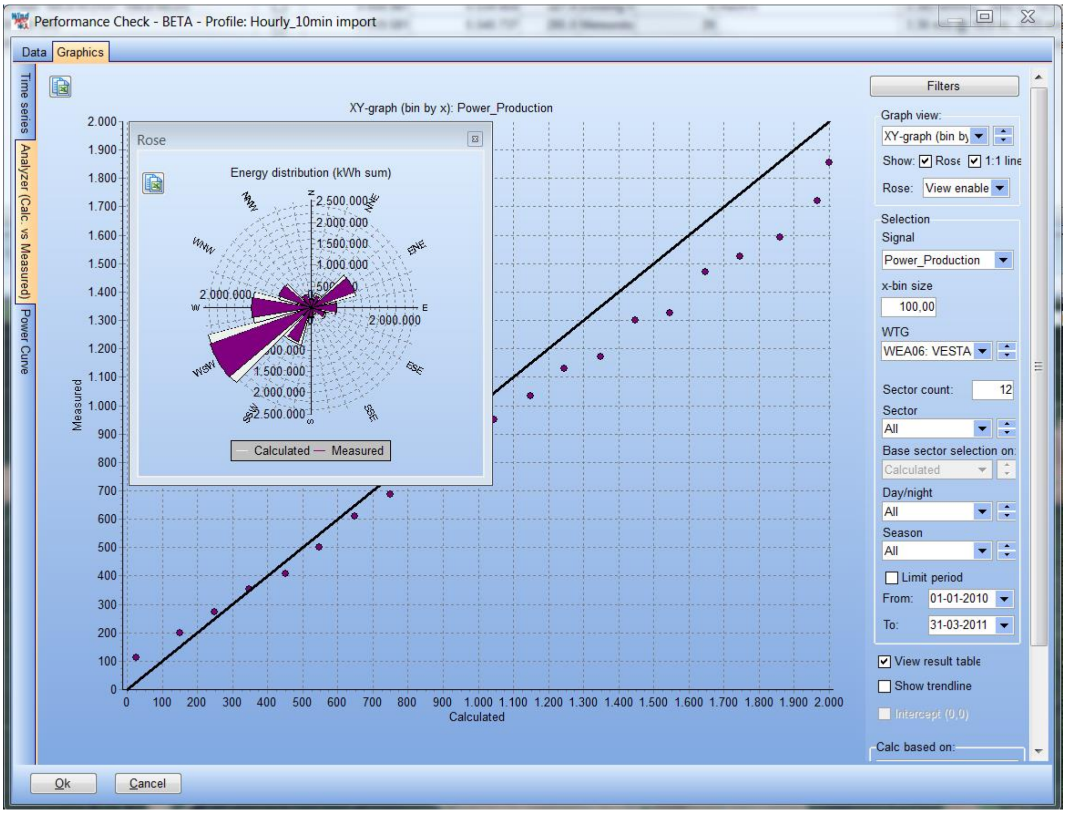
Another important thing is that applying filters will take out the availability problems of the analyze and the comparison is then made only on the good data, where turbines are in normal operation. And with filters applied, reasonable precise production losses due to availability can be identified.



In the above we filter actual power from -99 to 0,1 kW. This results in this evaluation:

