

## 11 PART II: OPERATION, POST CONSTRUCTION

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## 11.1 Methodology of Post Construction Evaluation

The post construction module in windPRO allows the user to analyse 10-minute SCADA production data together with wind turbine error/event logs to evaluate lost production of individual errors and predict the future long-term corrected production.

The calculation is based on the *actual 10-minute SCADA data* of the wind turbines, combined with the error/event logs to identify each 10-minute period stop or non-optimal performance, identify the cause of each event, and categorise and assign responsibilities. If error codes are logged in separate files with start/stop times the information can be synchronised with the 10-minute SCADA time series. This results in a 10-minute time series of production, wind data and relevant error codes and their description.

Once all events with errors and/or non-optimal performance have been filtered out, the remaining records describe normal operation which is used to establish the *historic power curve* for each turbine for typically 0.5m/s wind speed bins. For periods with faults or stops the nacelle wind speed and the *historic power curves* of the individual WTG are used to derive the *potential production*. The loss categories follow IEC 61400 26-1. In this process, the logged actual production during error (and non-optimal) periods is being replaced with the production found by applying the *historic power curve* to the nacelle wind speed at the relevant time steps. The *potential production* values will tell, what the turbines would have produced on average under normal operation, if it was not affected by an error event or partial performance. It represents 100% availability. The *actual production* from the SCADA data and *potential production* are then compared in periods of irregular operation. The difference results in the *lost production* for each time step.

Please note, that internal wake losses and losses from neighbouring wind farms are inherent in the SCADA data, and are not quantified. Electrical losses (i.e. cable losses from the turbine to the metering point) are handled separately as they appear after the SCADA data are logged.

This potential production is then long-term corrected using a wind energy index based on mesoscale data or other sources and results in the *normalised production*. Subsequently, expected future long-term losses are deducted from the *normalised production* to assess the *expected future net production*. Future losses are either assumed to be identical with previous losses or defined by the user, if for example, there have been changes in the losses. Additionally, electrical losses and losses due to degradation, can be included.

This method is primarily used for evaluation of operating wind turbines/farms, as the uncertainty of the net production is typically half of the traditional pre-construction yield estimates based on wind measurement and models. It can also be used for a detailed investigation into the causes of lost production and to evaluate if actions should be taken to potentially remove causes of lost production.



### 11.1.1 Workflow

The most typical application and workflow for post construction analysis is described in the Quick Guide.

However, since only a few error code logs follow the IEC 61400-26-1 structure, the user can be confronted with various formats. In case of cascading errors and alarms it might be difficult to identify the relevant event. Therefore, iterations in the work process might be necessary. For example, the user might find that some events with a specific fault show no poor production. This could be due to the fact that the time stamp in the SCADA data belongs to the end of the 10-minute period and not the start. Consequently, the user has to revisit the loading of the 10-minute SCADA data, change the setting, load the data again and pair the production data with the right WTGs.

Next to the pure analysis of SCADA data, the *post construction* module can be operated together with *Performance Check* such the user can fine-tune and validate a chosen model set-up by comparing real production with modelled production. Specifically, for assets with poor availability, or poor data recovery of the SCADA data, it might be advisable to use Performance Check rather than Post construction to predict the future production.

Therefore, there are interfaces between the two methodologies. Please note, that both tracks require at one point running a time-varying *PARK* calculation. In case of post construction, the nacelle wind speed and historic power curve of the individual power curve will be used to calculate for each time step what the WTG should have produced. The time-varying *PARK* calculation does not require any flow modelling in this case. It can be started from within the Post construction module.

In case of *Performance Check*, a full flow model has to be set-up. As wind speed it is possible to use local masts as well as mesoscale data. The model can be queried, for example to find the most suitable scaling factor of the mesoscale data, or to find the best wake parametrisation which reflects the observed wakes best. The actual production data can be prepared in the *Post construction* module and filtered for events with error codes or non-optimal performance. One of the key parameters to identify the success of a specific model set-up is the Goodness factor which describes how well the model reproduces the measured production.

### 11.1.2 File Type Overview

By default, all windPRO files are located in the folder \windPRO Data\Projects\...

What	Project file extension
wind base file	*.wbf
Performance Check Error Settings file	*.pfc
Performance Check Import Setup	*.pci



## 11.2 Data Preparation

For post construction analysis typically 10-minute SCADA data are used. The data have to be in form of an ASCII text file, e.g. comma or tab delimited. If they are in Excel files (xls/xlsx), these must be saved as .txt or .csv or other text file formats. Tab file separated text data are recommended.

For the import of the files it is convenient if the turbine identification in the import files is identical to the ID in the *existing* WTG object (description or user label). It is important that the files contain data organized in rows, each row starting with the time stamp, preferably something like dd-mm-yyyy hh:mm. Please note that midnight (00:00) will be empty in Excel, however, there is no reason for concern as this empty time stamp is handled correctly later in the data importer. Month names (e.g. JAN, FEB....) must be converted to numeric formats.

The temporal resolution of SCADA data is typically 10-minutes. windPRO is currently able to handle data with a granularity of 1-minute.

As a minimum, the files have to contain production data and wind speed. Both production data in kW and kWh can be handled, as well as accumulated production. Additionally, wind direction and any operational parameter like rpm, pitch angle, etc. can be read in. The direct use of error codes is also possible as long as the error codes come in 10-minute steps. If the error codes are available in a separate file with start/stop times they can be converted to 10-minutes later in the process (see Section 11.1.12).

Table 1 shows an example for a data structure. Each signal contains the WTG ID. Please note that the data structure is shown transposed! For importing the file structure has to be in rows per time stamp.

	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

Table 1: Example SCADA data structure – please note for display reasons the table has been transposed!



## 11.3 Data

### 11.1.3 Start Post construction and Concept Choice

The prepared text files are imported using the *Performance Check* module (Figure 1). Start with creating a new “session” or open a previously created session.

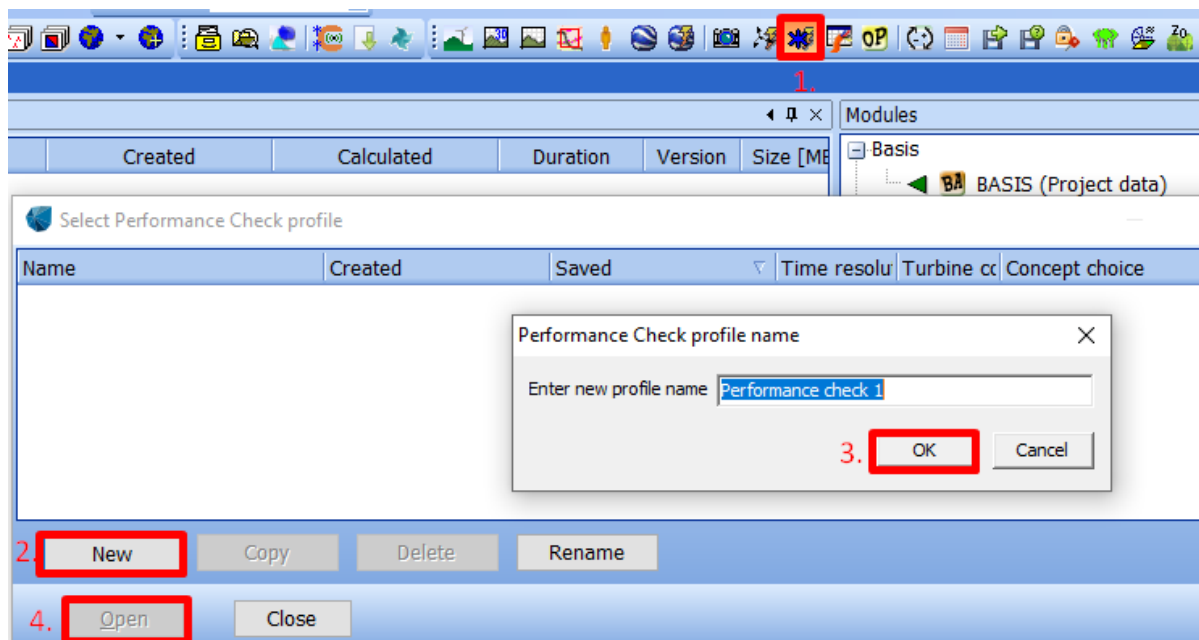


Figure 1: Start Performance Check Module

It is also possible to start *post construction* from the main menu (Figure 2).

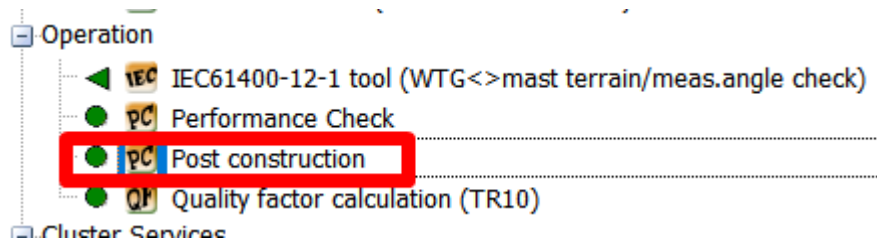


Figure 2: Start post construction from main menu

*Performance Check* offers different workflows. In this section we explain the workflow and functionalities for *Post construction evaluation* (Figure 3). The process follows the IEC 61400-26-1 structure. The use of this functionality requires a license for Post construction.

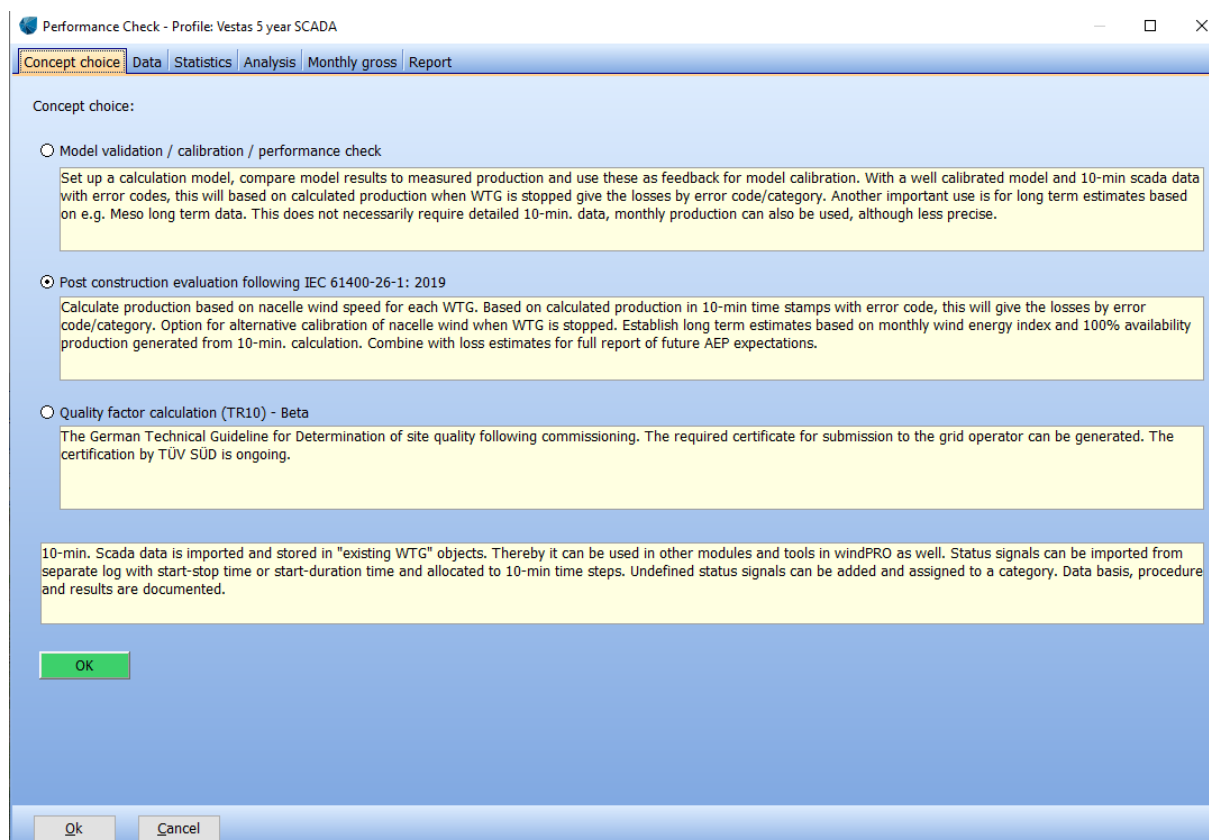


Figure 3: Choice of workflow in Performance Check

#### 11.1.4 Data – Data Source

After having chosen the concept (*post construction evaluation*) the user has to define which type of data are imported (Figure 4).

For SCADA data analysis typically 10-minute data are used. This category also handles other temporal resolutions like 1-minute or hourly data.

In case the *existing* WTG object already contains data, the user can decide to use the already imported data.

Starting a new session requires the user to decide if new data are to be imported into the *existing* WTG objects, or already imported shall be used. In the latter case the import process is skipped.

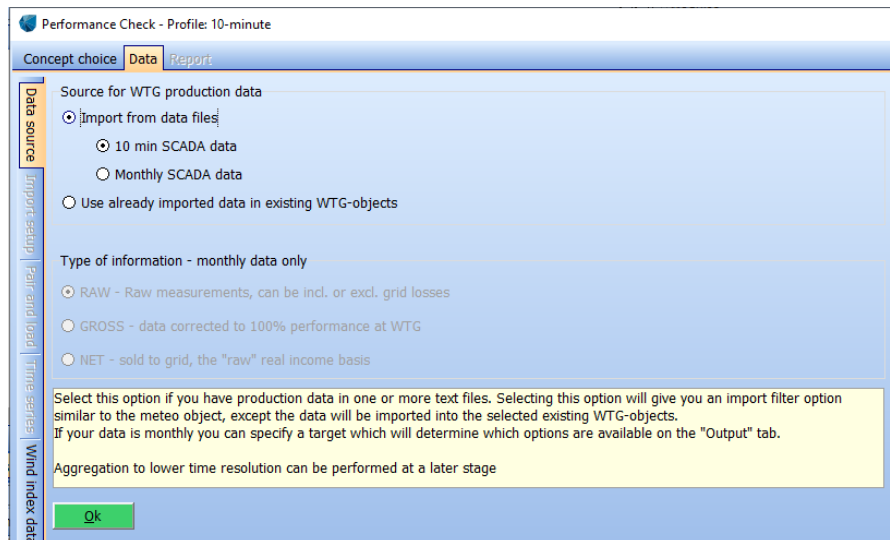


Figure 4: Define type of import data

### 11.1.5 Alternative: Import of Production Data in Existing WTG Object

As an alternative it is also possible to import production data directly into the *existing* WTG object (Figure 5) outside the *Performance Check* module. However, for large amount of data it is recommended to use the *Performance Check* module.

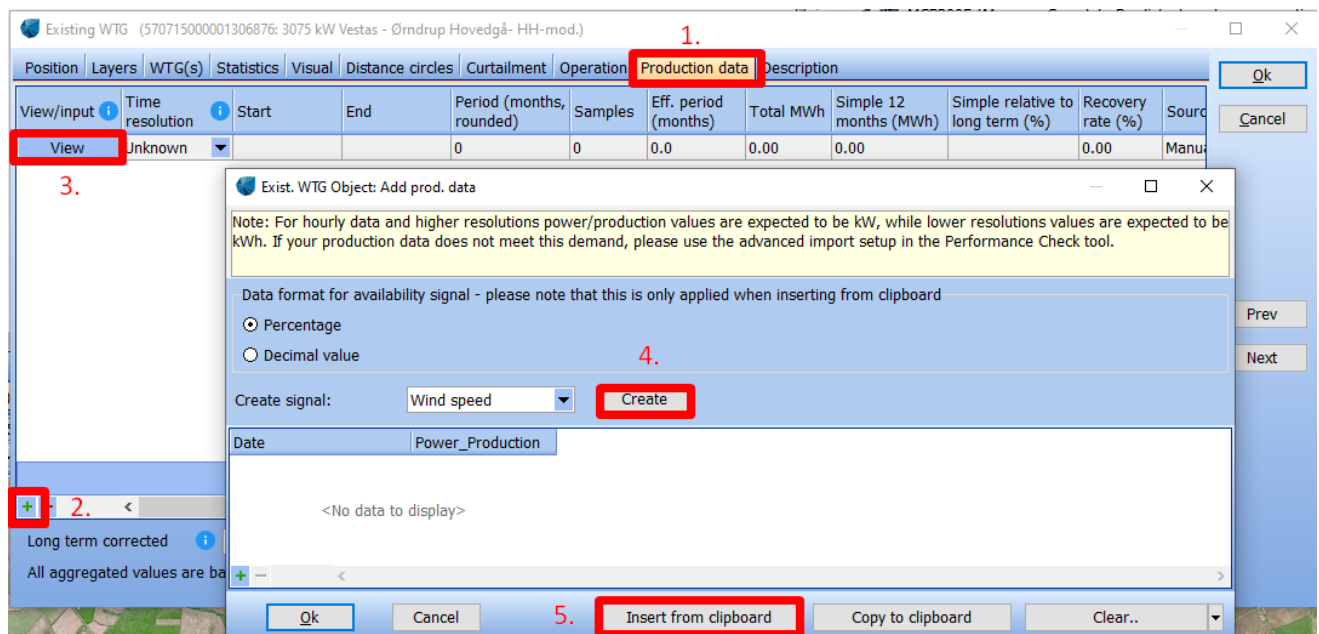


Figure 5: Direct import of production data into existing WTG object

It is possible to load several data sets (press +) with different temporal resolutions. Please note you cannot mix temporal resolutions in one time series.

For monthly data there are some further options:

- RAW measurements, typically from Scada system, metered within the turbine controller and thereby excluding the grid losses (can include availability information)
- GROSS – the 100% availability production
- NET – The metered (sold) production



## 11.1.6 Data – Import Setup

The Importer for SCADA data is very similar to the importer in the *Meteo* object. The user has to either directly select text files or a folder which contains the text files.

The time zone has to be specified.

The *Auto detect* button will suggest a structure. This might identify some of the signals, but typically some manual adjustment will be needed. The user has the option to modify the suggested structure and specify the line with the header, the first line with data and field separators. At any step the user can preview the file structure and adjust file formats if required. It is also important to define if the time stamps refer to the start of a 10-minute period or to the end of a 10-minute period. SCADA systems often log the data at the end of a 10-minute period, however this is not a universal practice. The impact of this setting can become important later in the process when the production data is coupled with error codes.

Performance Check - Profile: 10-minute

Concept choice: **Data** | Report

Files/folders (must have exact same structure, if differently structured files, add more import filters)

C:\Users\wl\Documents\Projects\Krogstrup Enge\Data\_Scada\10MINUTEDATA\_APR18-JAN19\_SCADA-OUTPUT.txt

Add file(s) Add folder

Remove Edit

View file

Time zone for measurements: Same as in the project properties: (UTC+01:00) Brussels, Copenhagen, Madrid, Paris

Structure of the files (import filter):

Auto detect Load Save

Decimal separator: , Select WTG-ID location: WTG-ID Guide Filename WTG-IDs based on current selection: 10MINUTEDATA\_APR18-JAN19\_SCADA-OUTPUT

Select all columns Set all selected columns to: Sub type: Unit: Apply Validate Import/WTG-ID setup

Time stamps are logged in: Beginning of a period 0 seconds Use text-to-number Text to number

Line with header Header field separator First line with data Data field separator Additional

2 Tab 3 None Recalibration

Column	Header	First data	Type	Sub type	Unit	Name	Convert
1	PCTimeStamp	13-04-2018 11:00	Time stamp	Date&Time	d-m-y h:m		2018-04
2	WTG01_Ambient Temp. Avg. (1)	10	Temperature		Deg C	WTG01_Ambient Temp. Avg. (1)	10.0 Deg
3	WTG02_Ambient Temp. Avg. (2)	11	Temperature		Deg C	WTG02_Ambient Temp. Avg. (2)	11.0 Deg
4	WTG03_Ambient Temp. Avg. (3)	11	Temperature		Deg C	WTG03_Ambient Temp. Avg. (3)	11.0 Deg
5	WTG04_Ambient Temp. Avg. (4)	10	Temperature		Deg C	WTG04_Ambient Temp. Avg. (4)	10.0 Deg
6	WTG01_Ambient WindDir Absolute Avg. (5)	112,7	Wind direction		Degrees	WTG01_Ambient WindDir Absolute Avg. (5)	112.7 D
7	WTG02_Ambient WindDir Absolute Avg. (6)	97,7	Wind direction		Degrees	WTG02_Ambient WindDir Absolute Avg. (6)	97.7 Deg
8	WTG03_Ambient WindDir Absolute Avg. (7)	87,9	Wind direction		Degrees	WTG03_Ambient WindDir Absolute Avg. (7)	87.9 Deg
9	WTG04_Ambient WindDir Absolute Avg. (8)	96,6	Wind direction		Degrees	WTG04_Ambient WindDir Absolute Avg. (8)	96.6 Deg

Ok Cancel

Figure 6: Importer for 10-minute data

For post construction analysis users are required to have the production and the wind speed as bare minimum. Following additional pre-defined signals are available:

- Wind direction
- Availability
- Error Code
- Temperature
- Pressure
- Pitch angle
- RPM

For some signals it is necessary to define the sub-type: Is the wind speed signal representing the mean, max, min or std? Is the production signal accumulated? Once the sub-type is defined, and the units are set, the data are converted and appears in the rightmost column. Please note that you also have to specify the unit for the time stamp. Specific care has to be taken in setting the unit of the power signal correctly. It is, however, at any time possible to return and change the unit.





Please note that all negative production is set to zero. For any selected period, the sum is logged and documented as a total for the selected turbines.

Multi-editing of the signal is possible by marking the signals you want (by dragging the mouse or by “Shift-click”), specify the type and sub-type and finally pressing “Apply” (Figure 7).

Select all columns Set all selected columns to: Error code 2. Sub type: Unit: 3. Apply

Time stamps are logged in: Beginning of a period 0 seconds Use text-to-number Text to number

Line with header Header field separator First line with data Data field separator Additional

1 Tab 3 Tab None Recalibration

Column	Header	First data	Type	Sub type	Unit	Name
19	WTG02_Total Active power (18)	50289560	Power_Production	Power_Product	kWh	WTG02_Total Active
20	WTG03_Total Active power (19)	49386304	Power_Production	Power_Product	kWh	WTG03_Total Active
21	WTG04_Total Active power (20)	52299872	Power_Production	Power_Product	kWh	WTG04_Total Active
2	WTG01_System Logs First Active Alarm No (21)	0	Error code			WTG01_System Logs
3	WTG02_System Logs First Active Alarm No (22)	0	Error code			WTG02_System Logs
4	WTG03_System Logs First Active Alarm No (23)	0	Error code			WTG03_System Logs
5	WTG04_System Logs First Active Alarm No (24)	0	Error code			WTG04_System Logs

Figure 7: Multi-editing of signals

Further it is possible to change text to numbers. E.g. if your date stamp contains text like DEC you can translate this into 12. Or if invalid data is marked NAN you can change it to -999.

It is possible to save the structure as a \*.pci file and use it for other projects. It is also possible to use several import filters in case the SCADA data has been provided in different formats.

In the next step of the process it is necessary to assign the production data to a specific WTG. There are two options: In case you do not know where to find the WTG-ID a *WTG-ID Guide* will help you with the necessary specifications, or alternatively you can directly enter where to find the WTG-ID in the file (Figure 8).

1. WTG-ID Guide Column header WTG-ID Options No WTG-ID found!

Performance Check WTG-ID Guide alternative

Performance Check WTG-ID Guide

This guide will help select a unique "WTG-ID", which is used for pairing production data from data files with windPRO WTG objects.

Cancel Back Next 2.

Figure 8: WTG-ID Guide

In first step of the *WTG-ID Guide* you have to specify the number of WTGs you want to analyse. Then, you have to define whether the data are in individual files per WTG, if the WTG ID is inside each file or if the WTG-ID is part of the file name. If the WTG-ID is inside the file, you have to specify if the WTG-ID is part of the column header (e.g. WTG02\_Spd as column header) or in a column.

In the next step you have to define the first and second WTG ID as well as the last WTG by clicking at the top of the columns (Figure 9). This assists the tool to identify the remaining WTGs automatically. You have to specify the delimiter, which separates the WTG-ID from the signal name. In Figure 9 the



delimiter is an underscore “\_”. Sometimes the column name might include several underscores (e.g. WTG03\_Spd\_1). Therefore, it is possible to define which sub-string includes the WTG-ID, in our example it is the first sub-string that contains the WTG-ID.

If the selection has been successful, the WTG-ID will now show up (Figure 10). You now have to pair the production data with *existing* WTG objects.

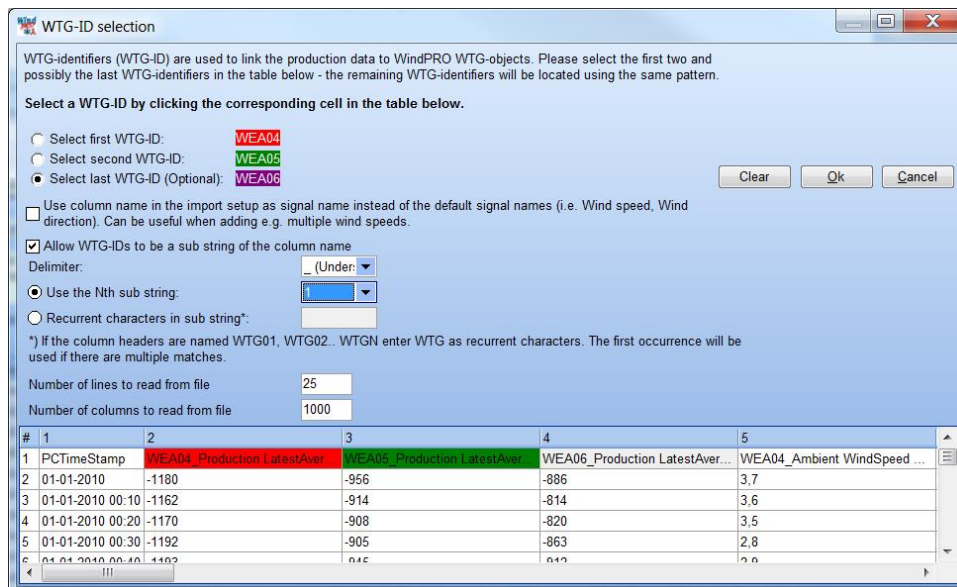


Figure 9: WTG-ID selection

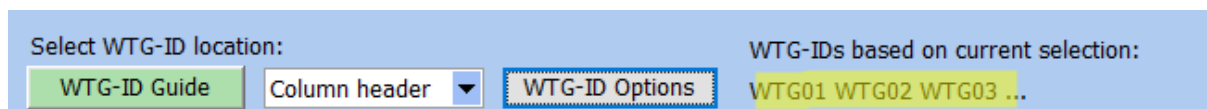


Figure 10: Successful selection of WTG-ID

## 11.1.7 Data – Pair and Load

The user has to choose which of the existing WTGs to add to the analysis (Figure 11).

In the case where the naming convention of the *existing* WTGs is identical with the WTG-ID used in the SCADA files, windPRO will automatically pair the object with the production data. In the case where the automatic pairing does not work properly, use the drop-down in upper right corner to match the ID in the import filter to the objects.

Once correctly paired, click **Load measured data** and the data will be imported into the WTG objects (Figure 12).

It is possible to re-visit **Load measured data** at a later time. This might be the case, if you have received further data: For example, you started out by only having monthly production data but now you want to add data with a different temporal resolution e.g. 10-minute production data. Depending on the application you might want to load all data, or you might want to load only the new, additional data into the *existing* WTG object and consequently maintain data that was earlier loaded. Or you want to load production data, which you had loaded directly into the *existing* WTG object into the post construction calculation (see Section 11.1.5).

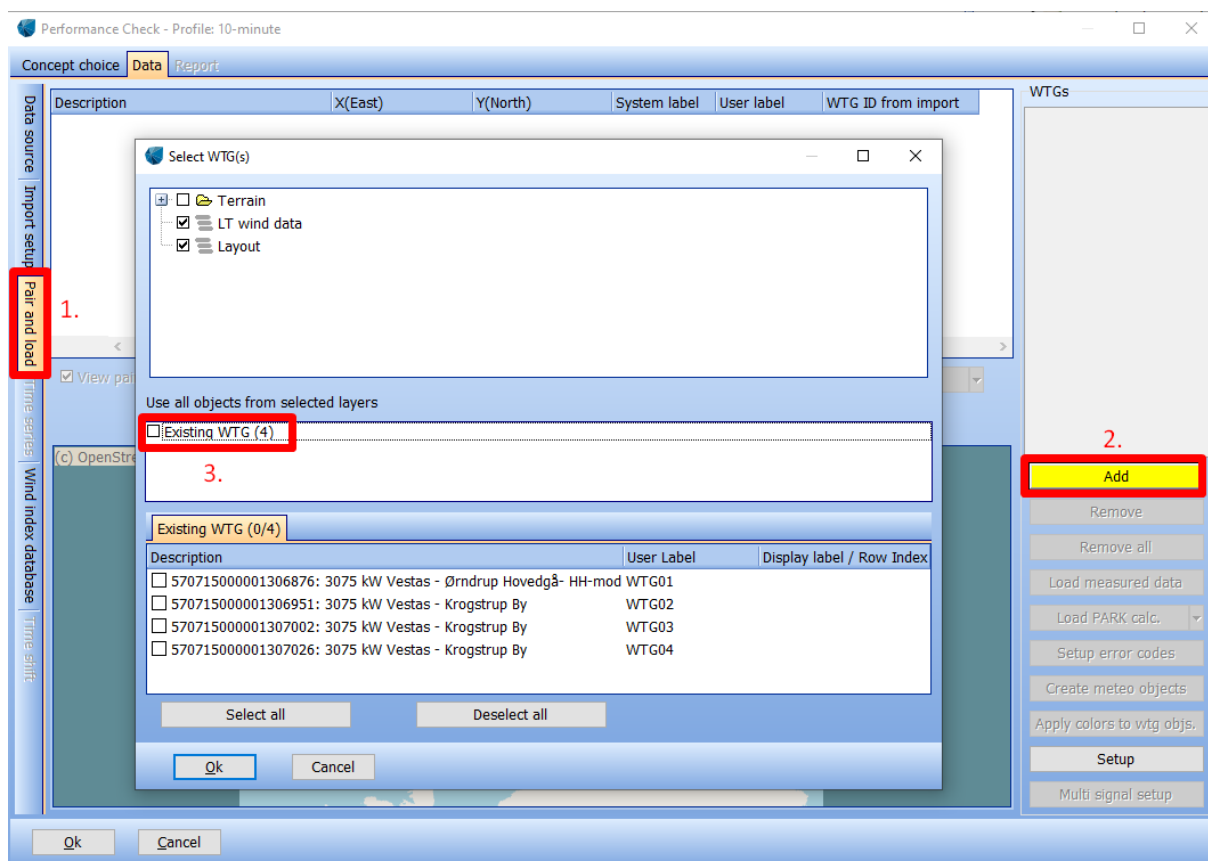


Figure 11: Chose existing WTGs for pairing

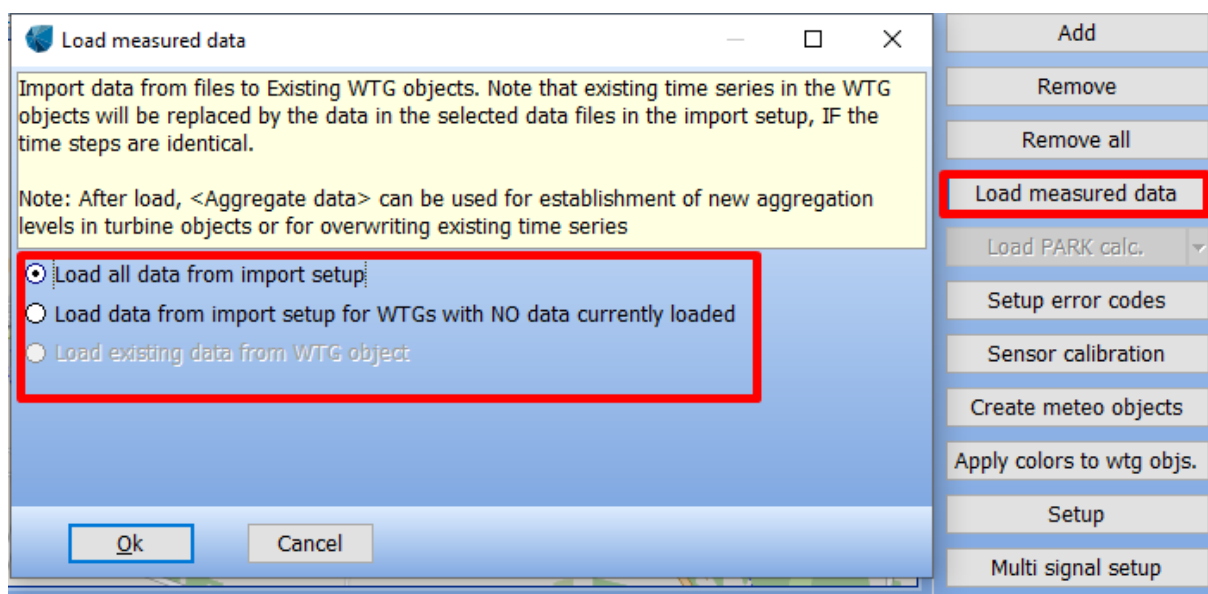


Figure 12: Load measured data

On the tab *Pair and Load* a lot of other functions can be found. Some of them will be treated in a different manual section (as annotated in Figure 13).

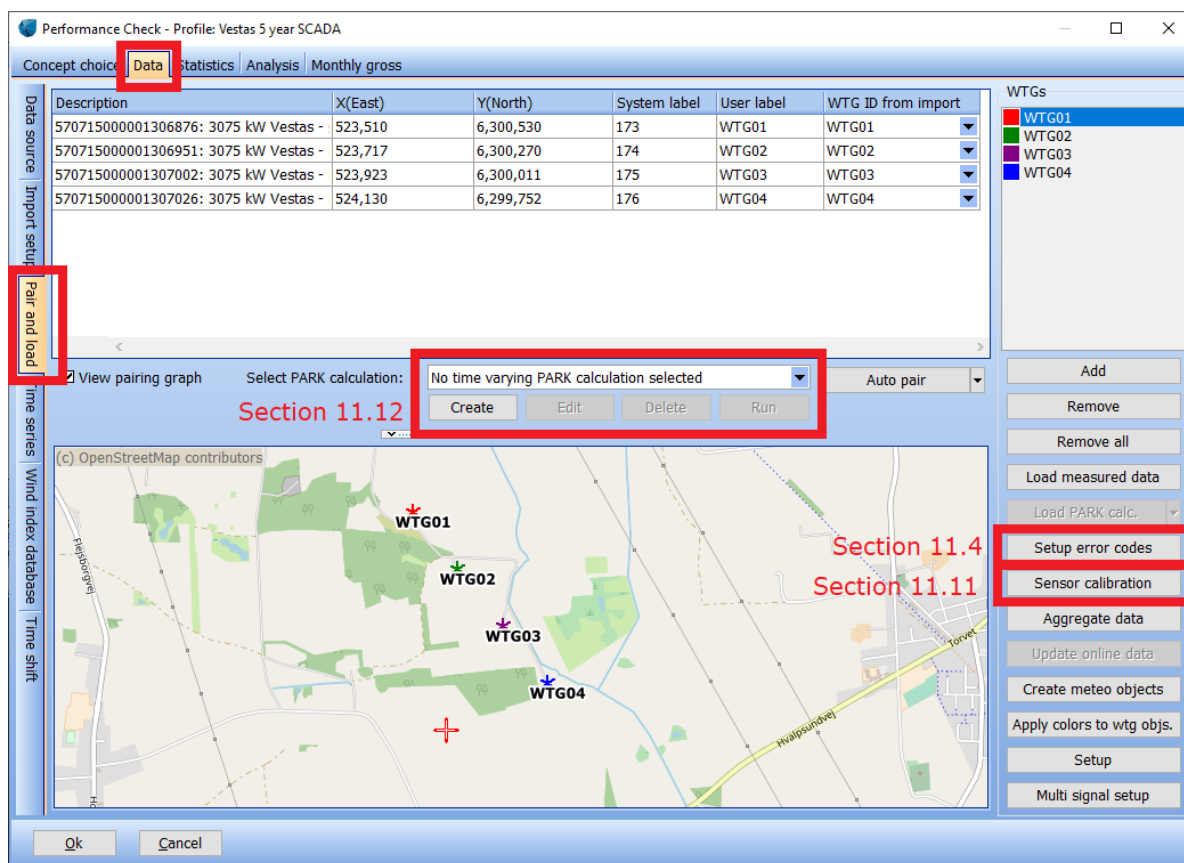


Figure 13: Additional functions on Pair-and-Load tab

**Setup error codes** is described in Section 11.4. It deals with how to combine the error code logs, error descriptions and categories with 10-minute SCADA data.

**Sensor calibration** is described in Section 11.11. It deals with checking the nacelle wind speed for consistency by comparing with references.

**Create time varying park calculation** is described in Section 11.12. It allows the user to run a time-varying PARK calculation.

Additionally, to these larger functionalities following possibilities can be accessed:

**Create meteo objects:** This button will convert the wind speed signal of each WTG into a *Meteo* object.

**Apply colours to WTG objects** will give the WTG symbols the same colours as used in the graphics within Performance Check. This is very convenient when evaluating results WTG by WTG.

**Setup:** Here a number of boundary conditions can be defined (Figure 14). In the first section the user can define which signal should be used for further analysis, e.g. turbulence intensity is only considered for wind speeds above 4 m/s. Turbulence intensities at wind speed lower than this value are automatically disabled. It can also be defined how many samples must be present when aggregating data from e.g. 10-minute data to hourly data.



**Meteo object setup**

The listed signals will be disabled automatically based on the minimum wind speed requirement. Note that the data must be reloaded after changing the limit.

Signal name	Min. wind speed [m/s]
Turbulence intensity	4.0
Shear	2.0
Inflow angle	4.0
Veer	4.0

Maximum difference in time stamps for concurrency [minutes]

☐ High resolution time series. Check this if you wish to load time series with a time step smaller than one minute.

Setup of seasons and day/night:

Min. % of enabled and present data within a time period when aggregating data:

The threshold specifies the minimum number of present and enabled samples required for the target sample to become enabled.  
Example: If you aggregate a 10 minute time series to hourly values and specify an 80% threshold, at least 5 out of 6 samples within an hour must be enabled to ensure that the target sample is enabled.

Object data placement:  ☐ Set as default for new time series

This option allows you to select where time series data should be saved after it has been imported from file(s). Internal folder means that the data will be part of the project file, whereas project folder means that a subfolder will be created in the folder in which your project file is located, thus reducing the size of the project file.

Figure 14: Set-up settings

**Multi Signal setup** defines the handling of several signals of the same type, e.g. there might be two anemometers installed on a nacelle. If both signals are loaded, it can be decided to use the average, maximum, minimum or sum of the two signals.

Figure 15 shows an example with two wind speeds being imported. The two signals are combined by averaging. The user can further define which of the signals is used in future graphical displays.

**Setup for multiple signals of the same type**

In this form you can determine how Performance Check should handle multiple signals of the same type. Check at least two signals in the "Combine"-column to enable options for the "Combined"-signal. "Use in analysis" decides which signal is used when using e.g. a wind speed signal in the XY-power curve graph. If you wish to remove the combined signal simply load the original data from file(s) again.

Signal type	Use in analysis	Signal name	Combine	Combine option	Show in time series graph
<input checked="" type="checkbox"/> Mean wind speed	<input type="radio"/>	NC2LWSMEAN 16 - Lefthand Wind Speed (NC2)(avg )	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>
	<input type="radio"/>	NC2RWSMEAN 16 - Righthand Wind Speed (NC2)(avg )	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>
	<input type="radio"/>				
	<input checked="" type="radio"/>	Combined Mean wind speed (Average)		Average	<input checked="" type="checkbox"/>

Figure 15: Handling of multiple signals



### 11.1.8 Data – Time Series

Before moving on, it is a good idea to quality control all choices by visiting the *time series* tab. Here you can inspect your data and perform some basic filtering, please refer to [Meteo manual](#) for details as the functions are identical with those for the *Meteo* object.

The data can be sorted by clicking on the top of the column you want to sort by. If data are out of range or there are duplicates, etc., the small arrows will help you to jump to the specific time step.

The power signal can e.g. be checked by sorting after power. The maximum power [kW] should be identical with the rating of the WTG. If the maximum power is wrong by a factor of six, the reason could be the choice of units in the import filter: [kWh] or [kW]. If the maximum power is wrong by a factor of 1000, check if [Wh] or [kWh] should be used. Simply change the unit in the import filter (see Section 11.1.6) and reload the data.

Concept choice							
Data							
Statistics							
Analysis							
Monthly gross							
Report							
Data source	Disabled		Time stamp (UTC+01:00)	Ambient Temp. Avg. (1)	Ambient WindDir Absolute Avg. (5)	Wind speed - Mean	Power
			Brussels, Copenhagen, Madrid, Paris			Wind speed - StdDev	_Production
Import setup	<input type="checkbox"/>		2018-04-24 15:10	9.0	278.0	15.10	3096.0
	<input type="checkbox"/>		2018-04-24 16:40	10.0	291.2	15.00	3096.0
	<input type="checkbox"/>		2018-04-24 17:40	10.0	286.8	14.40	3096.0
	<input type="checkbox"/>		2018-04-24 19:30	9.0	278.4	11.50	3096.0
Pair and load	<input type="checkbox"/>		2018-04-30 15:00	8.0	67.1	14.00	3096.0
	<input type="checkbox"/>		2018-04-30 16:20	10.0	67.7	11.80	3096.0
	<input type="checkbox"/>		2018-06-11 13:40	16.0	286.9	14.10	3096.0
	<input type="checkbox"/>		2018-06-11 16:20	15.0	291.3	14.90	3096.0
Time series	<input type="checkbox"/>		2018-06-11 17:30	15.0	296.1	13.70	3096.0
	<input type="checkbox"/>		2018-06-13 15:20	15.0	295.5	13.70	3096.0
	<input type="checkbox"/>		2018-06-13 17:30	16.0	300.6	13.00	3096.0
	<input type="checkbox"/>		2018-06-14 15:20	18.0	223.7	16.80	3096.0
Wind index data	<input type="checkbox"/>		2018-06-14 16:30	16.0	234.0	16.20	3096.0
	<input type="checkbox"/>		2018-06-14 17:30	14.0	211.2	13.70	3096.0
	<input type="checkbox"/>		2018-06-20 13:10	19.0	243.6	13.00	3096.0
	<input type="checkbox"/>		2018-06-21 09:40	14.0	313.3	13.40	3096.0

Figure 16: Example resulting time series

### 11.1.9 Data – Wind Energy Index Database

In order to calculate later the long-term expected energy (WCP wind corrected power), it is necessary to load minimum one energy index. windPRO has its own file format for storing indices: \*.wbf file (wind base file).

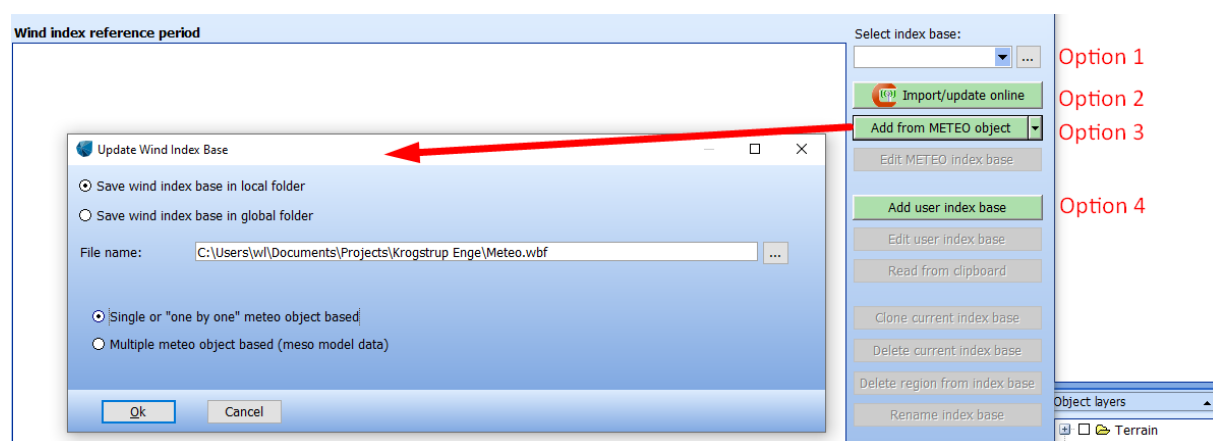


Figure 17: Different choices for energy indices



There are several options (Figure 17):

**Option 1:** You can load an existing \*.wbk file (wind base file) which you have created earlier.

**Option 2: Import/update online:** For some countries, there are “official” wind energy indices. So far, this online data includes only the DK-index. While the German BDB index is not included in windPRO and has to be added manually, windPRO assists in identifying the relevant region (Figure 18).

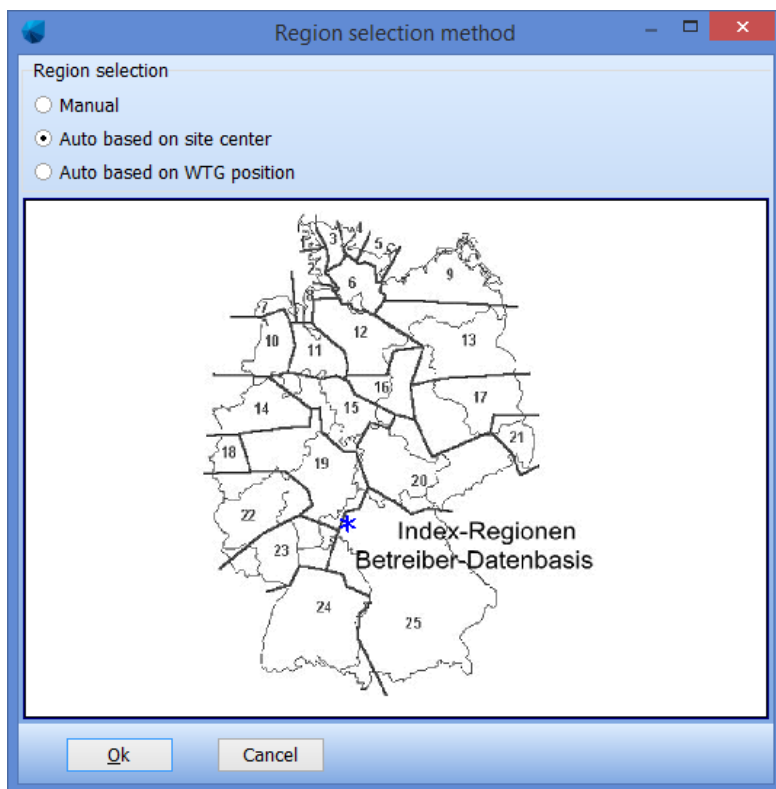


Figure 18: Identification of relevant region BDB index

**Option 3: Add from Meteo object:** You can create an index based on a *Meteo* object and save it either in a local or in a global folder (for later use). Typically, reanalysis data like MERRA-2 or ERA5 or mesoscale data like EMD WRF Europe+ are used. To convert wind speed to energy, the user can define a power curve and the expected long-term wind speed at hub height. The wind speed from the long-term data is scaled to match the expected long-term wind speed on site. This way the dynamic behaviour of the index reflects the production variations as best as possible, and it becomes possible to use also long-term wind speed data, which may be very different from the site conditions.

In the next step the relevant *Meteo* object is selected and the reference period defined.

Finally, the calculated wind energy index can be viewed graphically.

This process can be repeated for different sources and/or settings. All results are written into a Wind Index database (Figure 20).

**Option 4: Add user index base:** This function allows to create a user index either by manual editing row by row or by pasting from the clipboard.