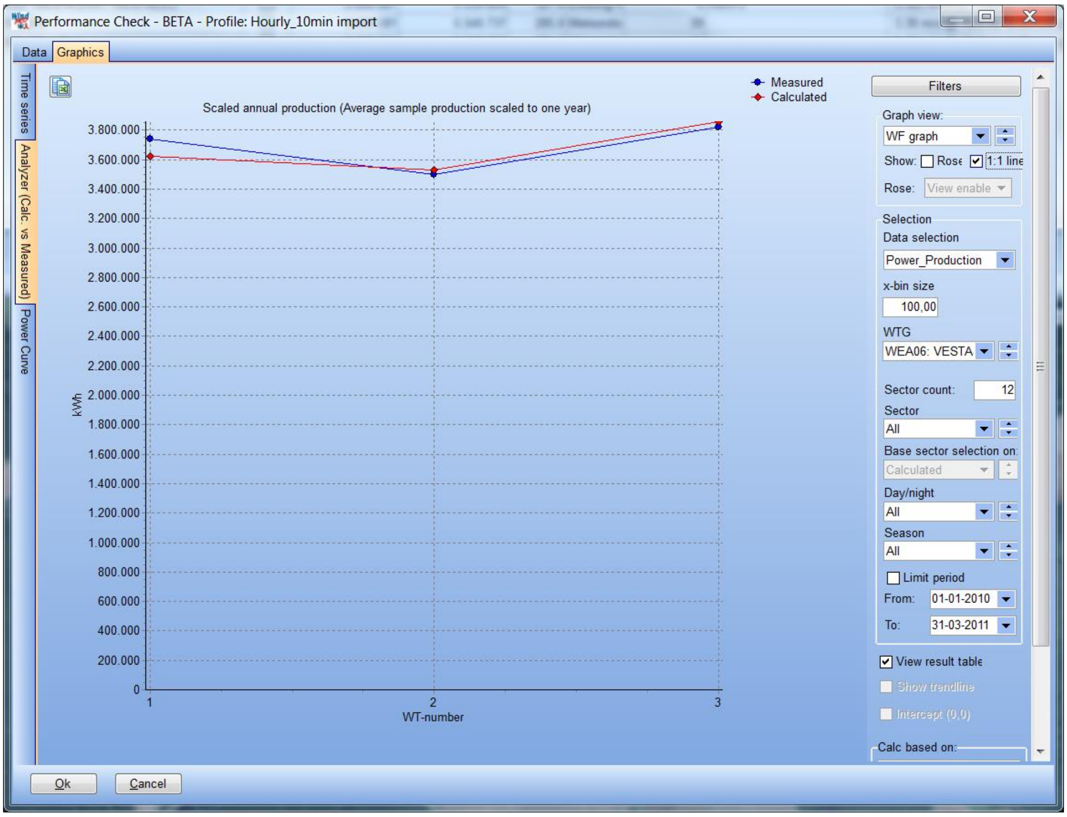
SUMMARY OF SELECTION: WEA06	Measured (kWh)	Calc. (kWh)	Measured - Calc. (kWh)	Goodness (%)	No. of samples	Samples, % of all	Loss (%)
Enabled	8.800.439	8.890.589	-90.150	**99,0**	20185	79,1	-1,0
Filtered	-29.409	284.525	-313.934	-10,3	5339	20,9	**-3,4**
Total usable	8.771.031	9.175.115	-404.084				-4,4
Disabled	0	0	0	0	0	0,0	
Missing/Error	0	0	0	0	0	0,0	
All data	8.771.031	9.175.115	-404.084	95,6	25524	100	-4,4

We are filtering -29.409 kWh in measurements, but 284.525 kWh in calculated. This indicates 3.4% production loss for almost 3 years of operation. The Goodness are 99% in the non-filtered data indicating that our calculation model is very precise – and we therefore can trust that also in the non-operating time steps, our calculation is reasonable precise.

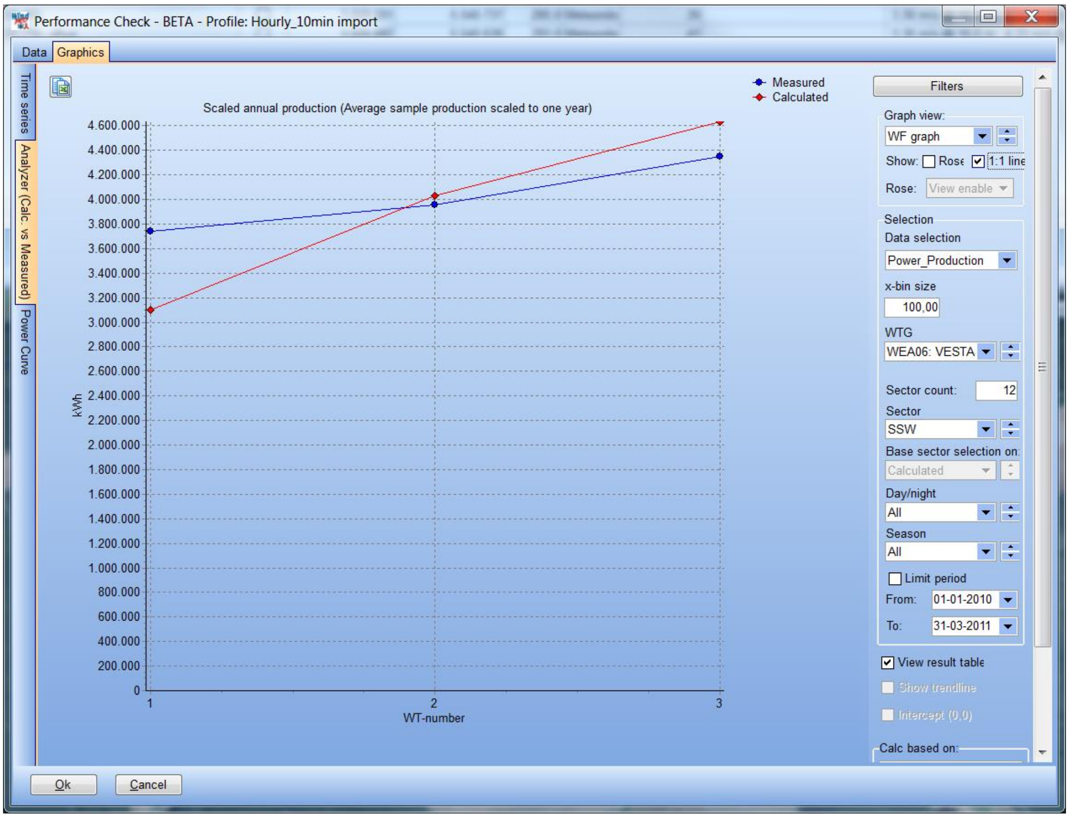


The binned version of the measured vs. calculated show that especially at high production, there seem to be deviations between model calculation and real performance. This might be as well a problem in the used meso scale wind data as a turbine issue or another model based problem.

We also see the rose here, showing very well correspondence between measured and calculated by direction.

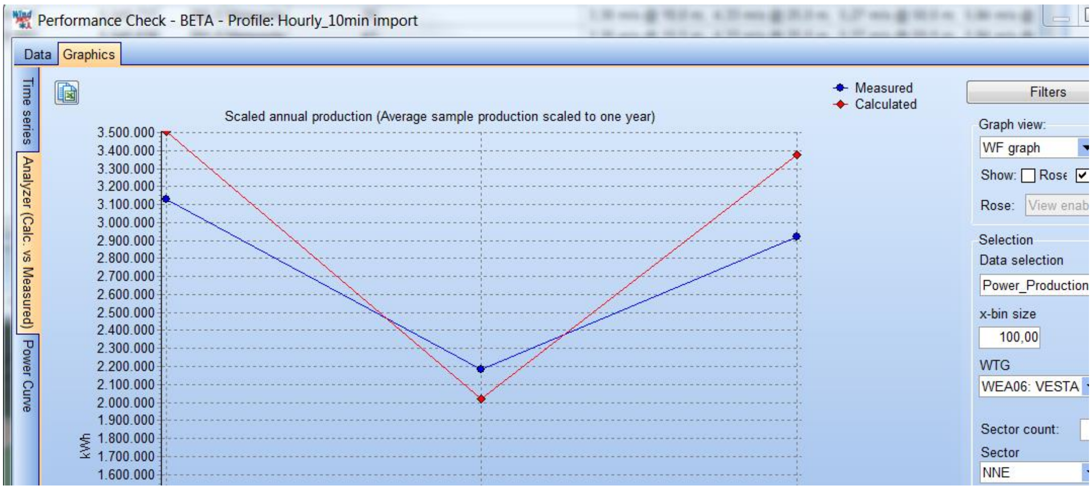


The WindFarm graph show results for all turbines in the same graph. Turbine 1 is slightly under predicted, while the two other match very well. This is an important feed back to the model setup.



Showing this graph direction by direction complement this further, like in SSW sector, the WT-1 is relative much under predicted.

An obvious explanation is that wake losses are calculated too high looking at the wind farm configuration. Especially in SSW, there is much influence from WT-2 (Asch-4) on WT-1(Asch-3). Then we should find similar relative under prediction for Wt-2 in NNE sector:



And we do. It' thereby not difficult to conclude that the wake model here does reduce more than it should, and adjustments can be made to wake model settings to get a more precise model setup.

Similar many other issues in the calculation model setup can be identified, like influence of forest near turbines, the roughness description etc.

When using meso scale data, it is also possible to "downscale" the meso scale data in a proper way, so the difference of the model conditions in the meso scale data and the local micro scale model is corrected. This part will be developed further in coming versions.