**Power curve setup**

☒ Use actual power curve of a selected WTG

WTG type: **VESTAS V90-2.0 MW 50 Hz VCS 2000 90.0**

☒ Always use default values

☐ Use simple power curve approximation with squared wind speeds

Simple power curve - truncate at: **14,0** m/s

Use only periods with at least **60** % data available

Expected long term mean wind speed in hub height (average of wind farm)

**5,50** m/s

(will be used for scaling wind speeds to correct level for wind index calculation)

Power curve

Copy graph

Power [kW]

Wind speed [m/s]

Selected power curve

Simplified power curve [sq(V/Vsp)]

**Time series setup**

Select meteo object:

**EmdConvwx\_N50.000\_E009.830\_100m\_scaled\_0,8 OLD:10,0m**

Period for reference wind index level:

All data: **January 1993** To: **March 2013** 20,2 years

Chosen ref. period: \* **January 1993** To: **December 2012** 20,0 years

\* Note that both months are included

Temperature data NOT present - no air density correction can be performed

☐ Air density correct

Reference period wind energy index: **100 %**

Evaluation:

Mean wind speed all data: **3,19** m/s

Mean wind speed reference period: **3,19** m/s

Region Name: **MERRA: 10,0E-50,0N-50m**

Normally a very long period, i.e. 30y, should be used and index set to 100%. If you have shorter, local measurements the level should be found by analysing e.g. MERRA data to find the expected level for the reference period.

Figure 19: From wind speed to energy index

Wind Index Database setup

Date	MERRA: 8,0E-55,5N-50m	MERRA: 8,0E-56,0N-50m	MERRA: 8,7E-55,5N-50m	MERRA: 8,7E-56,0N-50m	EmdConvwx: 7,6E-55,7N-75m
01-02-2010	0,90	0,83	0,91	0,84	0,83
01-03-2010	1,06	1,05	1,06	1,05	1,12
01-04-2010	0,89	0,90	0,95	0,96	0,96
01-05-2010	0,90	0,93	0,89	0,91	0,95
01-06-2010	0,49	0,53	0,50	0,56	0,56
01-07-2010	0,63	0,66	0,65	0,66	0,69
01-08-2010	0,74	0,76	0,73	0,75	0,75
01-09-2010	1,00	1,01	1,00	1,00	1,02
01-10-2010	1,20	1,19	1,16	1,14	1,21
01-11-2010	1,14	1,19	1,09	1,12	1,14
01-12-2010	0,96	0,92	0,92	0,89	0,94
01-01-2011	1,03	1,07	0,98	1,01	1,10
01-02-2011	1,51	1,46	1,50	1,45	1,45
01-03-2011	1,00	1,04	1,04	1,08	0,96
01-04-2011	0,88	0,84	0,88	0,84	0,93
01-05-2011	0,93	0,94	0,98	1,00	0,97
01-06-2011	0,69	0,70	0,73	0,76	0,72
01-07-2011	0,83	0,78	0,81	0,74	0,83
01-08-2011	0,87	0,88	0,90	0,91	0,86
01-09-2011	1,02	1,02	1,03	1,04	1,02
01-10-2011	1,30	1,31	1,25	1,27	1,30
01-11-2011	1,02	1,00	0,97	0,96	1,04
01-12-2011	1,48	1,46	1,46	1,43	1,46
01-01-2012	1,35	1,34	1,33	1,32	1,35
01-02-2012	1,09	1,08	1,07	1,05	1,12
01-03-2012	1,16	1,19	1,20	1,23	1,18
01-04-2012	0,88	0,88	0,88	0,90	0,90
	1,00	1,00	1,00	1,00	1,00

Select index base:

**Meteo(1) (Global)**

Import/update online

Add from METEO object

Edit METEO index base

Add user index base

Edit user index base

Read from clipboard

Clone current index base

Delete current index base

Delete region from index base

Load index region map

Wind index values

☒ Absolute

☐ Percentages

Figure 20: Example Wind Index Database

### 11.1.10 Data – Time Shift

In the *time shift* tab (Figure 21) time shifts can be applied, either to individual or to all WTGs. Such a time shift might become necessary when you want to compare data with, for example, mesoscale data or production generated from a flow model. The user can add as many lines as necessary. The status column keeps track if the time shift has been performed. First by pressing *Load measured data* the time shift is applied.



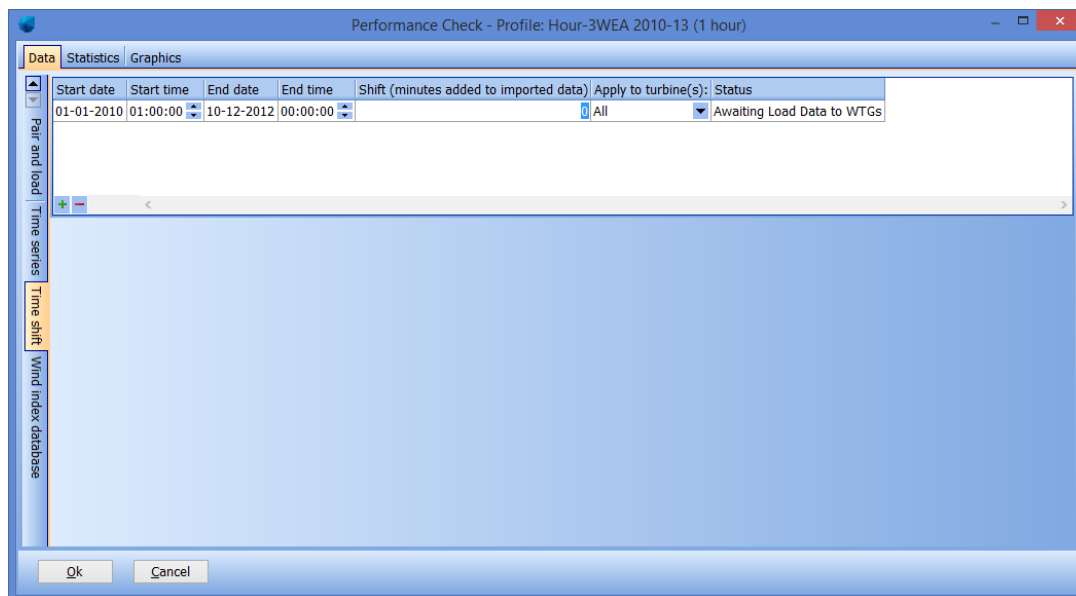


Figure 21: Use of time shift function



## 11.4 Setup Error Codes

The setup of error codes can be accessed from the *Pair-and-Load* tab. In Section 11.1.4 it is explained how SCADA data are loaded. Some SCADA data might include an error code in the 10-minute time series, but it might not include a description of what that error code means. Also, a category has to be added. This allows the allocation of lost production to different responsibilities. Other SCADA systems do not include error codes at all in the 10-minute time series. Consequently, the SCADA data has to be linked with a separate error log. Besides the error code number (e.g. 309) you might also want to add a description to that specific number and introduce sub-categories based on the description. The user is required to define and add these categories.

In this part of the post construction module, you learn how you can connect all the information so in the end you have production data, error code, description of error code and the category tied together in a 10-minute time series.

This process can be time intensive and might require a number of iterations. However, the resulting settings can be saved and can be used for other projects with the specific error code structure (\*.pfc file).

After loading 10-minute SCADA data you have three concepts to choose from (Figure 22) depending on which information is accessible. Depending on which option is chosen the user has to run through various steps to load error logs, connect error code numbers with descriptions, categorize the errors, convert them into 10-minutes (if they are provided as start/stop time), and connect with the *existing* WTG objects. You can also define whether any lost production related to a specific error code is compensated for or not.

- **Error codes in the time series:** Here the error codes are already part of the production data and are consequently already imported along with the production data. The next step is to *manage error codes* to assign descriptions and categories.
- **Separate error code file(s):** Error codes are available in a separate error log file with start/stop times. This file can be added to the production time series using an advanced interpreter.
- **No error codes available:** In case error codes are not available, it is possible to define user error codes based on the scatter plot of the power curve.

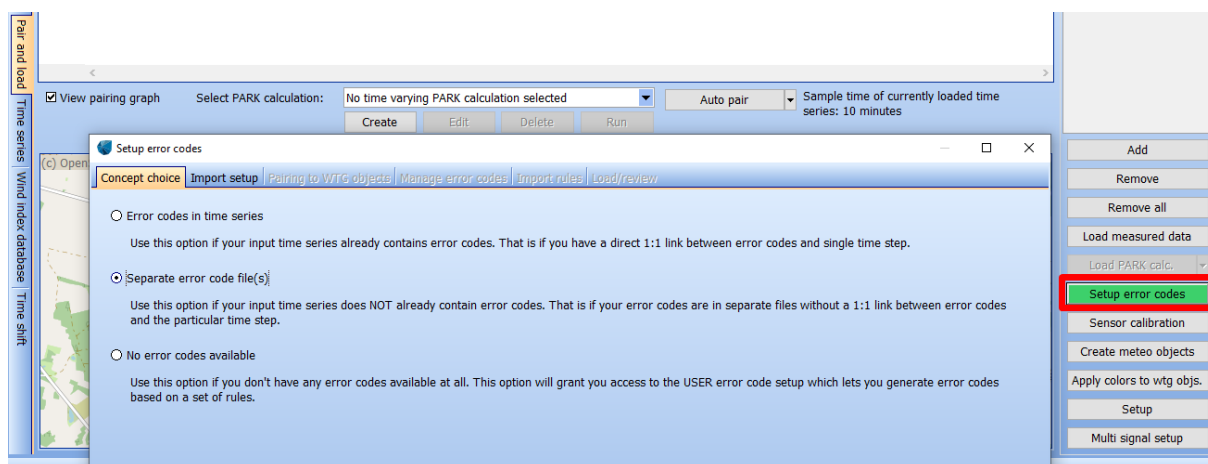


Figure 22: Setup error codes: Concept choice

### 11.1.11 Error Code in Time Series

Some SCADA systems includes an error code in the 10-minute time series, e.g. the manufacturer logs the first error code within each time stamp. In such a case the error code can be imported together with the production data (Figure 23). Information can be found in Section 11.1.6 Data – Import Setup.



Column	Header	First data	Type
22	WTG01_System Logs First Active Alarm No (21)	0	Error code ▼
23	WTG02_System Logs First Active Alarm No (22)	0	Error code ▼
24	WTG03_System Logs First Active Alarm No (23)	0	Error code ▼
25	WTG04_System Logs First Active Alarm No (24)	0	Error code ▼

Figure 23: Loading error codes in Data – Import Setup

It is important to note that only ONE error code column per WTG can be loaded. If there are more columns (e.g. a main and a secondary error code), these must be merged into ONE error code column before loading. This can be done, for example, by multiplying the first error code with 10000 and then adding to the other. This way a unique error code for each sub-category is created.

If an error code is a text string, it must be converted to a number (e.g. in Excel) before loading. Merging two error code numbers is possible in the importer based on a log file, see Section 11.6.

Even though the 10-minute time series includes the error code number, you might want to add a description to the error code. Additionally, it can be defined if losses due to curtailments are compensated for or not. Also, the loaded error codes have to be categorised such that the user is able to differentiate between compensated and non-compensated losses. Pressing the top button (*Error Codes in Time Series*) in Figure 22 brings you to *Manage Error Codes*.

## 11.5 Manage Error Codes

The *Load Error Code Translator* allows you to assign categories and descriptions to the already loaded error codes. It is also possible to define curtailments, which can add significant value to the analysis: If a turbine is curtailed, e.g. for flicker or bats, this is an upfront known loss included in the pre-construction AEP expectations. Therefore, this would often be given a special treatment, which is possible by marking this. An example for compensated curtailment could be grid curtailment, where the operator is reimbursed for shut-down due to grid limitations.

Setup is the same as if error logs were from files, see Section 11.8

### 11.1.12 Separate Error Code File(s)

In this section you learn how you can merge start/stop error logs from separate files with the 10-minute production time series.

Several manufacturers do not store the error codes as part of the 10-minute time series in the SCADA system. The error codes might be available in a separate error log files where the time stamp for start and stop of individual error codes and/or the duration of the error will be found. Often error codes are cascading, meaning that there are several error codes active within a 10-minute period.

The tool presented here gives the user different options for the interpretation of such data and the possibility to evaluate the consequences of the chosen interpretation.

The error log file has to be in ASCII format. It is advisable to align the naming of the WTG such that it is the same in the SCADA data and the error logs. The error code importer can load two columns of error signals (primary and secondary level). Consequently, it is not necessary to merge primary and secondary error codes before loading. Only numerical values can be imported, any error codes in form of text have to be converted to numbers.

The use of error logs in separate files requires several steps, starting with the *import*. After importing the error log(s) have to be *paired with the WTGs*. The next step involves *managing the error codes*. *Import rules* can be set and finally the resulting statistics can be *loaded and reviewed*.



## 11.6 Import Set-up

The error log files (in ASCII format) are selected. The format has to be defined, including the line which the header is in, the first line with error code and the delimiter (Figure 24).

Column	Header	First data	Type	Format	Converted
1	Unit	WTG04			
2	Serial no.	201180			
3	Code	309	Primary Error code		309
4	Description	Pause over RCS 1	Error description		
5	Detected (ms)	01-07-2013 10:21:55.000	Start date time	dd-mm-yyyy hh:mm:ss.ms	2013-07-01 10:21:55
6	Device acknowledged	01-07-2013 10:23:35.000			
7	Reset/Run	01-07-2013 10:23:35.000			
8	Duration	00.01.40	Duration	hh:mm:ss	100
9	Event type	Alarm log (A)			
10	Severity	201			
11	Remark	Pause over RCS 1			

Figure 24: Importing error log file(s)

The concept is similar to the error code translator loader described in Section 11.5. However, since error logs normally do not come as 10-minute time series, not only the error code and its description but also the start and stop time have to be defined.

The user has to set the correct format for date and time. If both stop time and duration is available, only one of these can be chosen. Some SCADA systems have neither a duration nor end time in the log. Instead they might have a time stamp with a text, e.g. “incoming” means that the event starts, “reset” or “phasing out” means the end of the event. In such a case the type has to be set to “start/stop text”. An extra box will appear (Figure 25) where you can specify the text which stands for activating the event (e.g. “incoming”) and which text deactivates the event (e.g. “reset” or “phasing out”). It is possible to specify several words, which have to be separated by semicolon. The setup is case sensitive.

Column	Header	First data	Type	Format	Converted
1	Timestamp [GMT+01:00]	16/11/2018 14:11:44:846	Start date time	dd/mm/yyyy hh:mm:ss.ms	2018-11-16 14:11:44
2	Status code	6300	Primary Error code		6300
3	Status code name	Yaw error	Error description		
4	Control program	BP 052	<Ignore>		
5	Status	Error	Error description, continued		
6	incoming/phasing out/Reset	Reset	Start/stop text		
7	Filter (service)	1			
8	Snapshot		<Ignore>		
9	Control system	Wind turbine control system			

Figure 25: Set-up for start/stop text

It is essential to assign the error codes to the specific WTGs. In our example the WTG-ID can be found in a column (Figure 26).

Figure 26: WTG-ID in error log

## 11.7 Pairing to WTG object

After the import of the file the error log has to be paired with the *existing* WTG object similar to Section 11.1.7. If the WTG-ID in the error log is identical with the name of the *existing* WTG the tool will automatically pair the object with the error log. In case the automatic pairing does not work properly, use the drop-down in upper right corner to match the ID in the import filter to the objects.

## 11.8 Manage Error Codes

Since error logs have various forms, it depends very much on the individual error log how much information is included. The aim is to have not only the error code but also the error description and category connected to the 10-minute time series.

In this tab the error codes are given both descriptions and categories. It can be specified if some of the curtailments are compensated, e.g. for grid curtailment. There are five options on how to connect error codes with their description (if required) and categories.

It is also possible to define curtailments, which can add significant value to the analysis: If a turbine is curtailed, e.g. for flicker or bats, this is an upfront known loss included in the AEP expectations. Therefore, this would often be given a special treatment, which is possible by marking this. An example for compensated curtailment could be grid curtailment, where the operator is reimbursed for shut-down due to grid limitations.

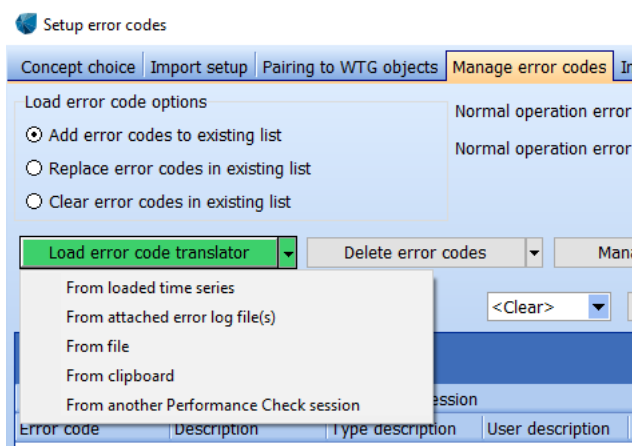


Figure 27: Five options to load error code translator

**Option 1: From loaded time series** – this transfers the error codes which you have loaded before (Section 11.1.6) into a table. The user has now the possibility to assign manually descriptions and categories to each error code. As modern turbines can have several thousands of error codes this can become a time-consuming process.

**Option 2: From attached error log file(s)** – in contrast to Option 1 here the error log file is used to connect the error code numbers with their descriptions. Often categories have to be assigned manually.

**Option 3: From file** – From previous experience you might have built up a directory which connects error codes with their descriptions for a specific SCADA system. The main advantage compared to Option 2 is that you can benefit from your own error code library, which can also include categories.

The user has to specify how the ASCII file is structured (Figure 28), e.g. in which line (row) the header is and what the delimiter is. Via a drop-down menu the user can define the type of data. Normally just the error code and description are needed.

Sometimes files containing error codes and their descriptions are part of the contract with OEM. The contractual agreement might refer to the error codes the manufacturer is responsible for and thereby is included in the calculated availability guarantees.

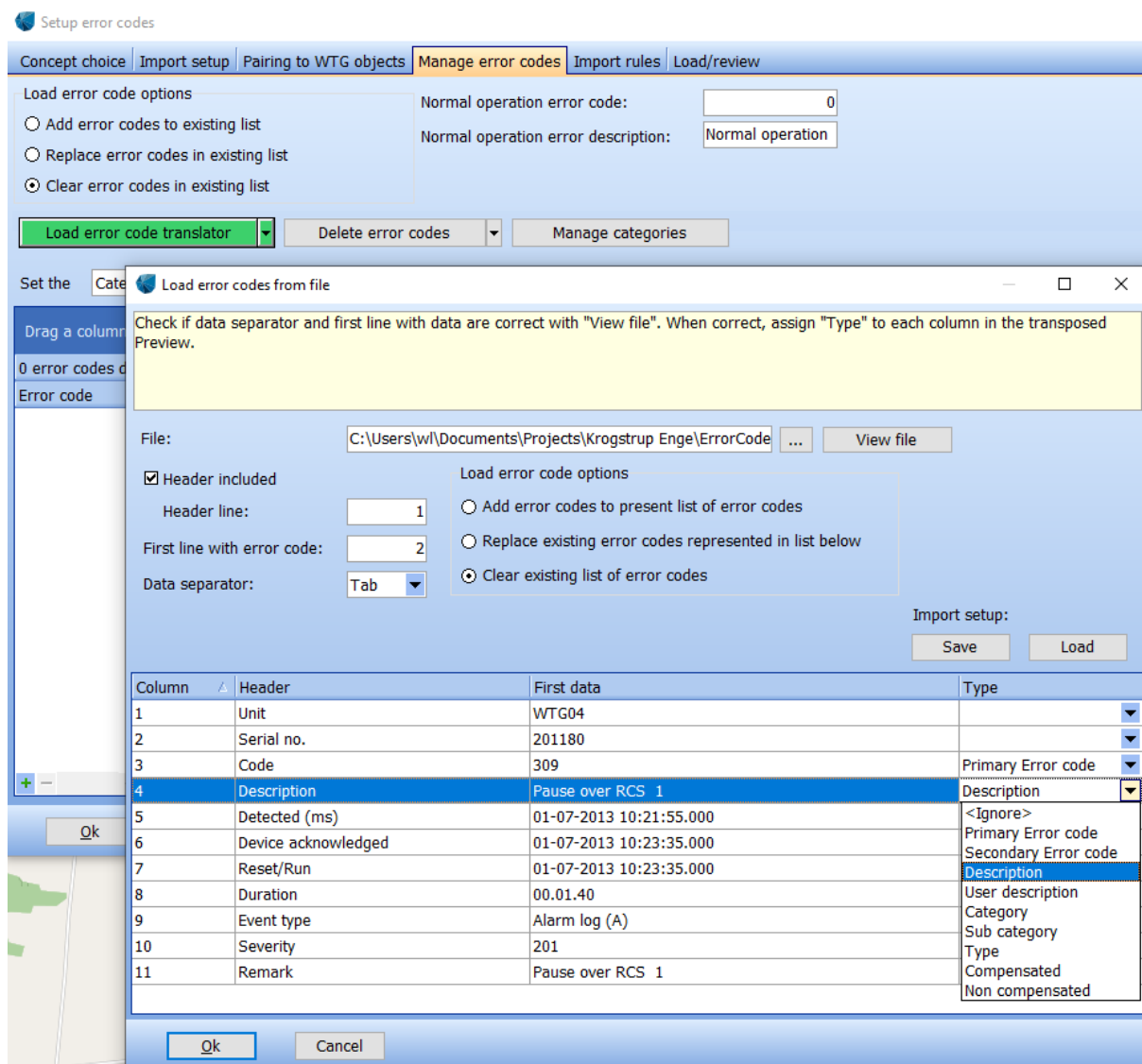


Figure 28: Define types in error code file

As a special feature it is possible to define both primary and secondary error codes (Figure 29). In such a case an extra item appears: By defining a multiplying factor for the primary (main) or secondary error code it is possible to create a unique error code. It is recommended that you assign a multiplier which exceeds the highest value of the secondary error code to ensure unique codes. In our example the primary error code 309 will be multiplied with 10000 resulting in 3090000 and 201 from the secondary error code will be added. The new, unique error code is 3090201.



Load error codes from file

Check if data separator and first line with data are correct with "View file". When correct, assign "Type" to each column in the transposed Preview.

File: C:\Users\wl\Documents\Projects\Krogstrup Enge\ErrorCode ... View file

☒ Header included

Header line: 1

First line with error code: 2

Data separator: Tab

Load error code options

☐ Add error codes to present list of error codes

☐ Replace existing error codes represented in list below

☒ Clear existing list of error codes

Multiplying factor: 1,000

Main error code: 1,000

Secondary error code: 0

Import setup: Save Load

Column	Header	First data	Type
1	Unit	WTG04	
2	Serial no.	201180	
3	Code	309	Primary Error code
4	Description	Pause over RCS 1	Description
5	Detected (ms)	01-07-2013 10:21:55.000	
6	Device acknowledged	01-07-2013 10:23:35.000	
7	Reset/Run	01-07-2013 10:23:35.000	
8	Duration	00.01.40	
9	Event type	Alarm log (A)	
10	Additional Status	201	Secondary Error code
11	Remark	Pause over RCS 1	

Ok Cancel

Figure 29: Secondary error codes

**Option 4: From Clipboard** is like above Option 3 but having the data in the clipboard after e.g. copying from Excel.

**Option 5: From another Performance Check session** – This option is only available when you create a new *Performance Check* session within the same windPRO project. To get access to a list from another project, use the Export – Import option.

In general (independent of the chosen option) multi-editing is possible by marking a group of error codes (Figure 30). The list is auto sorted by the most frequent occurring error codes.

Setup error codes

Concept choice | Import setup | Pairing to WTG objects | **Manage error codes** | Import rules | Load/review

Load error code options

☐ Add error codes to existing list

☐ Replace error codes in existing list

☒ Clear error codes in existing list

Normal operation error code:

Normal operation error description:

One or more error codes with no category found. Please set a category for all error codes

Load error code translator | Delete error codes | Manage categories

Display/include: Error code;Description

Set the  of all selected error codes to **2.**  **Ok** **3.**

Import settings | Export settings

Drag a column header here to group by that column

176 error codes defined in current Performance Check session

Error code	Description	Type description	User description	Category	Sub category	Type	Frequency	Count	Compensated	Non compensated
0				Full performa		Alarm	97.0	156,435	<input type="checkbox"/>	<input type="checkbox"/>
309	Pause over RCS					Alarm	1.2	1,930	<input type="checkbox"/>	<input type="checkbox"/>
220				Partial perfor		Alarm	0.6	893	<input type="checkbox"/>	<input type="checkbox"/>
900	Pause pressed or			Partial perfor		Alarm	0.3	527	<input type="checkbox"/>	<input type="checkbox"/>
3419	Shadow Detected					Alarm	0.3	451	<input type="checkbox"/>	<input type="checkbox"/>
3475	SafetySys Conver					Alarm	0.1	198	<input type="checkbox"/>	<input type="checkbox"/>

Figure 30: Multi-editing of error code categories

A problem can arise if a unique error code has more meanings. An example is shown in Table 2. In our example error code 309 appear in more variants.





308	System log reestablished	Log	Normal operation
309	Pause over RCS __	Alarm	Manufacturer
309	Pause over RCS __	Alarm	Environmental
309	Pause over RCS __	Alarm	Owner
309	Pause over RCS __	Alarm	Utility
309	Pause over RCS __	Alarm	Normal operation
309	Pause over RCS __	Alarm	Owner
309	Pause over RCS __	Alarm	Owner
309	Pause over RCS __	Alarm	Utility
309	Pause over RCS __	Alarm	Owner
309	Pause over RCS __	Alarm	Manufacturer
309	Pause over RCS __	Alarm	Environmental
310	Run over RCS __	Log	Normal operation

Table 2: Example error code with various meanings

If windPRO identifies an error code with varying descriptions, a green menu “Separate error codes” bar will appear. A pop-up window lists all observed error codes, which have varying descriptions. For each description a new error code is suggested. Update error code list all events under error code 79000 will be split into subevents with a new, unique error code and a specific description.

Setup error codes

Concept choice | Import setup | Pairing to WTG objects | **Manage error codes** | Import rules | Load/review

Load error code options

☐ Add error codes to existing list

☐ Replace error codes in existing list

☒ Clear error codes in existing list

Normal operation error code:

Normal operation error description:

Load error code translator | Delete error codes | Manage categories | **Separate error codes**

Set the  of all selected error codes to

Drag a column header here to group by that column

209 error codes defined

Error code | Description

0 | Normal operation

100 |

144 |

202 |

220 |

296 |

309 |

356 |

604 |

900 |

2863 |

2871 |

2908 |

2956 |

Ok

Setup error codes

Error codes with varying descriptions have been detected in the error code log. Each variant can be split into separate error codes.

Select all | Deselect all | Expand all | Collapse all | **Update error code list**

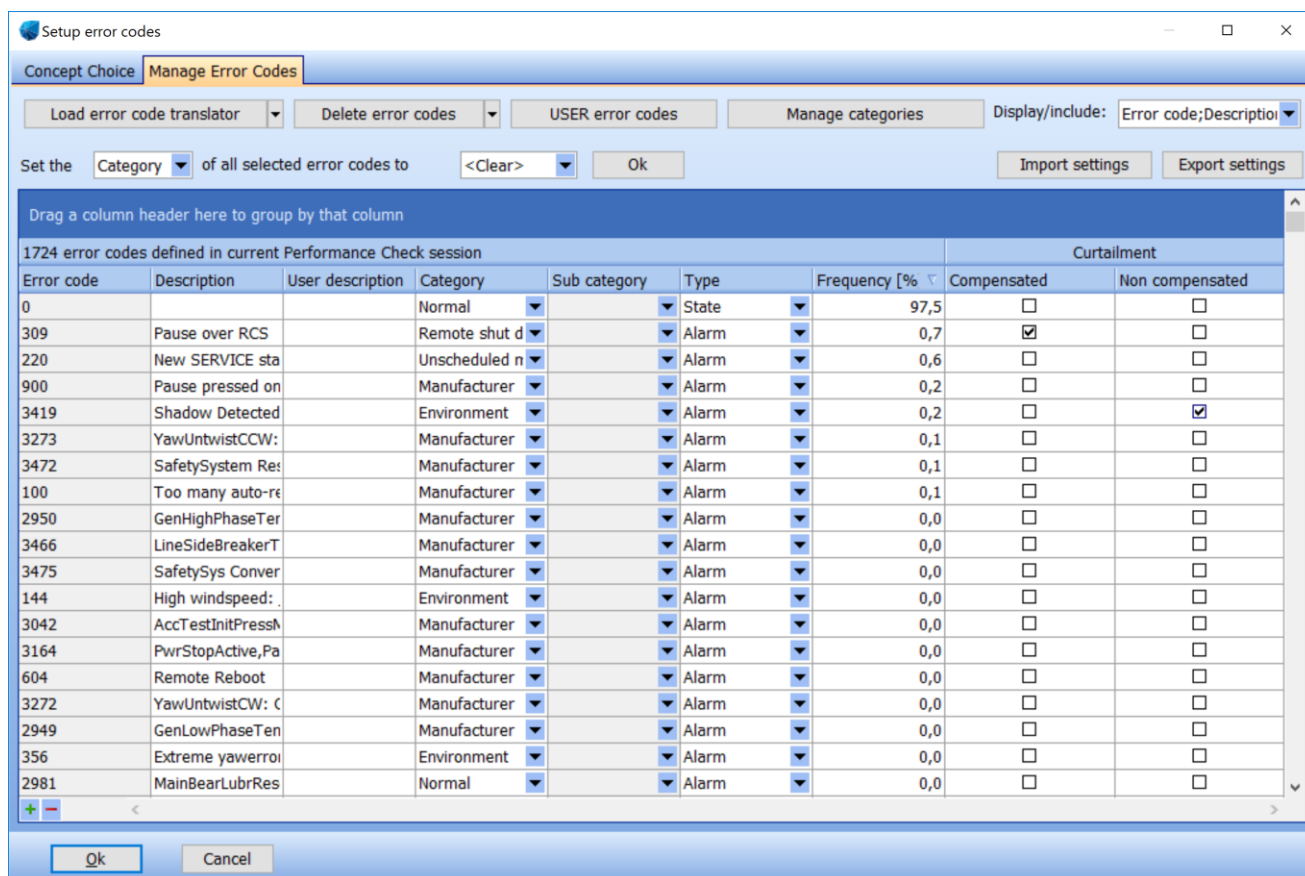
Enabled	Original error code	Description	Suggested new error code
<input checked="" type="checkbox"/>	79000		
<input type="checkbox"/>		Max. Yaw error: 151.7°	790000000000
<input type="checkbox"/>		Max. Yaw error: 315.1°	790000000001
<input type="checkbox"/>		Max. Yaw error: 29.5°	790000000002
<input type="checkbox"/>		Max. Yaw error: 251.5°	790000000003
<input type="checkbox"/>		Max. Yaw error: 138.5°	790000000004
<input type="checkbox"/>		Max. Yaw error: 200.2°	790000000005
<input type="checkbox"/>		Max. Yaw error: 217.9°	790000000006
<input type="checkbox"/>		Max. Yaw error: 211.9°	790000000007
<input type="checkbox"/>		Max. Yaw error: 192.6°	790000000008
<input type="checkbox"/>		Max. Yaw error: 223.4°	790000000009

81000

82000

Figure 31: Separate error codes with multiple meanings

After setting up error codes with description and category, the list could look like Figure 32. The list is sorted by the most frequent occurring error codes. Some errors are curtailments, of which some are compensated for. In our example “Remote shut down” is a grid curtailment, compensated by the utility.



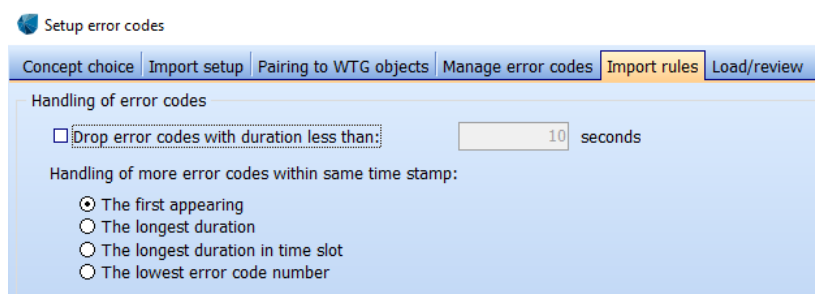
Error code	Description	User description	Category	Sub category	Type	Frequency [%]	Compensated	Non compensated
0			Normal		State	97,5	<input type="checkbox"/>	<input type="checkbox"/>
309	Pause over RCS		Remote shut d		Alarm	0,7	<input checked="" type="checkbox"/>	<input type="checkbox"/>
220	New SERVICE sta		Unscheduled n		Alarm	0,6	<input type="checkbox"/>	<input type="checkbox"/>
900	Pause pressed on		Manufacturer		Alarm	0,2	<input type="checkbox"/>	<input type="checkbox"/>
3419	Shadow Detected		Environment		Alarm	0,2	<input type="checkbox"/>	<input checked="" type="checkbox"/>
3273	YawUntwistCCW:		Manufacturer		Alarm	0,1	<input type="checkbox"/>	<input type="checkbox"/>
3472	SafetySystem Re:		Manufacturer		Alarm	0,1	<input type="checkbox"/>	<input type="checkbox"/>
100	Too many auto-re		Manufacturer		Alarm	0,1	<input type="checkbox"/>	<input type="checkbox"/>
2950	GenHighPhaseTer		Manufacturer		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>
3466	LineSideBreakerT		Manufacturer		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>
3475	SafetySys Conver		Manufacturer		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>
144	High windspeed:		Environment		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>
3042	AccTestInitPressN		Manufacturer		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>
3164	PwrStopActive,Pa		Manufacturer		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>
604	Remote Reboot		Manufacturer		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>
3272	YawUntwistCW: (C		Manufacturer		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>
2949	GenLowPhaseTen		Manufacturer		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>
356	Extreme yawerroi		Environment		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>
2981	MainBearLubrRes		Normal		Alarm	0,0	<input type="checkbox"/>	<input type="checkbox"/>

Figure 32: Example of categorized error codes

## 11.9 Import Rules

The tab *Import rules* give different options for handling the import. In most cases it will be ok to choose the default option.

In some cases, the control system uses an error code called “alarm chain activated” independent of the reason. Consequently, all errors will have the same code, which of course will prohibit any meaningful analysis. Therefore, more choices are available.



Setup error codes

Concept choice | Import setup | Pairing to WTG objects | Manage error codes | **Import rules** | Load/review

Handling of error codes

☐ Drop error codes with duration less than: 10 seconds

Handling of more error codes within same time stamp:

- ☒ The first appearing
- ☐ The longest duration
- ☐ The longest duration in time slot
- ☐ The lowest error code number

Figure 33: Import rules

## 11.10 Load/Review

Here the error codes are loaded from the error log file(s) into the *existing* WTG objects by pressing the “Load” button. There are two tabs on the left-hand side: *WTG time series* and *Error code frequency*.



In **WTG time series** the resulting 10-minute time series is displayed (Figure 34). Please note that only 10-minute periods without any error will fall in the category “Normal operation”. If within the 10-minute period there is one milli-second subject to an error event, the whole 10-minute period will be marked with that specific error code.

Clicking on individual 10-minute time stamps with an error code allows to see in the bottom of the window all error codes that were active in that time stamp. It is possible to manually select (button on the right) another error code within the 10-minute time stamp other than the one selected by the import rules setup.

Figure 34: 10-minute time series from error log

On the tab **WTG time series** the user has again access to *user error codes* (see Section 11.1.13) as there might be time stamps remaining, where the WTG clearly does not operate optimally but has no error code. Through the use of *user error codes*, it is possible to assign manually an error to these events.

On the second tab to the left **Error Code Frequency** the main statistics are shown for each error code together with the description: MTTR (mean time to repair), the period count (how many time steps has this event been logged) and frequency (how often has the event been logged).

A plausibility check can be performed by pressing the “Preview” button. The specific error code can be reviewed. In Figure 35 events for yaw untwist are shown. Luckily the control system untwists the WTG during low wind speeds.

As a second example, the events which belong to error code 309 are shown in Figure 36. Not all events are below the power curve as one might expect, since the error codes description is “remote shut-down”. However, as explained earlier, a 10-minute time stamp is marked with an error code even if the error has been active for a millisecond. This might have been the case in this example, where the shut-down has only been active for a very small part of the time stamp.

However, it could also be the case that the assumptions as to which period the SCADA data refers to were wrong. In the initial data import of the SCADA data the user had to choose if the time-stamp



refers to beginning or the end of the 10-minute period (see Section 11.1.6). If the wrong choice has been made, the 10-minute error table and 10-minute production table do not refer to the same time but are shifted by 10 minutes. In such a case the user has to exit the *error code set-up* and go back to the start. The *data import setup* has to be revisited (see Section 11.1.6), the time stamp setting has to be changed, and *pair& load* has to be repeated. The *Setup Error Codes* has to be started again. After reloading the error logs files and converting them to 10-minutes the stop events should now concur with zero production. It can consequently be assumed that the production and error logs are now synchronized.

And finally – in case the user has merged error codes – the merged code can be checked for plausibility.

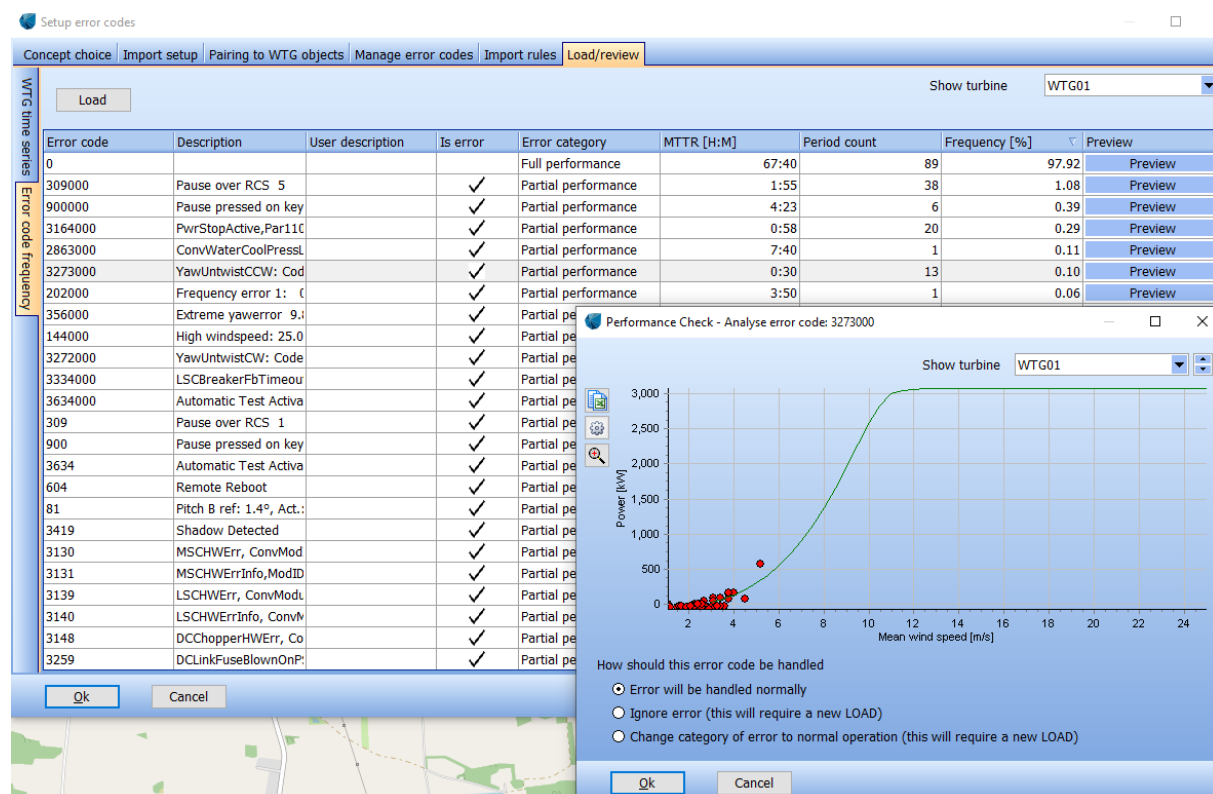


Figure 35: Error code statistics and plausibility check

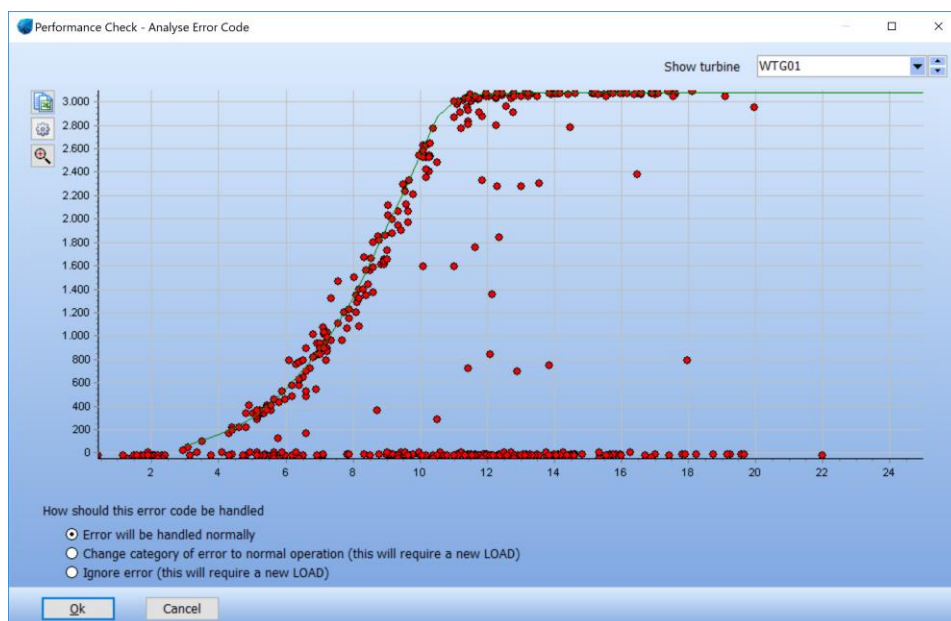


Figure 36: Error code 309 – remote shut-down: Likely wrong import setting for time stamp.

### 11.1.13 No Error Code Available

This feature can be used when error codes have not been provided. It can also be of use, if the error codes have been provided, but not all events are assigned an error code. E.g. the WTG de-rates, but the operational status shows normal operation. Please note that user error codes will NOT overwrite imported error codes. Here is demonstrated how it is used where no error codes are available, but it will work similarly if error codes are already loaded.

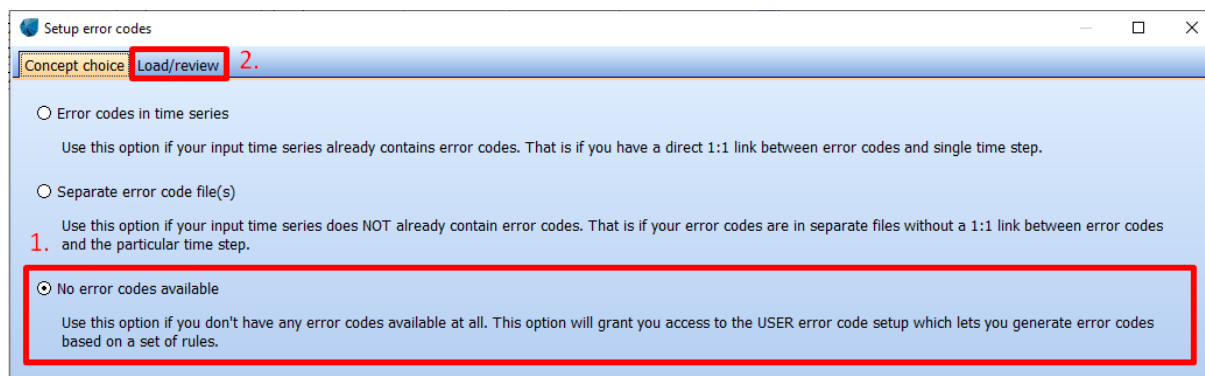


Figure 37: No error codes available

User error codes can be defined in the *Load/review* tab: The button “User error codes” brings you to the following form (Figure 38).

Figure 38: Form for defining user error codes

Four different types of user-defined error codes are setup. Please note that you can specify from which WTG you will see the scatterplot. The user-defined error codes however will apply to all WTGs.

**Type 1** allows to identify events with stops without error code: A combination of wind speed and power is used to find these events. The algorithm is based on that the when wind speed is bigger than x m/s (default 5 m/s) and the power is smaller than x% of rated power. You can specify a new error code number for these events. The *Preview* button brings you to the scatter plot and shows the impact of the chosen settings (Figure 39). In the scatter plot the filtered events are shown in a colour. The new, user defined error code becomes effective after you have closed the preview and pressed *Run*. The new error code has now been added to the 10-minute production time series.



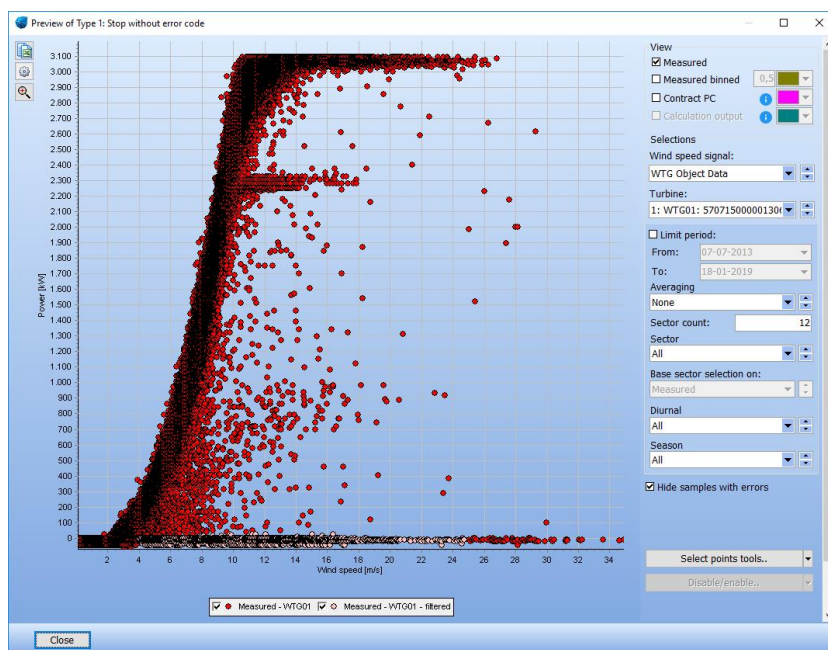


Figure 39: Preview: Stop without error code

**Type 2** addresses power curtailments and outliers without error codes. Two sets of parametrisations are used, one for the steep part of the power curve below rated power and one for the flat part of the power curve above rated wind speed.

For the *steep part* of the power curve events below a fictive, shifted power curve are filtered. The user can specify if the measured, binned SCADA power curve or the contracted power curve from the WTG catalogue is used, which is assigned to the *existing* WTG object. The user can also specify how much the power curve is shifted to the right. Obviously the further the power curve is shifted to the right, the less aggressively it is filtered. Please note that the filtering affects the measured, binned power curve. Consequently, running the same filter once more will pinpoint a few, additional time stamps.

For the *flat part* of the power curve events with x% of the rated power can be filtered.

It is possible to assign several user-defined error codes. E.g. first you might want to isolate the rating at approximately 2300kW. Once you have found appropriate settings you can run the tool, which will add the error code to the 10-minute time series. You can then re-visit the scatter plot and define new, different error codes.

In the example in Figure 40 the filtering might have been too aggressive as possibly too many data are taken out especially in the knee area. In such a case it is possible to go back and adjust the settings, e.g. a bigger shift of the power curve.