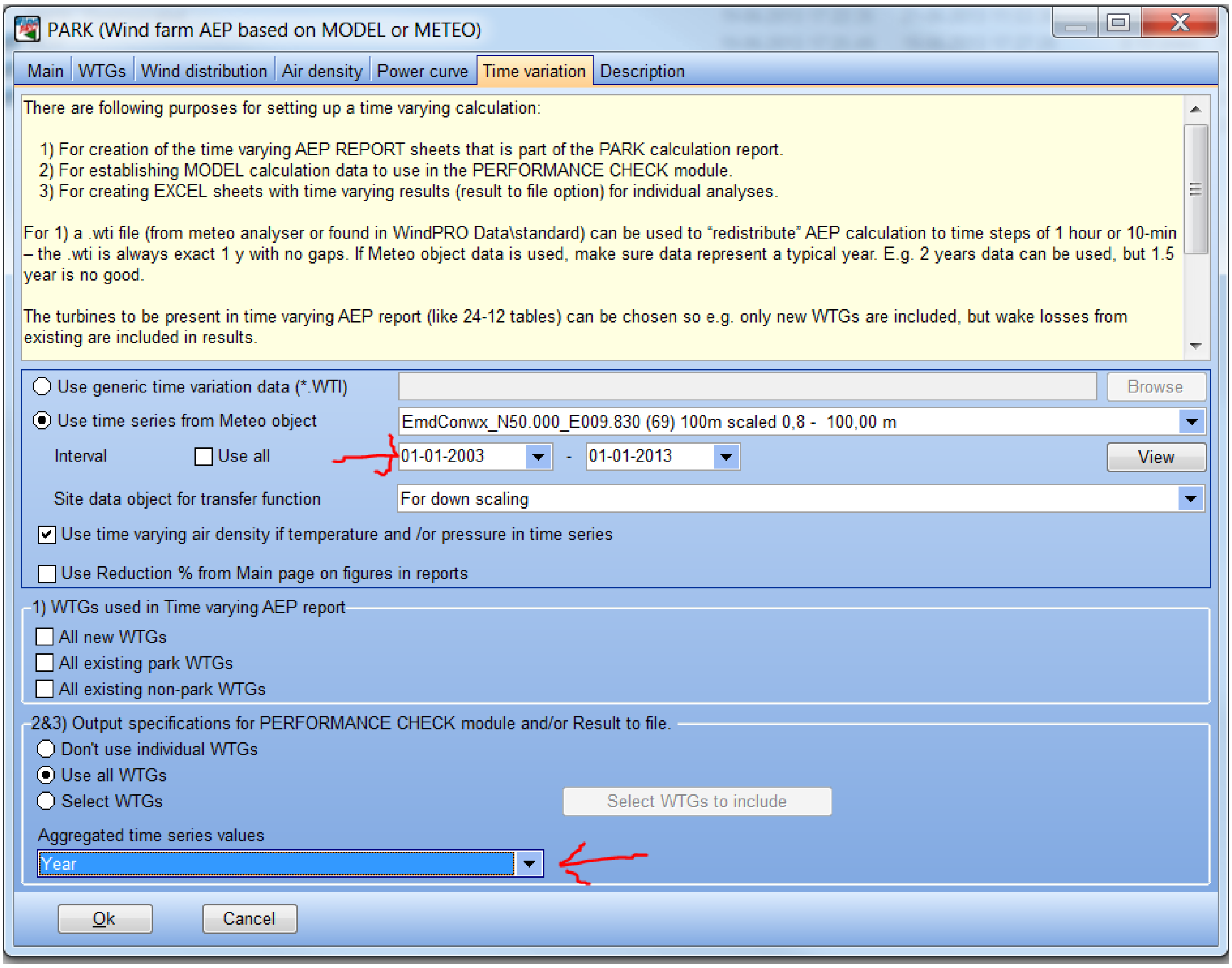
Please get the "Exercise for Performance Check" to see more evaluation features.

14.7.4 General X-Y

This part is not yet implemented. With this tool, any signal can be plotted against any signal. To utilize this feature in present version, it is possible to load turbine operation data in Meteo objects and use the feature from there.