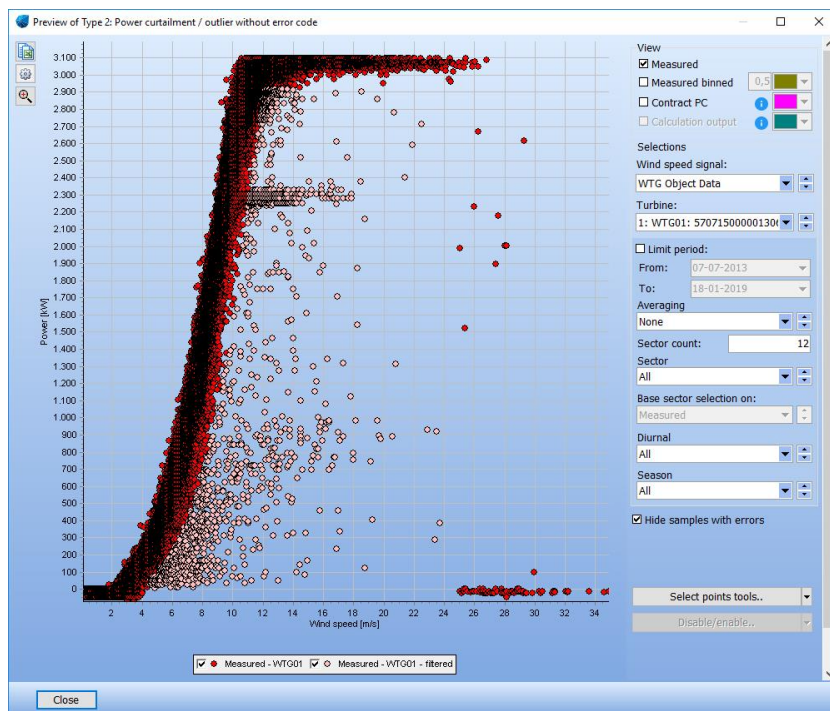


Figure 40: Preview: Filtering for curtailments and non-optimal performance

**Type 3** is optional to establish an error code for operation above cut-out wind speed. The purpose of this option is mainly to avoid these samples disturbing the comparison between measured and modelled production from a time-varying PARK calculation.

**Type 4** can be used to catch a specific operating mode which has no error code, by selecting a box parametrised by a wind speed and a power range. Pressing preview allows you to drag & drop a box to mark an area for filter.

The history of the user-defined error codes can be re-visited. The user can see how many samples have been affected by which setting. The user-defined error codes can be deleted again.

As mentioned above the user-definition of error codes can also be used even though you have the error code in the 10-minute SCADA data. You might want to use this option e.g. if the WTG de-rates, but this de-rating is treated as normal operation in the SCADA system. In the bottom of the form (Figure 38) you have to confirm if you want to replace the existing error code with the user-defined error code.

With the user-error codes established, a rough loss evaluation for each WTG can now be performed (Figure 41). The WTG can be changed in the top right corner.

The statistics include the period count (how many time steps has this event been logged), the frequency (how often has the event been logged) and the MTTR (mean time to repair). The MTTR is mostly relevant for specific events, like gearbox failure.



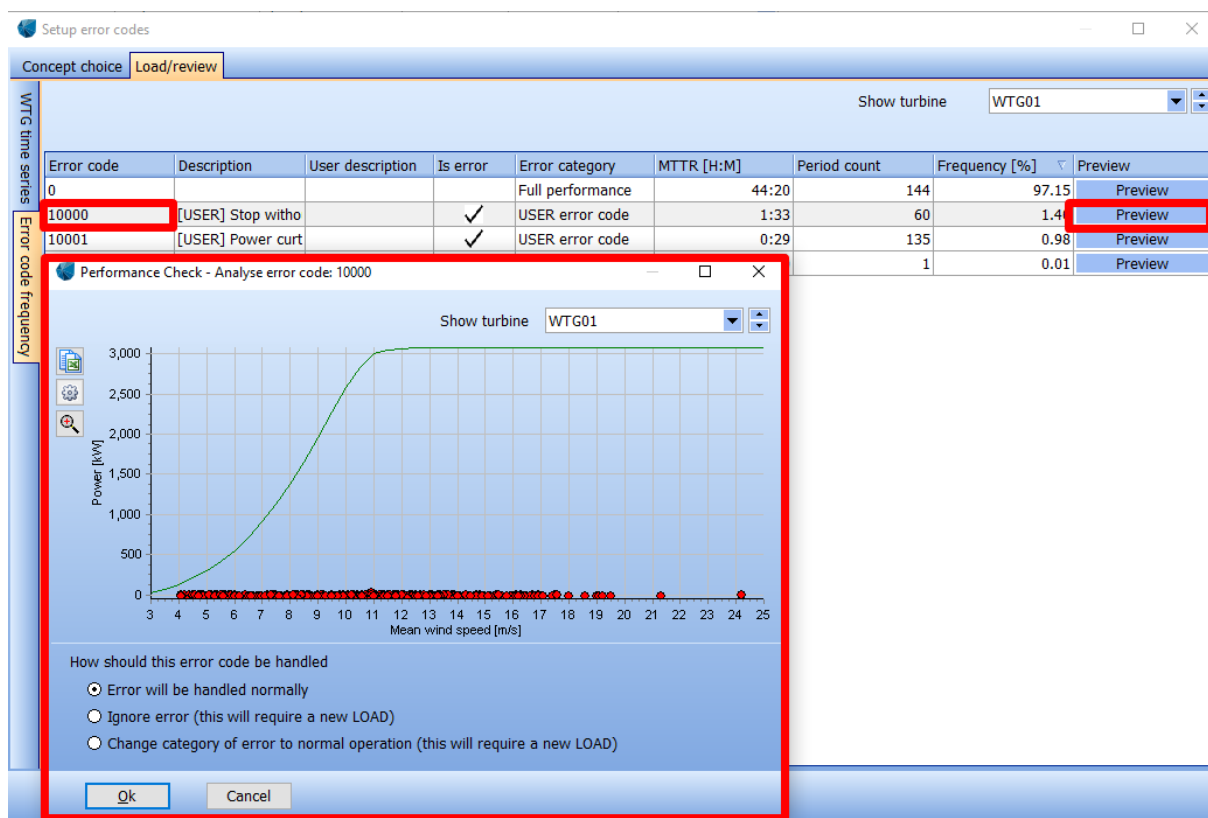


Figure 41: Loss evaluation of user-defined error codes: example user code 10000

As a check, it is possible to see the events which have been assigned to a user error code by pressing the preview button.

The user can choose to ignore the error code. Alternatively, the error can be treated as normal operation. Both options require loading the data again (see Section 11.1.7).



## 11.11 Sensor Calibration

Since the methodology behind the post construction analysis assumes consistent nacelle wind speeds, the wind speed signal should be checked for any inconsistencies. Inconsistencies could occur due to anemometer exchange or changes of the scaling factor of the wind speed signal in the turbine controller and should be corrected before undertaking loss evaluations.

The *Sensor Calibration* can be found under the tab *Data*.

In the upcoming window (Figure 42) the daily average wind speed signal of a single “Selected WTG” is compared to a daily average reference wind speed signal, obtained from the average of all available signals for each day of the chosen reference turbines and or other measurement. The reference wind speed signal can come from another single WTG or from a reference wind speed signal (e.g. mesoscale data). The upper graph shows the two wind speed signals to be compared. The lower graph displays the selected time series minus the reference time series with a set averaging time. The averaging time can be annual, monthly or daily.

Please note, that by default only data is shown where the WTG operates optimally by switching filters on. This ensures that the comparison is not affected by a changing behaviour of the nacelle anemometer when the WTG is switched off, de-rated or similar.

The analysis is supported by a heat map (Figure 43) and the scatter plot of power curve.

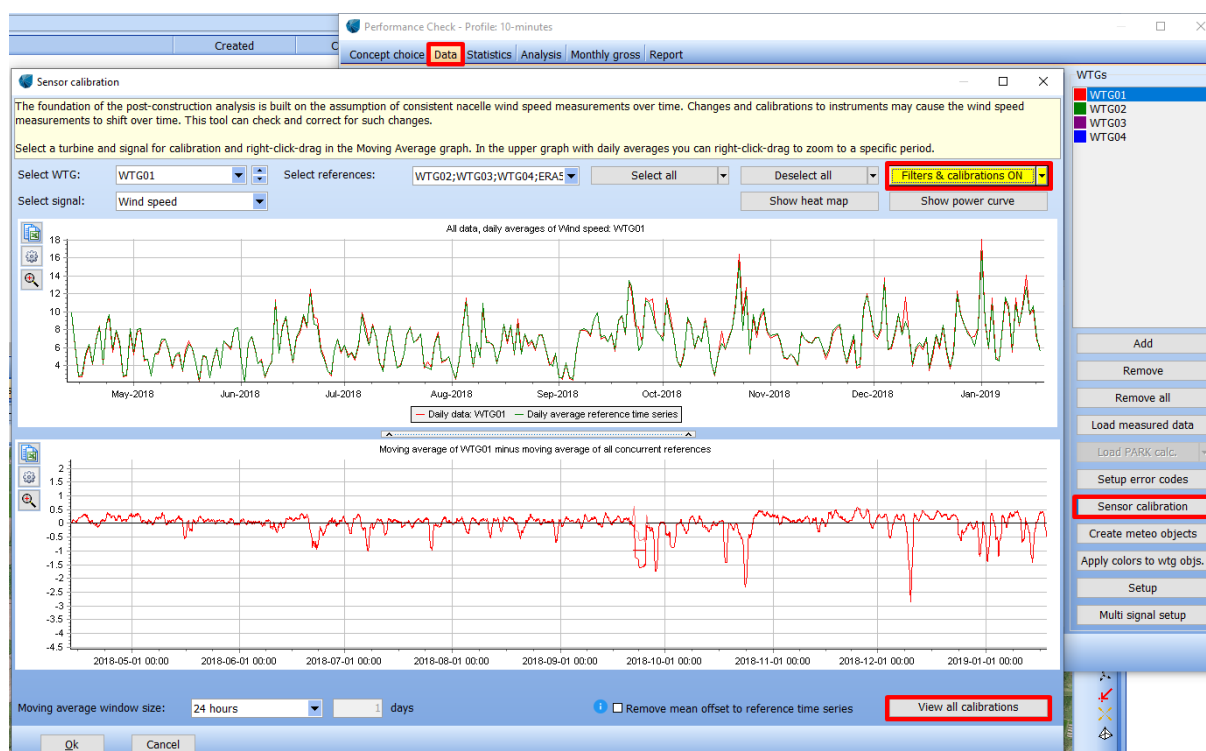


Figure 42: Sensor calibration

The heat map indicates that there is an offset between the average of all chosen reference data sets and the turbine under investigation. It is strongly recommended to also visit the scatter plot of the SCADA power curve for a plausibility check before concluding which signal is trustworthy and which one is not.

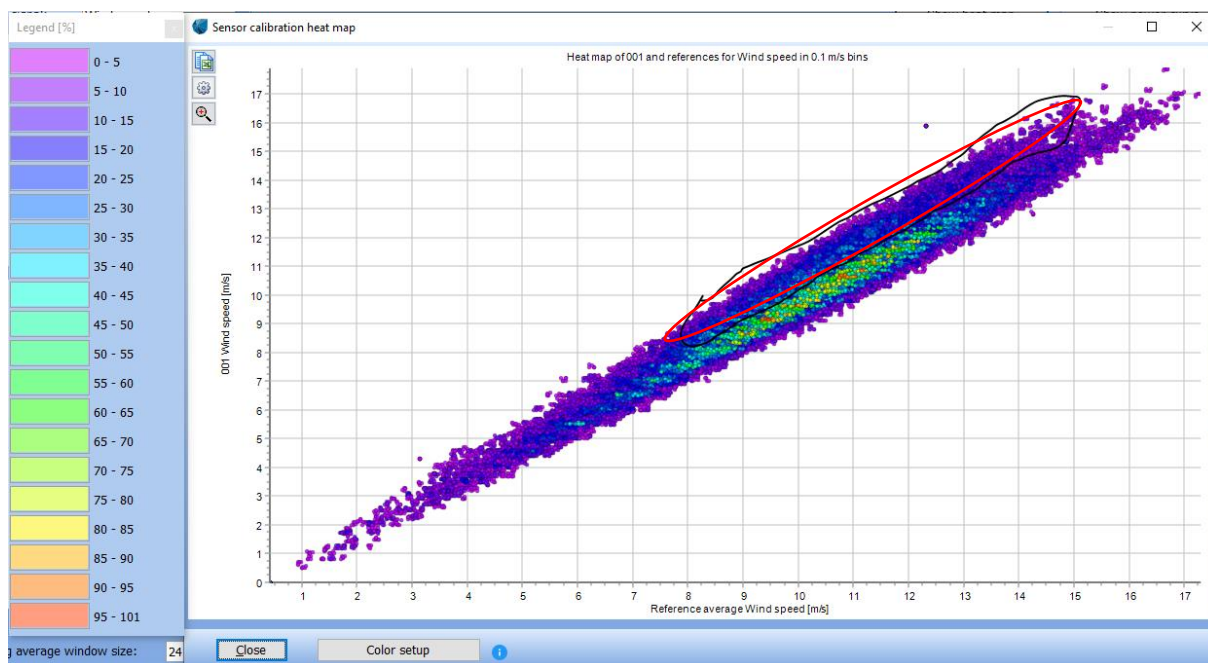


Figure 43: Heat map of reference versus individual wind speed

In this case a persistent offset is found in the data, the affected time period can be marked by pressing the right mouse button and drag to the end period. Let go of mouse right button and a pop-up window informs about the difference in wind speed between the two signals during the marked period (Figure 44). The user can now decide if the offset should be applied or not. In the shown example the wind speed difference is as large as 1.09m/s.



Figure 44: Example of inconsistent nacelle wind speed

Under the condition that the filters are switched on, the graph will update and display the original as well as the resulting corrected signal. It is recommended to plausibility-check the impact on the power curve. E.g. if you chose to compare two individual WTGs rather than using an average as reference, using the heat map and power curve will help which of the two signals is the correct one.

In the bottom right of the window all applied calibrations can be revisited and deleted again.



## 11.12 Create Time-Varying Park Calculation

In order to calculate the lost production a *PARK* calculation has to be performed (Figure 45). It calculates the potential production based on the historic power curves of each WTG and the nacelle wind speed. The nacelle wind speeds of each WTG should have been checked for consistency by comparison with a reference wind speed (see Section 11.11). The basic time-varying *PARK* calculation does not require a detailed flow model set-up. Terrain and roughness information are not required.

Prior to starting the *PARK* calculation, the user has the possibility to perform a more detailed plausibility check of the wind speed signal (Figure 46). While the *Sensor Calibration* addresses consistency in time, the *Wind Speed Correction* allows the user to check consistency for different operational conditions: It is known that the flow around the nacelle of the WTG is different during stand-still than during operation. Consequently, the wind speed measured on top of the nacelle might not be comparable for these two conditions. Since the nacelle wind speed is used for calculating the potential energy, a correction of the wind speed signal during non-optimal performance might be required. It is possible to enter a correction for all WTGs. Alternatively, it is possible to determine a correction factor for each individual WTG.

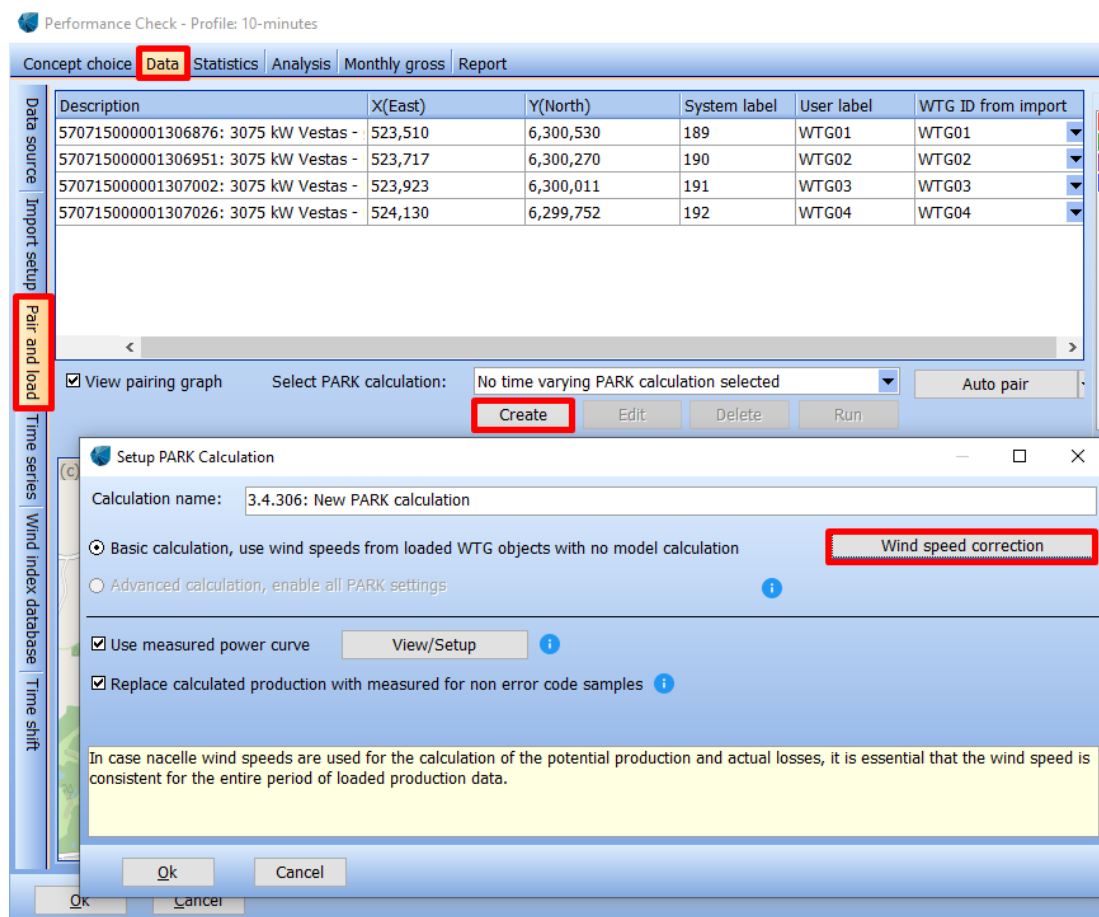


Figure 45: Create time-varying PARK calculation

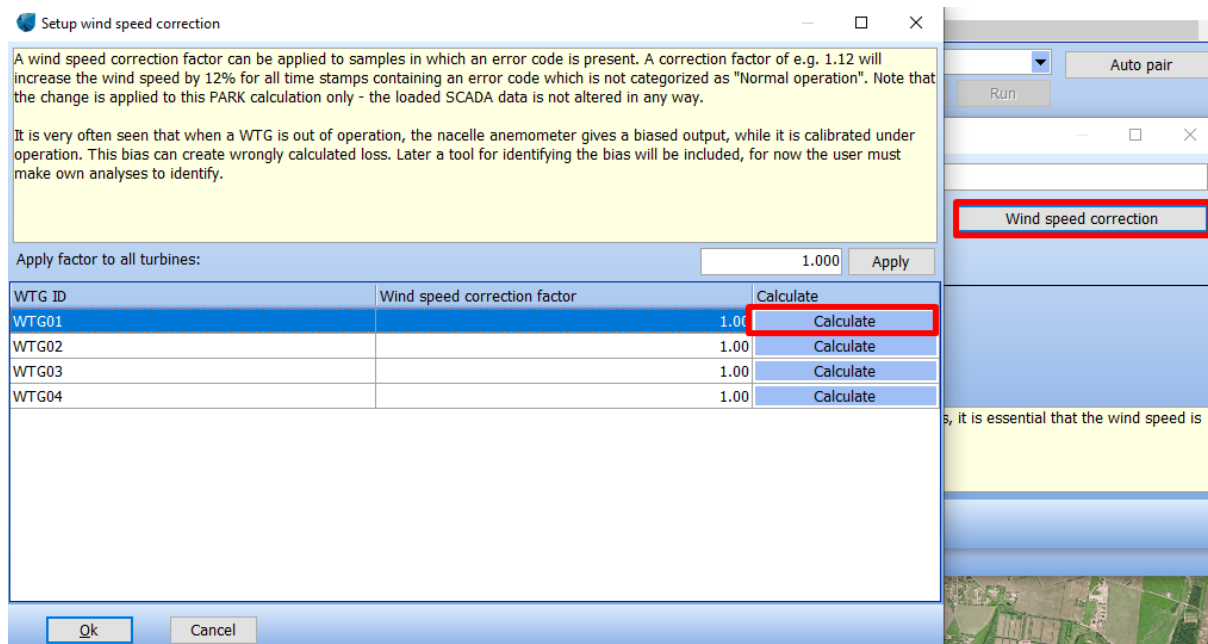


Figure 46: Wind speed correction

The function *Wind Speed Correction* helps the user to make a qualified decision and allows the correction of the wind speed. For each WTG the nacelle wind speed is plotted against a reference WTG of the user's choice (right graph - Figure 47). Typically, two neighbouring WTGs are compared. The trend line for concurrent time steps with both WTGs operating optimally is shown (red scatter with black trend line). Additionally, another trend line shows the relationship of the nacelle wind speeds for time steps, where the WTG under investigation is operating non-optimally, but the reference WTG is fully operational (pink scatter with pink trend line). As a plausibility check the scatter plot of the WTG under investigation is shown on the left-hand side. In our example all pink dots indeed represent non-optimal operation or stand-still. The difference of the slope between the two trend lines is suggested as a correction factor for the nacelle wind speed and will be applied for each time step with non-optimal performance.

The user can define specific directions in order to ensure that the two WTGs that are compared are not wake-affected.

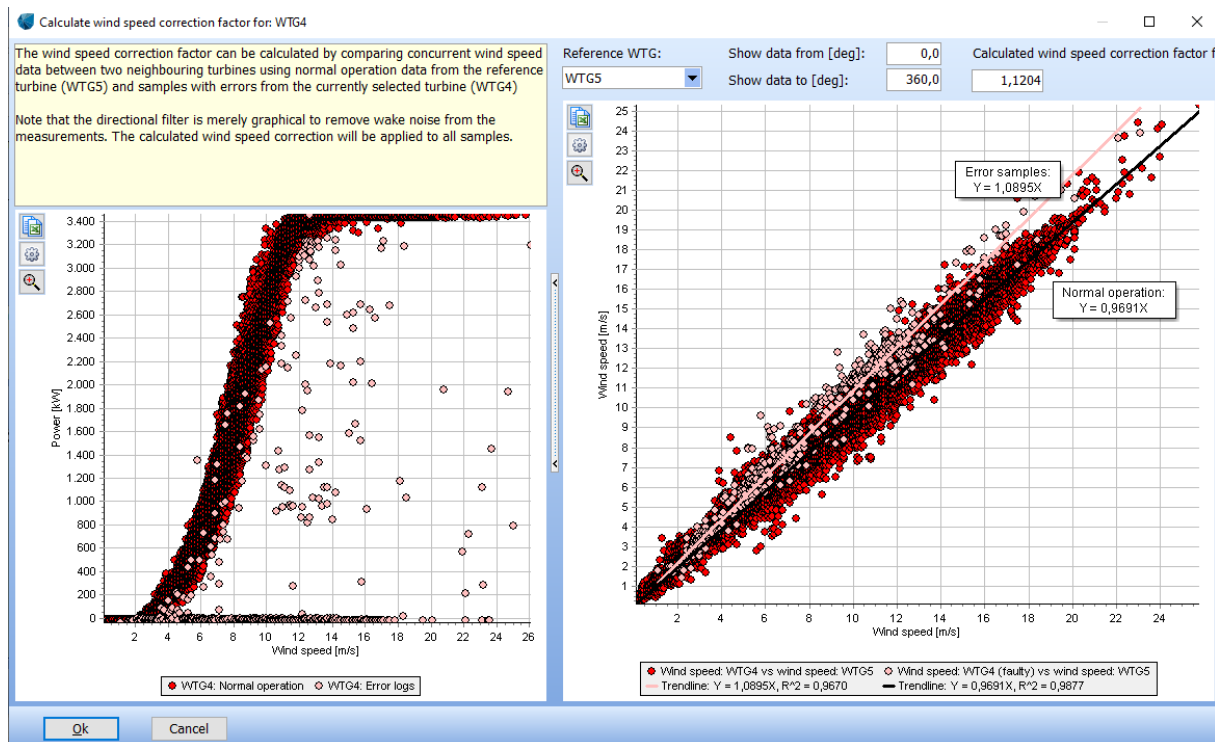


Figure 47: Evaluation of impact of operational condition on the nacelle wind speed

After correction of the nacelle wind speed the user has to pay attention that the measured power curve is selected. If the filters are switched on (which they are by default), all time steps with non-optimal performance are disabled. The remaining data forms the historic power curve. The button

**View/Setup** displays the historic power curve (Figure 48). By pressing the right mouse button, it is possible to copy the data from the historic power curve from the table.

The binned measured power curve as well as the contracted power curve from the *existing* WTG object can be displayed. It is also possible to use alternative set-ups for displaying the data (Figure 49). The user can either display the scatter curve of a different WTG of the wind farm, chose another wind speed signal or limit the period.

Finally, the user has to ensure that the second tick is enabled to “Replace calculated production with measured for non-error code samples”.

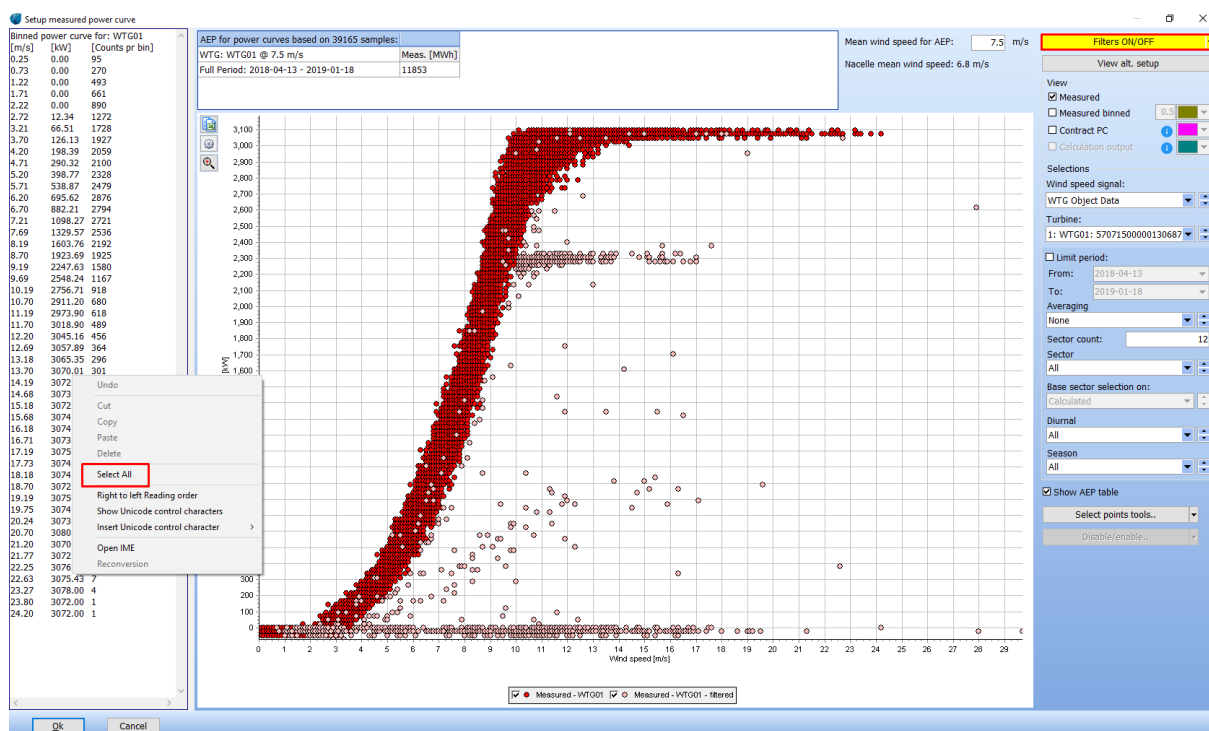


Figure 48: Historic power curve

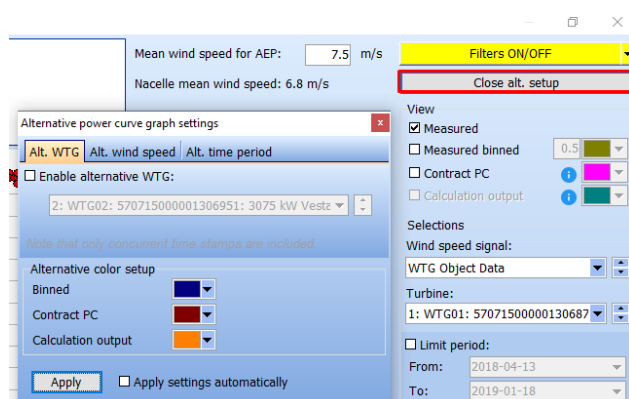


Figure 49: Alternative set-up for historic power curve display



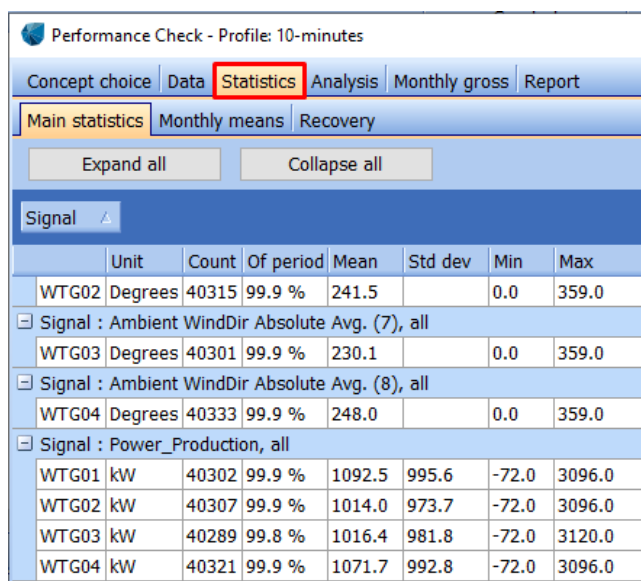
## 11.13 Statistics

After having loaded the 10-minute time series, having combined it with error codes, description of error codes and their categorisation, the recovery rate and some basic statistics can be found in the *Statistics* tab.

For each signal for each WTG the count, recovery rate, mean, standard deviation, minimum and maximum are shown (Figure 50).

For each signal for each WTG the monthly means can be visited (Figure 51).

Finally, the recovery rate per day can be visited for each WTG (Figure 52). It is possible to mark specific samples in the table and change the status from disabled to enabled or vice versa.



	Unit	Count	Of period	Mean	Std dev	Min	Max
WTG02	Degrees	40315	99.9 %	241.5		0.0	359.0
Signal : Ambient WindDir Absolute Avg. (7), all							
WTG03	Degrees	40301	99.9 %	230.1		0.0	359.0
Signal : Ambient WindDir Absolute Avg. (8), all							
WTG04	Degrees	40333	99.9 %	248.0		0.0	359.0
Signal : Power_Production, all							
WTG01	kW	40302	99.9 %	1092.5	995.6	-72.0	3096.0
WTG02	kW	40307	99.9 %	1014.0	973.7	-72.0	3096.0
WTG03	kW	40289	99.8 %	1016.4	981.8	-72.0	3120.0
WTG04	kW	40321	99.9 %	1071.7	992.8	-72.0	3096.0

Figure 50: Main statistics



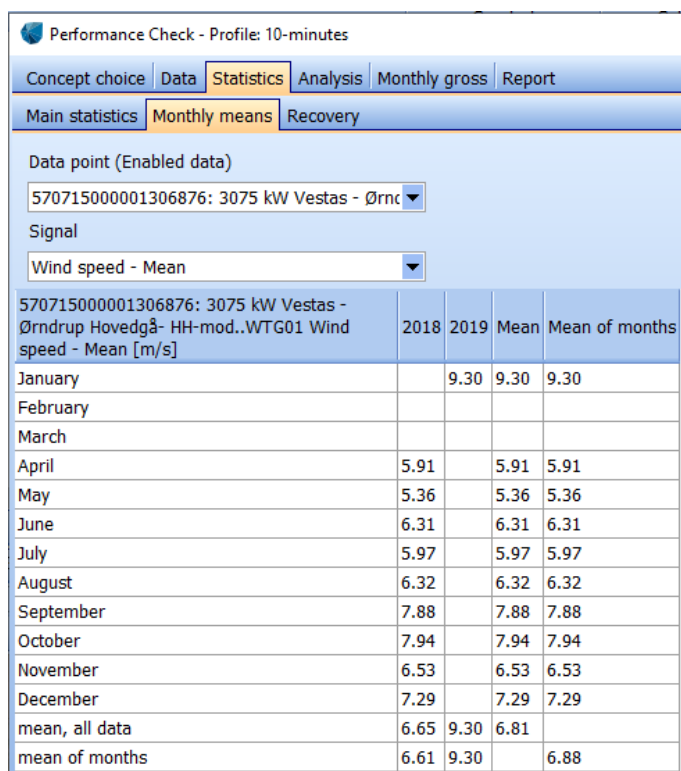


Figure 51: Monthly mean

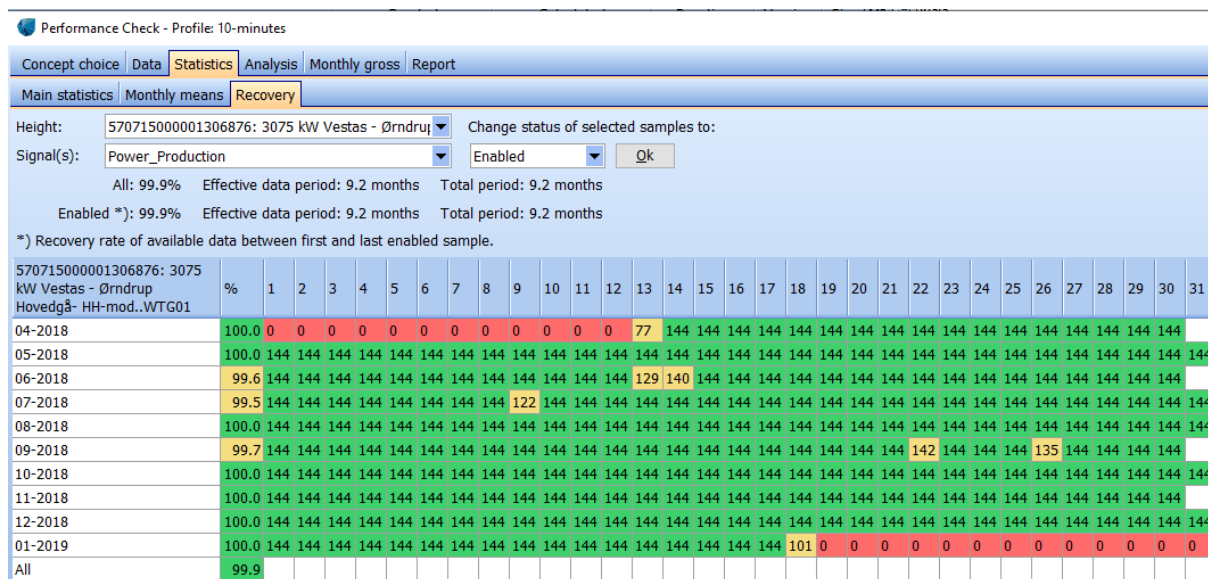


Figure 52: Daily recovery rate



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## 11.14 Analysis

In the *Analysis* tab it is now possible to visualise the data.

### 11.1.14 Analysis – Time series

All loaded signals from each WTG can be displayed in various ways, either as time series in the temporal resolution they have been loaded in, as monthly values, as a diurnal plot or as radar plot. The functionality is very similar to the tools in the *Meteo* object.

In Figure 53 the time series of wind direction and speed are shown together with the production from two WTGs. The user can adjust how many days are displayed in the window. By clicking and holding the left mouse button it is possible to zoom in a specific area. It is also possible to display an averaged timeline.

Further it is possible to manually enable/disable data. Specifically, the wind speed should be checked as the potential production is later determined using the nacelle anemometer. For example, the nacelle anemometer could be suffering from icing and shows zero or a constant small value, this data should be corrected or disabled. The methodology assumes consistent nacelle wind speeds, thus jumps occurring from anemometer exchange or changes of the scaling factor of the wind speed signal in the turbine controller should be corrected before undertaking loss evaluations (see Section 11.12).

A number of extra functions become accessible when the user has prepared a time-varying *PARK* calculation. As explained in Chapter 11 it is also possible to compare the measured production data with modelled production data. As preparation the user have to run a time-varying *PARK* calculation. There are two concepts available:

In case of post construction, the nacelle wind speed and historic power curve of the individual power curve will be used to calculate for each time step what the WTG should have produced. The time-varying *PARK* calculation does not require any flow modelling in this case. It can be started from within the Post construction module, see Section 11.12.

In case of *Performance Check*, a full flow model has to be set-up. As wind speed it is possible to use local masts as well as mesoscale data, see Manual for [PERFORMANCE CHECK model validation](#):

If a time-varying *PARK* calculation has been performed, the thin line represents the modelled signal for periods where there has been an error code. If the filters (top right corner) are switched off, also the corresponding measured values are visible as thick line.

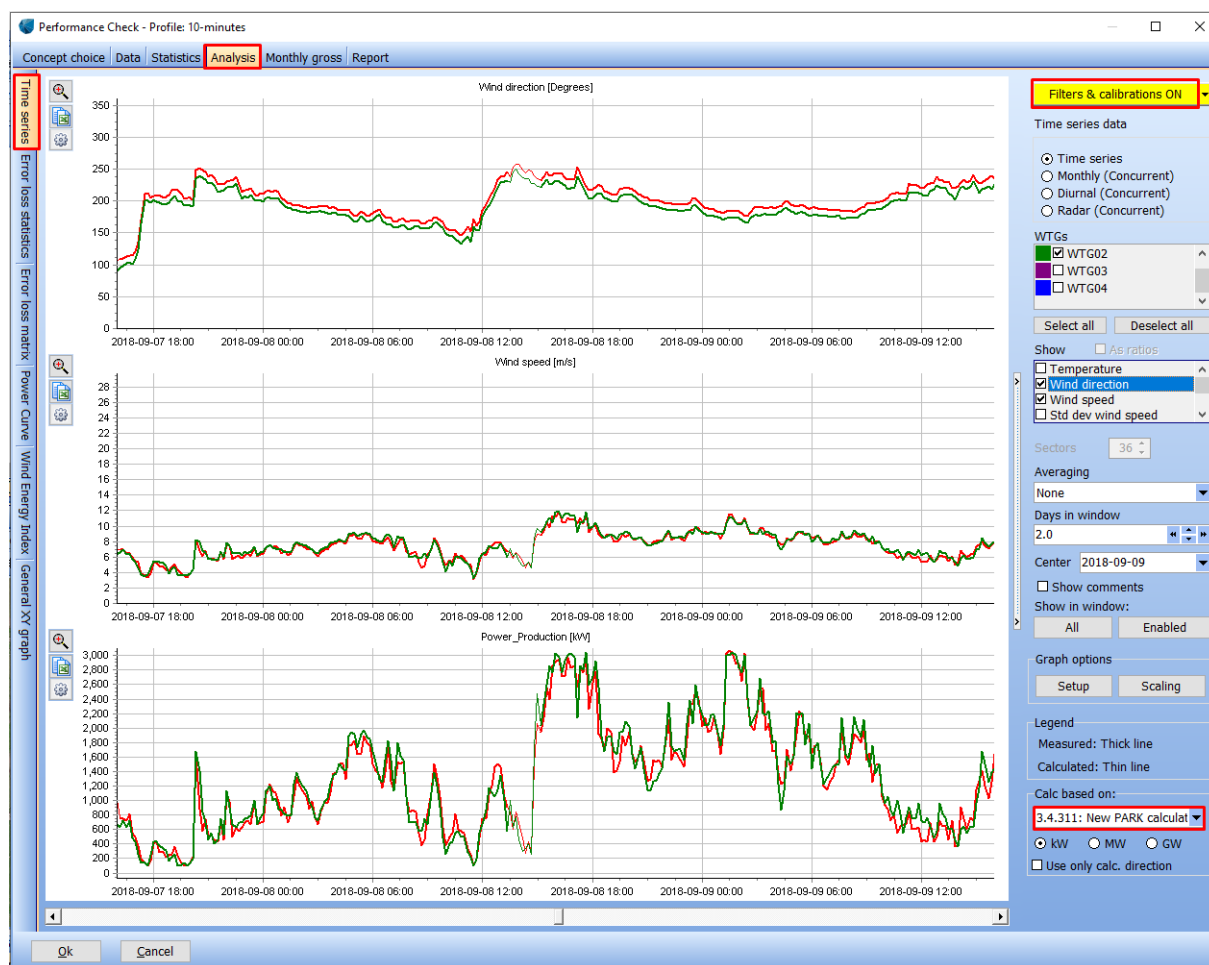


Figure 53: Display time series

By default, the filters are switched on and all error codes different from zero are filtered out (Figure 54). This is necessary to calculate the potential production later in the process. It is possible to define additional filters. For example, the user might want to investigate a specific direction and/or a specific wind direction range. “*Inside Range*” means that the data inside the range will be filtered out. If a PARK calculation has been loaded it is also possible to add filters to the modelled signals.

Please note, that if you use the “Excel” button on the left-hand side of the graph all data including the filtered data will be copied.

If sensors have extra calibration they can be applied here (Figure 54). Please note that *sensor calibrations* are explained in Section 11.11.

It is possible to define the minimum number of WTGs that must be operating simultaneously.

It is also possible to filter events out depending on how much the measured production deviates from the modelled production.



Filter settings

Filter data based on these selections. Filtered data will not be used in the aggregated graphs/tables, but will be shown as white dots in the non-aggregated graphs.

☐ Update graphs automatically

☒ Apply sensor calibrations

Filters applied to measured data:

Selection	Signal	From	To	Unit	Apply to data
<input checked="" type="checkbox"/>	System Logs First Active Alarm No (21)	0.0	0.0		Outside range
<input type="checkbox"/>	Ambient Temp. Avg. (1)	0.0	0.0	[Deg C]	Inside range
<input type="checkbox"/>	Ambient WindDir Absolute Avg. (5)	120.0	270.0	[Degrees]	Outside range
<input type="checkbox"/>	Wind speed - Mean	0.0	0.0	[m/s]	Inside range
<input type="checkbox"/>	Wind speed - StdDev	0.0	0.0	[m/s]	Inside range
<input type="checkbox"/>	Power_Production	0.0	0.0	kW	Inside range
<input type="checkbox"/>	RPM - Rotor	0.0	0.0		Inside range

Filters applied to calculated data:

Selection	Signal	From	To	Unit	Apply to data
<input type="checkbox"/>	Wind direction	0.0	0.0	Degrees	Inside range
<input type="checkbox"/>	Wind speed	0.0	0.0	m/s	Inside range
<input type="checkbox"/>	Power_Production	0.0	0.0	kW	Inside range

Requirements for production data within each time stamp:

☐ Min. number of WTGs operating simultaneously

☐ Min. measured production as % of calculated production  %

Filters & calibrations ON

Time series data

☒ Time series

☐ Monthly (Concurrent)

☐ Diurnal (Concurrent)

☐ Radar (Concurrent)

WTGs

☐ WTG01

☒ WTG02

☐ WTG03

☐ WTG04

Show ☐ As ratios

☐ Temperature

☐ Wind direction

☒ Wind speed

☐ Std dev wind speed

Sectors

Averaging

Days in window

Figure 54: Application of filters

### 11.1.15 Analysis – Error Loss Statistics

As explained in Section 11.4 the user can either combine the 10-minute SCADA time series with error codes and their description or as a fall-back plan set up user-defined errors in case error codes are not available.

Depending on these two options the tab *Error Loss Statistics* contains different levels of details.

With the simple approach using user-defined error codes, the statistics look like this (Figure 55):

Performance Check - Profile: 10min based (10 minutes)

Data Statistics Analysis Output

Turbine:

Category:

Sub category:

☒ Include error codes

☐ Include non-compensated curtailment

☐ Include compensated curtailment

☐ Limit period

From:  To:

Total calculated production for selected WTGs from 07-07-2013 to 18-01-2019 [kWh]: 240.083.890

Missing data in period: 0,00 %

Measured, negative production in period [kWh]: 266.944

Error code	Description	Category	Sub category	Loss (kWh)	Loss (%)	MTBF [Hour]	MTTR [Hour]	Count	Compensated	Non Compensated
10000	[USER] Stop with	USER error coc		6.125.304	2,551	87,3	1,6	2.184	<input type="checkbox"/>	<input type="checkbox"/>
10001	[USER] Power cu	USER error coc		1.035.150	0,431	44,5	0,3	4.328	<input type="checkbox"/>	<input type="checkbox"/>
10002	[USER] Above cu	USER error coc		-10.210	-0,004	2.132,2	0,6	91	<input type="checkbox"/>	<input type="checkbox"/>
				7.150.244	2,98					

Figure 55: Error loss statistics – user-defined error codes

For each user-defined error code the lost production in absolute number and as percentage are given. The lost production is the difference between the calculated and the measured production for all time steps with that error code.

Measured negative production is not accounted as a loss, but the amount is informed in the top right corner of the window. In addition the following are shown:

**MTBF** (mean time between failures): the average time between the error code's appearance and disappearance.

**MTTR** (mean time to repair): the average length of a specific error code.

**Count**: the number of periods with a specific error code (the count is independent of the length of the individual event; the count is 1 no matter if the event is one second or one week long)



If the user wants to change the categorisation if losses are compensated or not, it is possible to re-visit *Setup Error Codes*. It can be decided to exclude each of these in the sum.

It is possible to limit the period to see the losses within e.g. a specific month or year. Note its recommended to set the time to cover complete years for later use in long-term correction, to avoid potential seasonal bias.

It is also possible just to look a specific turbine or a specific category or subcategory.

With detailed error codes loaded, the above described information becomes available for each individual error code (Figure 56).

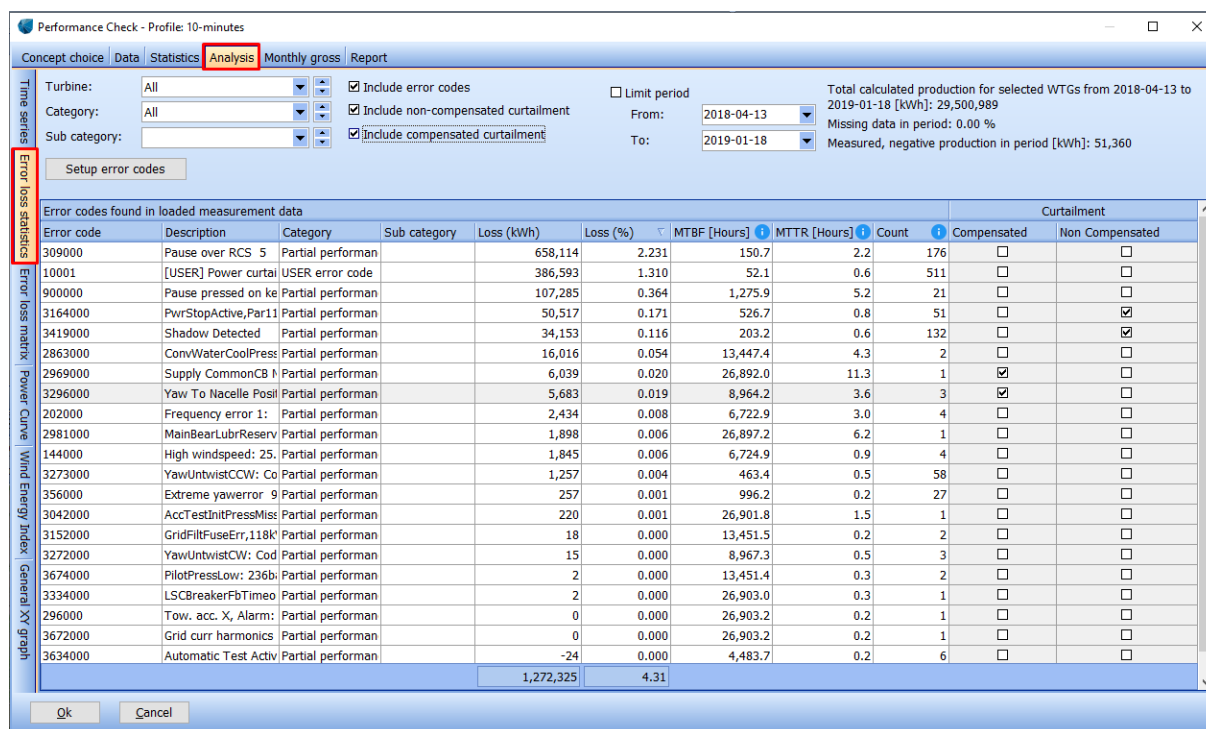


Figure 56: Error loss statistics – detailed error codes



### 11.1.16 Analysis - Error Loss Matrix

In this tab (Figure 57) functionalities similar to a Pivot table can be found. Different data fields have been defined, which can be dragged and dropped freely in the dark blue section to aggregate losses. The losses can be presented as absolute numbers or percentage. Following data fields are available:

- Year
- Month
- WTG
- Category

Within the two last listed data fields (WTG and Category) it is possible to deselect specific WTGs or categories and thereby only show a subset of the data by click on the arrow at the data field (Figure 58).