14.7.5 Getting the results out/reporting

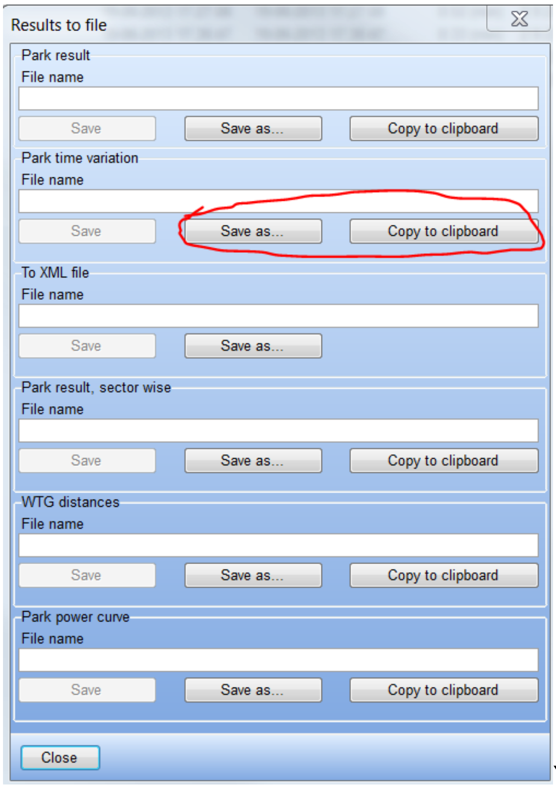
Having a setup established, where the time varying calculation performs "perfect" for the period with data, this setup should be used for calculating expected long term production. Perform a time varying calculation based on e.g. 10 y (could be 15-20… depending on what is believed to be most representative for future).



We need to change two places compared to our calibration calculations. The aggregation level could also be month, and then the results could be compared to the loaded measured monthly data for "an extra check".

This is VERY important:

The calculation result is NOT what you see in the PARK report. This is still based on the windstatistic and do not reflect the time varying results. So the correct result is what you find here: (Right click at calculation result and choose "result to file")



You can save as file or the easiest copy to clipboard and paste into Excel:

		Final result:			Asch-3	Asch-4	Asch-5	Asch-3	Asch-4	Asch-5
		Average of 10 year:		MWh/y	3.211	3.073	3.323	5,2	5,1	5,3
		Expected losses:		5%	-161	-154	-166			
		P50:			**3.050**	**2.919**	**3.157**			
Long term calculation, 10y EmdConwx_N50.000_E009.830 (69) 100m scaled 0,8 - 100,00 m Data are air density corrected										
Measure height	3559581	5540737			4	5	6	4	5	6
Time stamp	Wind spee	Direction	Temperatu	Pressure	Energy	Energy	Energy	Wake wir	Wake wi	Wake wi
	[m/s]	[°]	°C	[hPa]	[MWh]	[MWh]	[MWh]	[m/s]	[m/s]	[m/s]
01-01-2003	4,8	227	10,1	0	3.050.748	2.933.025	3.136.908	5,1	5	5,1
01-01-2004	5	259	9,5	0	3.375.658	3.230.225	3.487.542	5,2	5,1	5,3
01-01-2005	4,9	255	9,7	0	3.026.291	2.850.176	3.119.284	5,1	5	5,2
01-01-2006	5	227	10,3	0	3.223.394	3.128.251	3.364.037	5,2	5,1	5,3
01-01-2007	5,3	257	10,5	0	3.919.949	3.764.707	4.043.638	5,5	5,4	5,6
01-01-2008	5,1	239	10,1	0	3.318.976	3.221.804	3.471.903	5,3	5,2	5,4
01-01-2009	4,9	253	10	0	3.019.048	2.857.380	3.116.494	5,1	5	5,2
01-01-2010	4,8	285	8,4	0	2.922.763	2.747.870	3.003.753	5	4,9	5
01-01-2011	4,8	214	10,5	0	3.078.288	2.972.183	3.189.039	5,1	5	5,1
01-01-2012	5	242	9,9	0	3.170.358	3.024.044	3.301.745	5,2	5,1	5,3
				min	2.922.763	2.747.870	3.003.753	5	5	5
				max	3.919.949	3.764.707	4.043.638	6	5	6
				St.dev	8,9%	9,5%	9,0%	2,7%	2,8%	3,3%
				min/avg	91%	89%	90%	97%	96%	95%
				max/avg	122%	123%	122%	106%	106%	107%

The result to file (in yellow) and the manual additions in Excel to get the “end results”.