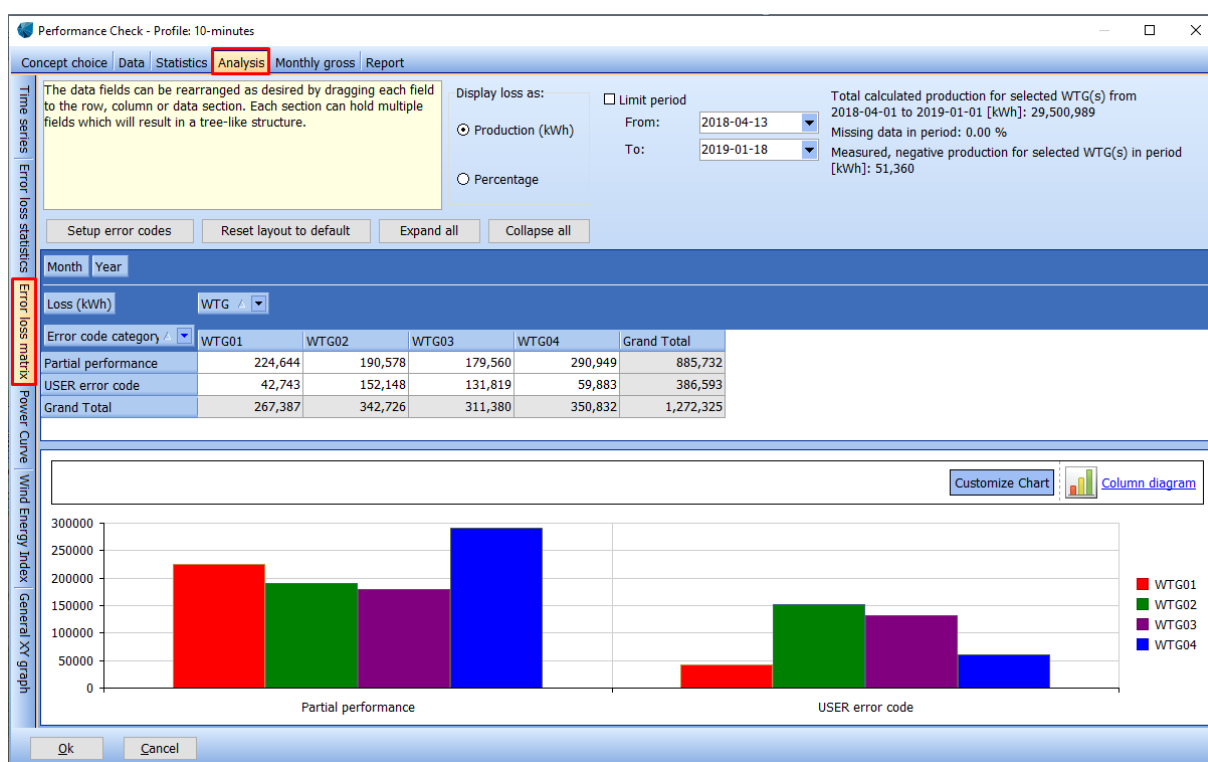


Figure 57: Error loss matrix

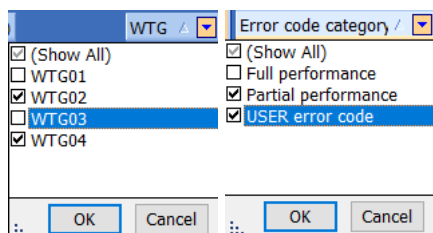


Figure 58: Selecting WTGs and categories





Further, when for example dragging additionally *Month* into table set-up, the *Expand All* and *Collapse All* button facilitate to reveal analysis such as monthly production per WTG quickly and easily.

The *Reset Layout to Default* button brings the default pivot set-up back.

The graphical display is fully customisable. The user can change from bar charts to pie charts, etc.

### 11.1.17 Analysis – Power Curve

Before explaining the functionalities on this tab, it has to be stressed that visualised power curve is not necessarily identical with the contracted power curve provided by the manufacturer. The contracted power curve refers to the free wind speed, while the power curve displayed here is based on the nacelle wind speed and does consequently not follow the IEC 61400-12-1. The IEC 61400-12-1 allows the validation of the power curve through use of the nacelle anemometer. However, this standard requires a very strict and precise measurement setup which is very rare for a commercial operating wind farm.

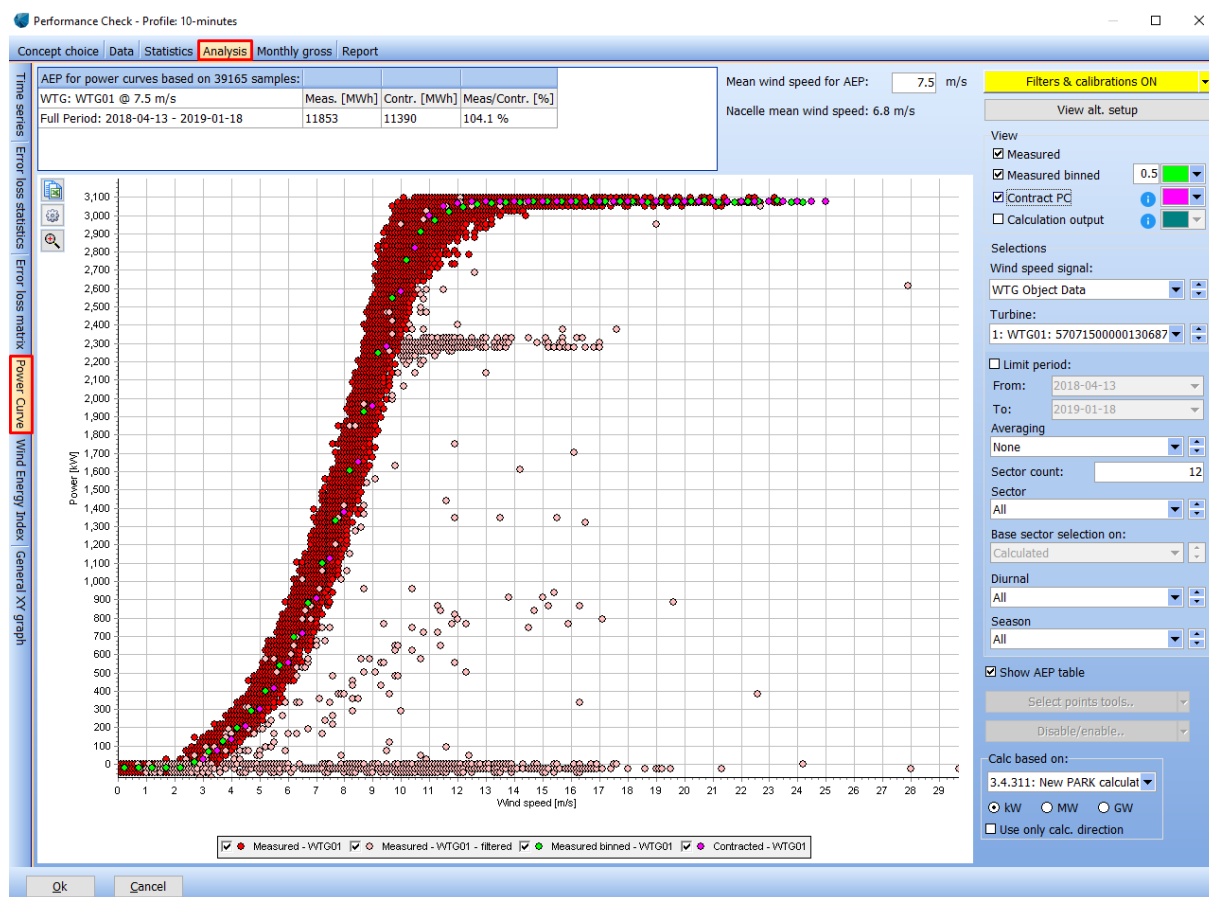


Figure 59: Power Curve tab

In the top left corner, the AEP table gives a quick overview about the expected production for a Rayleigh distribution for a user-defined wind speed. The measured power curve (normally based on the nacelle wind speed) can be compared with the contracted power curve. Of course, this only makes sense if the used wind speed signal is identical with free wind speed, which it not the case if the nacelle wind speed is used. Please note, that not all high wind speed bins might contain enough data to derive the full measured power curve. In such a case the power curve is extrapolated to the cut-out wind speed as specified at the power curve in the WTG object.

Following display options are available (starting from the top):



It is possible to use *alternative set-ups* for displaying the data (Figure 49). The user can either display additionally the scatter curve of a different WTG of the wind farm, choose another wind speed signal or limit the period. This can be useful for example for comparing two binned power curves from two different WTGs. If two WTGs are chosen here the AEP table will update accordingly and display both AEPs for the defined Rayleigh distribution. The user can also compare two periods with each other.

The *measured binned* power curve as well as the *contracted* power curve from the *existing WTG* object can be displayed. Please note, that the contracted power curve is valid for one, fixed air-density. Also, the *calculated* production can be displayed. If the user has run the time-varying *PARK* calculation as part of the post construction process, the calculated production corresponds to the potential production. If the user has run a full flow model based time-varying *PARK* calculation (see Section 11.3), the calculated production can optionally include site-specific correction for turbulence, shear, air-density etc.

The wind speed signal which is used for the scatter plot can be altered. By default, it is using the calculated wind speed. The difference between calculated wind speed and the wind speed in the WTG object consists of any correction the user might have applied to the nacelle wind speed, like described in Section 11.11 or *wind speed correction* as described in Section 11.12. If the user has run a full flow model based time-varying *PARK* calculation (see Section 11.3), the calculated wind speed comes from the flow model. Additionally, the user can load data from any *Meteo* object. Of course, all data can be exported to Excel for further analysis e.g. advanced comparison for different temperatures or turbulence intensities.

## 11.1.18 Analysis – Wind Energy Index

Note: For a new project setup, the user must first aggregate Monthly Gross production, before this tab is available. See Section 11.15

This tab allows the user to analyse the long-term correction of the potential production for each WTG. There are many different options available, but the basic concept is simple: Based on monthly production and monthly wind energy indexes, the Wind Index Corrected Production (WCP) is calculated.

There are two basic concepts for performing this calculation:

**The sum method:** The sum of production is divided with the sum of index for the enabled months

**The regression method:** A linear regression line is established for the potential production versus wind energy index, and the production for an index value of 100% is found.

The two methods deliver very similar results. Only for shorter periods and/or poor correlation with the index, will results from the two methods differ.

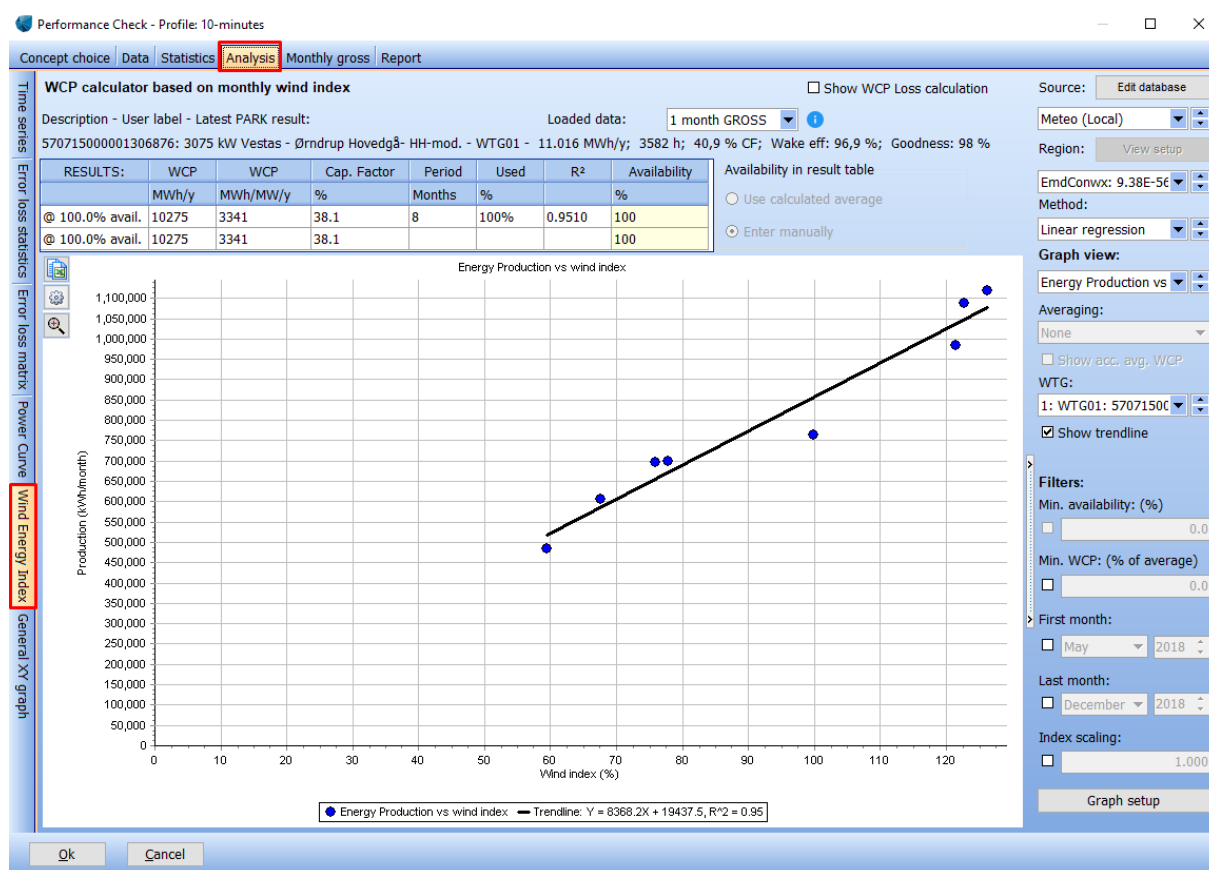


Figure 60: Wind Energy Index tab

The user can choose and edit the data base of wind indices (see Section 11.1.9). The indices which are part of the chosen database can be selected individually. This could be e.g. several re-analysis and mesoscale indices. The correlation ( $R^2$ ) of the different indices with the monthly potential gross production can be seen in the AEP table in the top left corner. Next to the correlation the WCP (Wind Index Corrected Production), the annual production per MW installed, the capacity factor, the length of the available data, and the usage of that data are shown. Please note, that all production at this point reflects 100% availability as all times steps with any form of non-optimal performance have been identified and corrected for.

Following graphical displays can be chosen from.



**Energy Production vs wind index** plots the monthly potential gross production against a chosen index (see Figure 60).

**Time series RAW** plots the monthly potential gross production per month. Additionally, the monthly index is shown referring to the secondary y-axis. Ideally the two curves should match each other.

**Time series WCP** shows the index-corrected production per month. The index-corrected production resembles a combination of the previous graph showing the monthly production and the index. This line should be ideally horizontal. Any deviations from the horizontal could point towards inconsistencies during time. Any slope could point towards degradation in performance or other issues. A step change could indicate that a neighbouring wind farm has been commissioned

**Time series WCP/MW** shows the index-corrected production per MW per month.

**WCP vs wind index** shows the index-corrected production against the wind energy index. Ideally the values should all exhibit the same production. Any slope indicates that the response for low and high wind speeds differs. This is typically the case when the index has been developed based on the wrong wind speed assumption (see Section 11.1.9 and Figure 19). The precise set-up of the wind energy index is more important when the production data only covers a short period.

The following option show results for all WTGs:

**All WTGs, AEP Avg + WCP** shows the measured AEP and the wind energy index corrected production for each WTG. If the production data spans a different period than an integer number of years, the measured production is corrected by dividing the production with the number of months (in Figure 60 it is 8 months) and multiplying with 12 months.

**All WTGs, AEP Avg + WCP/MW** shows the measured AEP per MW and the wind energy index corrected production per MW for each WTG

**All WTGs, Cap. Factor** shows the measured capacity factor and the wind energy index corrected capacity factor for each WTG

**All WTGs, Correlation** shows the correlation ( $R^2$ ) between monthly gross production per WTG and wind energy index. Ideally this should be 1.

**WF GEO** shows the map of the WTGs under investigation. This graph is most meaningful if a full flow-model based time-varying PARK calculation has been performed (see Section 11.3)

For some of the graphical displays further options are available like increasing the averaging from 1 month to several or showing the accumulated average WCP.

For the regression plot a simple tool can help to identify outliers by defining a maximum deviation in % from the WCP. So for example, 90% means that the actual monthly production should not be more than 90% different than the WCP of that very month.

Further, it is possible to limit the period, e.g. to filter out the first months of operation, because they could have some poorer performance.

A scaling option for the data is available.

The *WCP loss form* is not relevant in the context of post construction analysis.

### 11.1.19 Analysis – XY Graph

With this tool, any measured signal can be plotted against each other, either as scatter plot or binned. The x- and y-values can be from the same or different turbines, any signal imported can be chosen.

The period can be reduced to see if a specific phenomenon belongs to a specific period.

Averaging in time can give a better overview than having a large “point cloud”.



Finally, a trend line can be shown (limited to linear) – the formula will appear in the legend.

Figure 61 shows as an example how the direction measurements from the one WTG differ from the other WTG in systematic “bands”. This can be caused by periodic offsets of one of the two signals.

An example of operational strategy visualization based on the XY graph tool is given in Figure 62, where RPM is plotted against pitch angle with wind speed as colour scale.

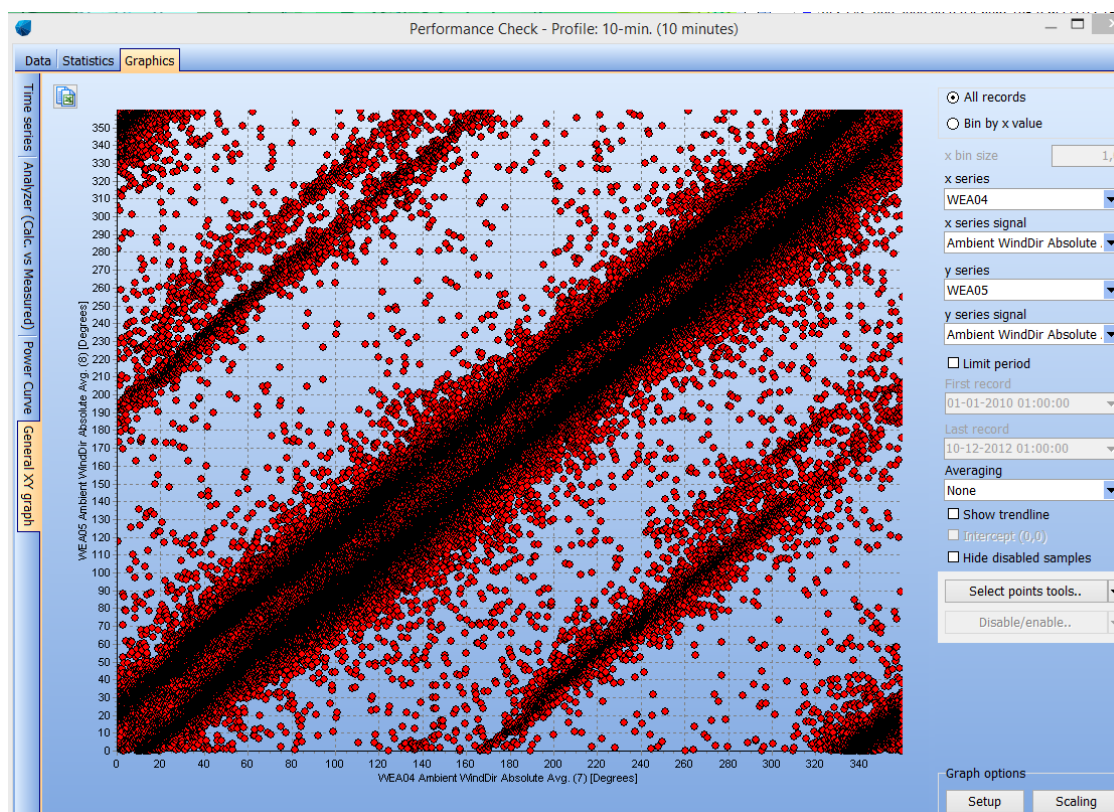


Figure 61: Example xy graph - nacelle directions



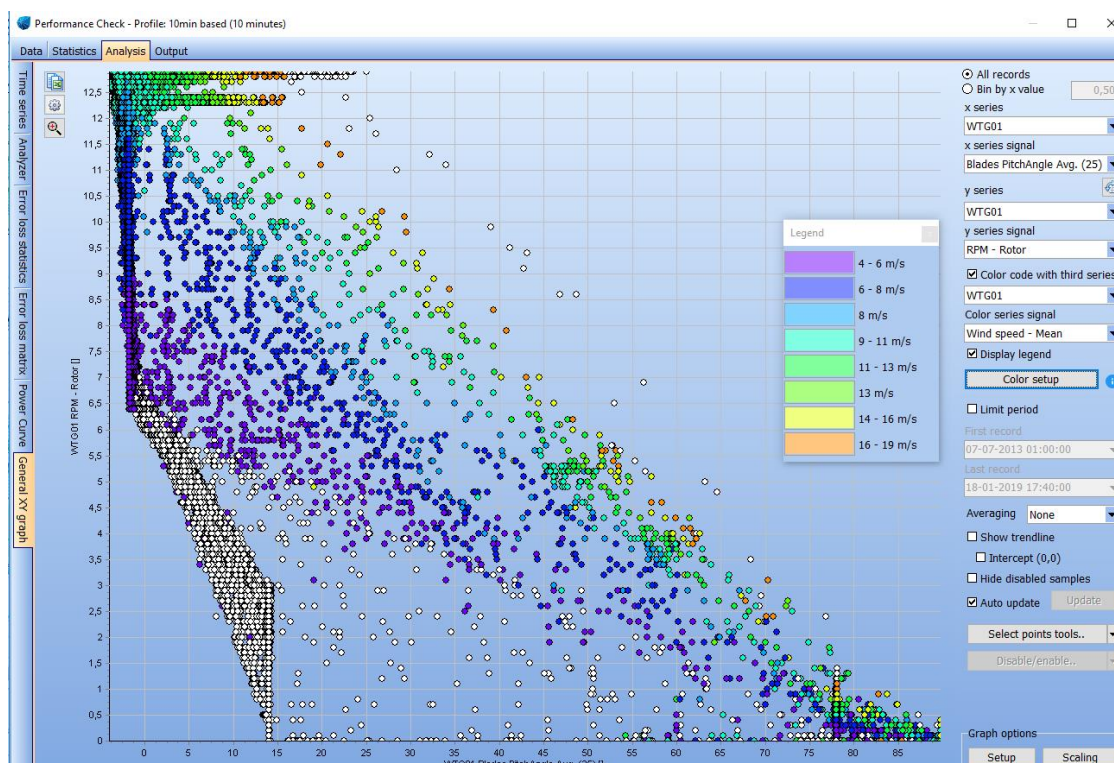


Figure 62: Example xy graph – operational strategy

## 11.15 Monthly Gross

The tab *Monthly Gross* aggregates the production data to a monthly time series, which is the basis for long-term correcting the production data. Depending on the available input data, different methods can be chosen to compensate for incomplete time series e.g. missing periods or unreliable nacelle wind speed. The output of this process is the GROSS production “Monthly Potential production”, which is fed into the WCP tool (wind corrected production = long-term corrected production) for long-term energy index correction, see Section 11.1.18. The resulting time series of monthly production will be saved in the *Existing WTG* object with the label *MonthGross*.

The user has to choose a time-varying PARK calculation, which is based on the nacelle wind speed (see Section 11.12).

Four different methods can be chosen to compensate for missing data. Note the recovery rate is based on the enabled pairs of nacelle wind speed and production.

**Divide with recovery rate:** Recommended for data recovery rate > 95%. The missing data is assumed to be caused by data loss. During the period of data loss, the WTG is assumed to produce as observed on average for the available data in each month.

**Ignore recovery rate:** Recommended for data recovery rate > 99%. The missing data is assumed to represent periods with lost production, which is also representative for the future.

**Skip month if recovery rate is too low:** If this option is chosen a field is activated where the user can define the minimum recovery rate, which only affects the long-term correction.

**Take from alternative calculation:** This is not to be used for post construction methodology.



Figure 63: Monthly gross tab

Further two methods become available if monthly data has been read directly into the *Existing WTG* object (see Section 11.1.5). These options are greyed out in the post construction process, if none of the required monthly data has been loaded into the *Existing WTG* object.

**Method 2: Month NET + calculated loss:** If the monthly NET (sold production) is loaded into the *Existing WTG* object, it is possible to evaluate the grid losses. Please note that 100% availability in the other methods, does not include the grid loss.

**Method 3: Monthly RAW divided with month availability:** If the monthly RAW is loaded into the *Existing WTG* object and includes monthly availability figures, the production can be availability-corrected by division with the availability. This very simple method assumes there is a column with availability information in the RAW data. The RAW data can both be with or without grid loss, this must be handled in the later loss settings when creating a report.

Pressing **Generate monthly time series** aggregates, the 10-minute data to monthly Gross and saves the monthly data to the *Existing WTG* objects. A graph appears on the right-hand side showing the actual production (called “measurement”) and the actual loss (called “substituted”).

The user can jump directly to the *Wind Energy Index* tab which is part of the *Analysis* tab (see Section 11.1.18).





## 11.16 Report

The post construction report highlights the actual production with actual losses as covered by the 10-minute SCADA data. The potential production represents 100% availability. The actual losses are ranked, the lost kWh, MTBF (mean time between failure) and MTTR (mean time to repair) are given. Long-term correction of the potential power results in the normalised production. Including future losses leads to the future expected Net production. The process follows the IEC 61400-26-1 structure using the historic power curve and nacelle wind speed.

The report consists of following sections:

- Main
- Historic Power Curve
- Actual Losses
- Normalized Production
- NET Production
- Comments

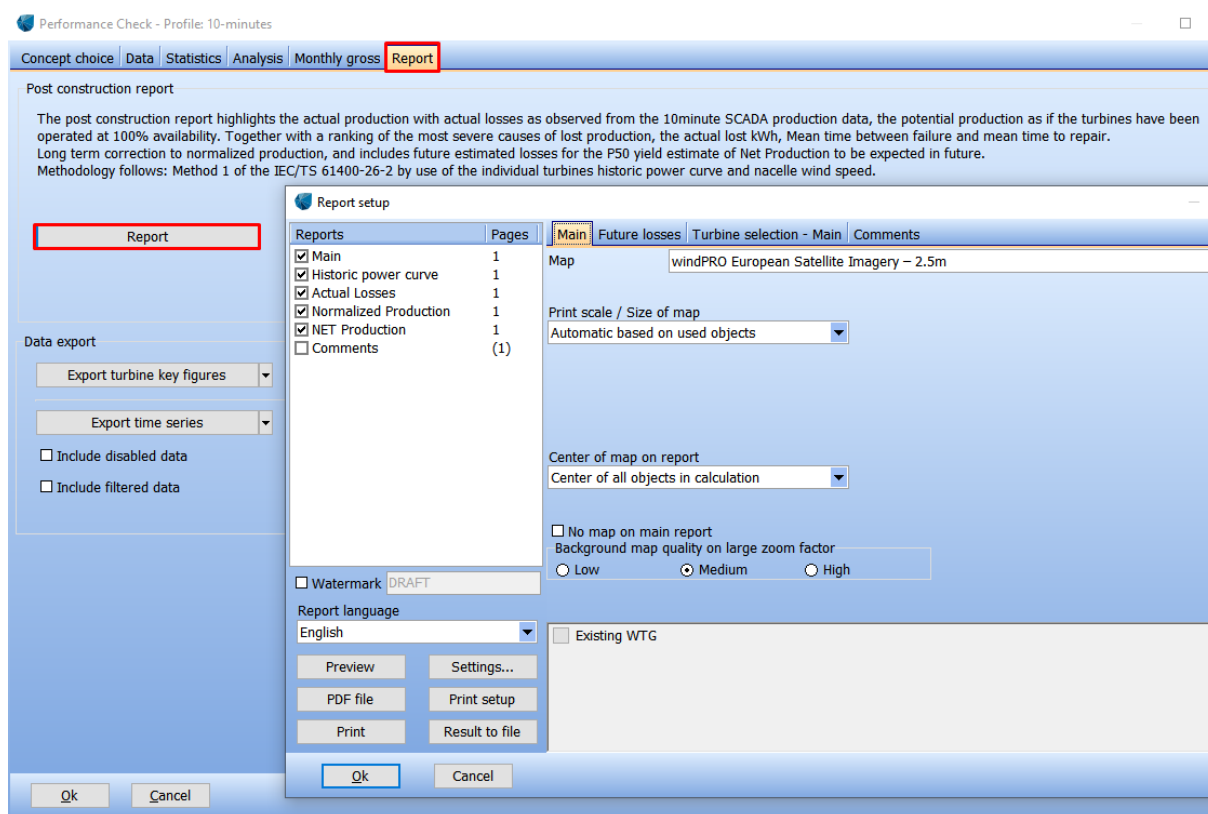


Figure 64: Post construction report

### 11.1.20 Main section

The Main section starts with an explanation of calculation method with the glossary. A table with the main results follows (Figure 65). The table includes the potential production of the analysed period (which could be different from one year) as well as an annual basis simply by correcting for the number of months. Please note, that having, for example 1.½ years of data with two summers and one winter can make the annual production look out of proportion due to seasonal bias. It is recommended to use complete years to avoid any misleading seasonal bias.



Results							
	Actual production	Actual losses	Potential production	LT correction*	Normalized production AEP	Expected total losses	Net production AEP
	[MWh]	[%]	[MWh] / [MWh/y]	[%]	[MWh/y]	[%]	[MWh/y]
Park	232110	3,11	239562 / 43013	0,86	43385	4,61	41385
WTG01	59632	2,72	61299 / 11028	0,86	11123	4,22	10653
WTG02	56978	2,62	58513 / 10507	0,88	10599	4,12	10162
WTG03	56156	4,13	58576 / 10510	0,87	10601	5,63	10004
WTG04	59343	2,99	61174 / 10969	0,85	11062	4,49	10565

\* Based on ratio between Potential productions AEP & Normalized production AEP, see Normalized Production section for details.

Figure 65: Main results

## 11.1.21 Historic Power Curve

The table with the results is followed by the scatter plot and the historic power curve (Figure 66). The filtered events are marked in a lighter colour.

The user can choose in the tab Turbine selection – historic power curve which WTG to display (Figure 67).

### Performance Check - Historic power curve for WTG: WTG01

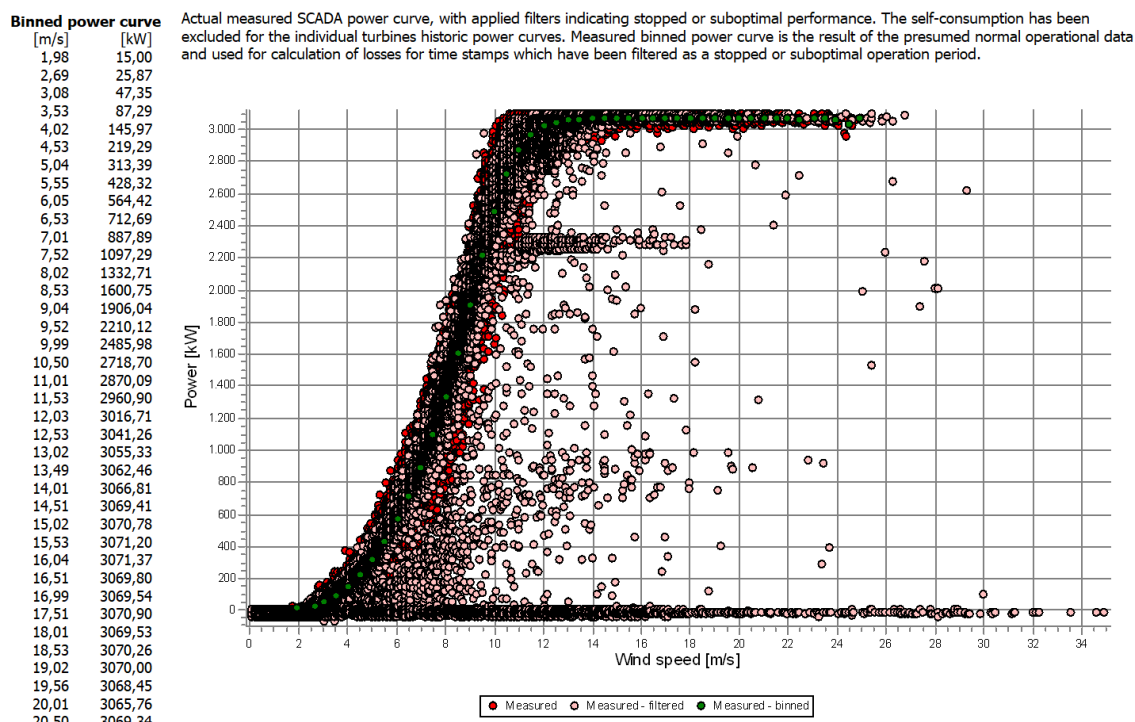


Figure 66: Example historic power curve based on the nacelle wind speed

Report setup

Reports	Pages
<input checked="" type="checkbox"/> Main	1
<input checked="" type="checkbox"/> Historic power curve	1
<input checked="" type="checkbox"/> Actual Losses	1
<input checked="" type="checkbox"/> Normalized Production	1
<input checked="" type="checkbox"/> NET Production	1
<input type="checkbox"/> Comments	(1)

Turbine selection - Historic power curve

Select which turbines should be included in the report:

- ☒ WTG01
- ☐ WTG02
- ☐ WTG03
- ☐ WTG04

Figure 67: WTG selection historic power curve



## 11.1.22 Actual Losses

The next pages show the actual losses aggregated in different ways: by WTG, by category, by error code and by month (Figure 68 and Figure 69). Combination of actual production and actual losses leads to the potential production which is summarized in a table (Figure 70).

### Performance Check - Actual Losses

The actual losses are derived for each time step concurrent with an error event as the difference between the measured power and the potential power based on the historic power curve and the (corrected) nacelle wind speed.

#### Actual losses in kWh

WTG ID	Others	Manufacturer	Normal	Utility	Environment	Remote shut down	USER error code	Grand Total
Grand Total [kWh]	4095	2165070	27564	24233	93635	2089973	3047604	7452175
WTG01 [kWh]	331	625773	0	1930	36562	466446	535814	1666857
WTG02 [kWh]	-50	320237	0	7778	7573	493544	705545	1534627
WTG03 [kWh]	3813	679373	27564	12577	26619	535720	1134407	2420072
WTG04 [kWh]	0	539688	0	1948	22881	594264	671838	1830619

#### Actual losses in %

WTG ID	Others	Manufacturer	Normal	Utility	Environment	Remote shut down	USER error code	Grand Total
Grand Total [%]	0,00	0,90	0,01	0,01	0,04	0,87	1,28	3,12
WTG01 [%]	0,00	1,02	0,00	0,00	0,06	0,76	0,87	2,72
WTG02 [%]	0,00	0,55	0,00	0,01	0,01	0,84	1,21	2,62
WTG03 [%]	0,01	1,16	0,05	0,02	0,05	0,91	1,94	4,13
WTG04 [%]	0,00	0,88	0,00	0,00	0,04	0,97	1,10	2,99

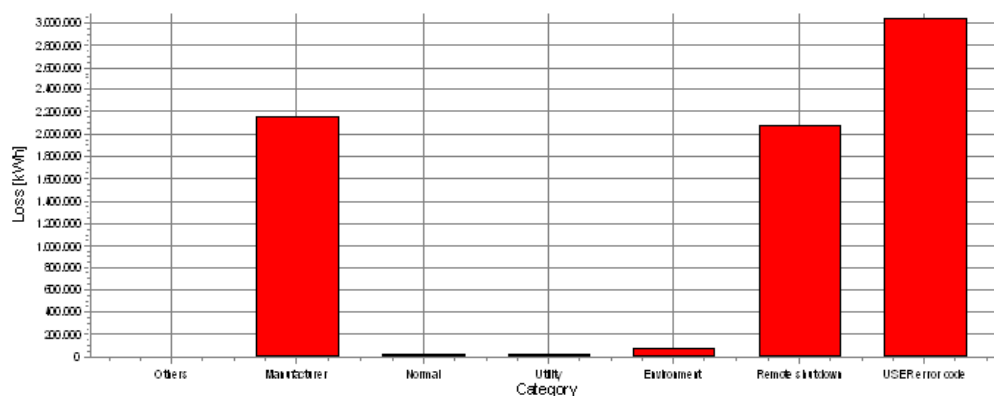


Figure 68: Actual losses by category and WTG



## Performance Check - Actual Losses

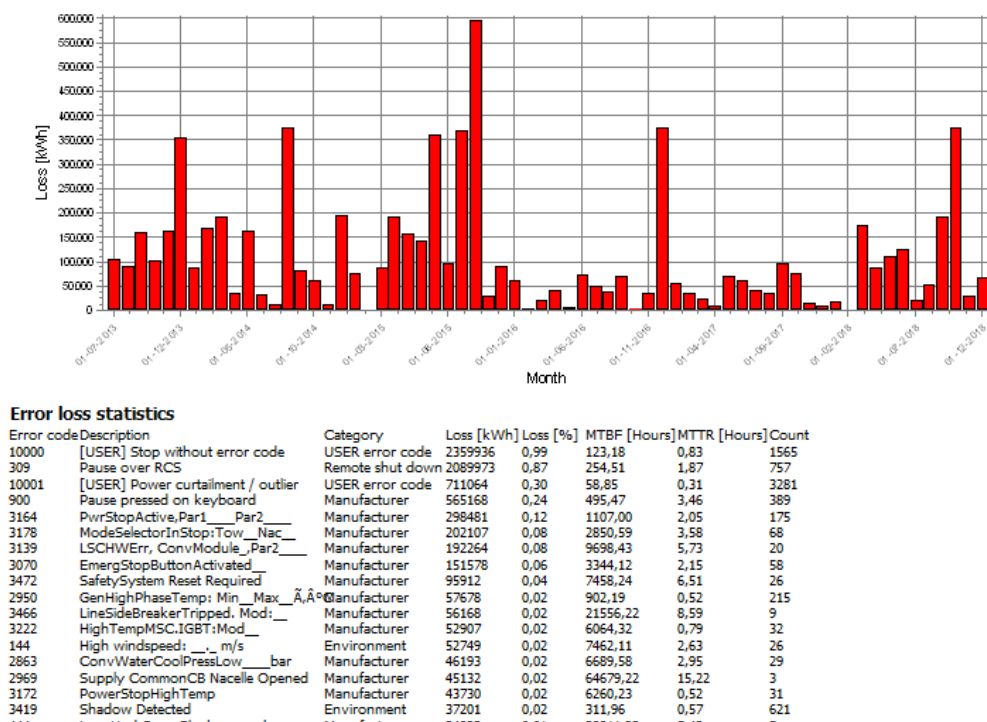


Figure 69: Actual losses by month and by error code

## Results: Potential Production

The potential production refers to what could have been realised if the turbine had been operating as per the full performance using the historic power curve. The potential production is consequently the sum of the actual production and the actual losses.

Performance Check data export, version:1

Data from: 2018-04-13

Data to: 2019-01-18

PARK calculation: 3.4.311: New PARK calculation - Measured power curve used - Calculated production replaced with OK measured values

Coordinate system: UTM (north)-ED50 (Europe) Zone: 32

WTG ID	Actual production	Potential production	Actual loss	Own consumption	Turbine type	Easting coordinate	Northing coordinate	Hub height	Recovery rate of wind speed* correction factor	Wind speed
	[kWh]	[kWh]	[%]	[kWh]				[m]	[%]	
WTG01	7,350,020	7,617,407	3.5	11,604	VESTAS V112 3075 112.0	10523,510	6,300,530	84.0	99.9	1.000
WTG02	6,824,904	7,167,630	4.8	12,844	VESTAS V112 3075 112.0	10523,717	6,300,270	94.0	99.9	1.000
WTG03	6,838,024	7,149,404	4.4	13,344	VESTAS V112 3075 112.0	10523,923	6,300,011	94.0	99.9	1.000
WTG04	7,215,716	7,566,548	4.6	13,568	VESTAS V112 3075 112.0	10524,130	6,299,752	94.0	99.9	1.000

\* Potential AEP has been adjusted to 100% availability per month based on the recovery rate ratio difference to 100%. I.e. recovery loss of SCADA data assumes that the turbine was in "average monthly" performance for the duration of missing information.

Figure 70: Potential Production

## 11.1.23 Normalized Production

This section of the report shows the normalized production. At the top of the page the normalized production per year and per MW/y is given. The normalized production is assumed to have 100% availability.

The monthly potential production versus the wind energy index, the time series of the production and the chosen wind energy index, as well as the timeline are displayed (Figure 71).

**Results:**

Calculated normalized production at 100,0 % avail \*) MWh/y 11123 MWh/MW/y 3617 Cap. factor 41,3 %  
 Correlation ( $R^2$ ) 0,94  
 \*) Losses are substituted so that the production represents 100% availability

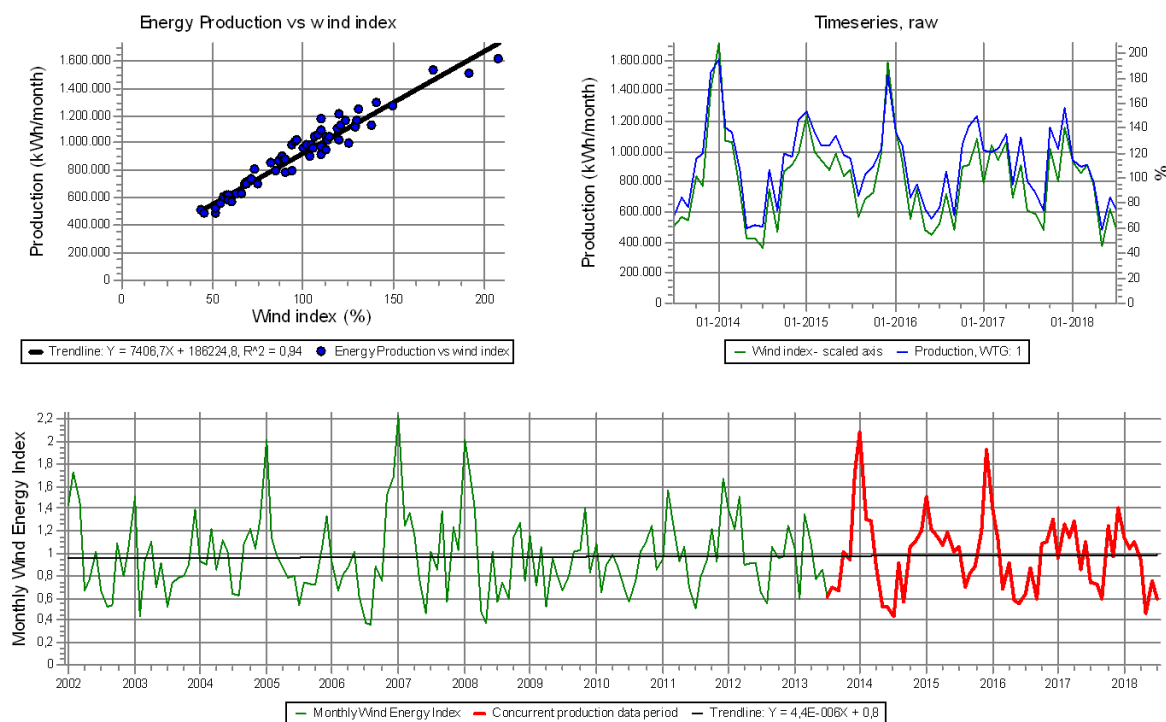


Figure 71: Normalized production - wind energy index correction

**11.1.24 NET Production**

The NET production requires the quantification of future losses (Figure 72). The actual losses are by default transferred as future losses; however, the user can modify these values, either manually one-by-one or through definition of the loss of a category. For the second option the Apply button has to be pressed to actively change the settings. An electrical loss default of 1% is assumed, with degradation 0.5% which is leaning against the FGW TR6.

The final table (Figure 73) summarises the NET production and lists all assumptions.

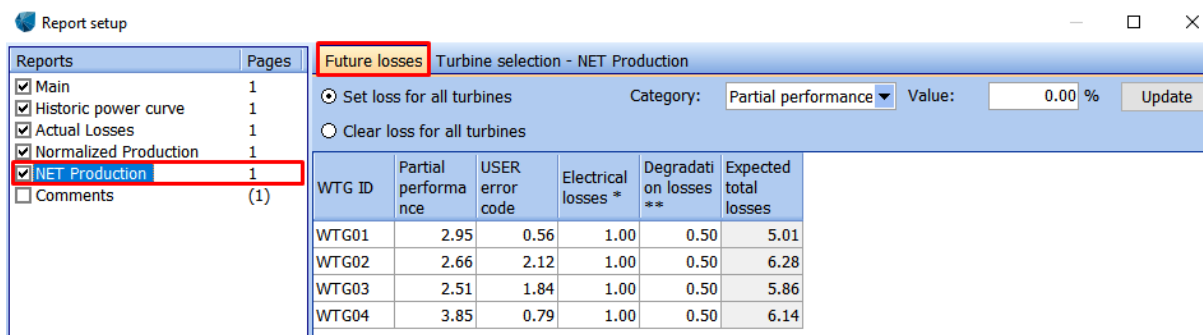


Figure 72: Quantification of future losses



## Performance Check - NET Production

The Normalized production represents the future optimal yield of the wind farm with 100% availability and 100% windiness (wind energy index). The Net production is the normalized minus expected future losses presented below.

The losses are accumulated depending on their statistical dependencies.

WTG ID	Normalized production	Others	Manufacturer	Normal	Utility	Environment	Remote shut down	USER error code	Electrical losses *	Degradation losses **	Expected total losses	Net production
Park	[MWh/y]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[MWh/y]
43385		0,00	0,90	0,01	0,01	0,04	0,87	1,28	1,00	0,50	4,62	41385
WTG01	11123	0,00	1,02	0,00	0,00	0,06	0,76	0,87	1,00	0,50	4,22	10653
WTG02	10599	0,00	0,55	0,00	0,01	0,01	0,84	1,21	1,00	0,50	4,12	10162
WTG03	10601	0,01	1,16	0,05	0,02	0,05	0,91	1,94	1,00	0,50	5,63	10004
WTG04	11062	0,00	0,88	0,00	0,00	0,04	0,97	1,10	1,00	0,50	4,49	10565

\* 1% electrical losses empirical standard value, a common standard electrical loss from SCADA data being measured before the transformer, and losses from SCADA point to metering point for Grid. For long distance between turbines and metering points electrical losses is assumed to be larger than 1%.

\*\* 0.5% degradation losses, industry practice suggests a future loss due to degradation of 0.5% (reference to FGW TR6).

Figure 73: NET Production

## 11.1.25 Export

The user can export either the key figures or the time series to the clipboard or to a file (Figure 74). Data that have been disabled or filtered can be included upon request.

Data export

Export turbine key figures

Export time series

☐ Include disabled data  
☐ Include filtered data

Export measured and calculated production, wind speed, direction as .txt file (tab separated)  
  
Exported data will be in selected time period, otherwise from first date/time to last

Figure 74: Export options