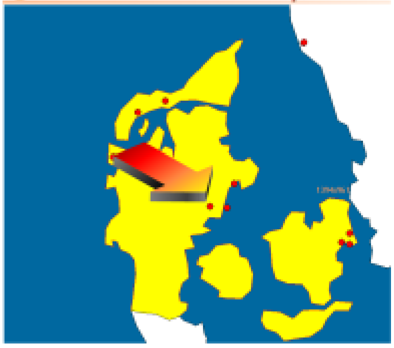

Torrild - WindSIM – Case study

Note: This study differs from the other case studies in format, while here another model; WindSIM is tested as alternative to the WAsP model. Therefore this case should be read additional to the Case 02 Torrild. Note also that the Torrild case is not the best for WindSIM, while it is not really complex regarding terrain steepness. It is where the terrain is so steep, that flow separation appear, WindSIM has its forces.

Content:

Site And Analysis Conditions

A total of 15 Bonus 150/30 kW MK II turbines are situated on site. The power production from these turbines is used for verification purposes. The hub height is 30 meters.

Company	BONUS
Type/Version	MK II
Rated power	150.0 kW
Secondary generator	30.0 kW
Rotor diameter	23.8 kW
Tower	Tripod
Origin country	DK
Blade type	LM 11
Generator type	Two generator
Rpm, rated power	40.4 rpm
Rpm, initial	30.3 rpm
Default hub height	30.0 m
Alternativ hub heights	0.0 m
Valid	No
Creator	EMD
Created	07-10-1998 00:00
Edited	07-10-1998 00:00

Two WindSIM run were made, one for a larger region (meso) for getting the boundary conditions for the smaller (micro) region run. The ‘Meso’-model was run with a grid resolution of 200 meters resulting in 10000 nodes. The micro model has been nested within the meso model. In the ‘Micro’ model test case, the grid resolution was chosen to be 20 meter, also resulting in 10000 nodes. Here, only results from the micro model will be presented. The main characteristics of the area is shown below:

Calculation area	4 km^2
Coordinate system	UTM zone 32 – datum ED50
Geographical limits	(y_{min}, y_{max})=(6203500, 6205500) (x_{min}, x_{max})=(563700, 565700)
Grid size	20 meters
Number of cells	10000
Wind data	Station 5 – Feb to Oct 2000 Station 36 – Feb to Oct 2000 (St 36: data acquisition very low)

A through description of the site with an analysis of the wind climate and the production from the turbines using traditional methods, see [i]. The orography and roughness for the calculation area are shown in Figure 8. These figures represent the initial extraction area, which was 4 x 4 km2. This was later reduced into a 2 x 2 km2 area. The approximate position of the final calculation area is shown by the black square in the figures.

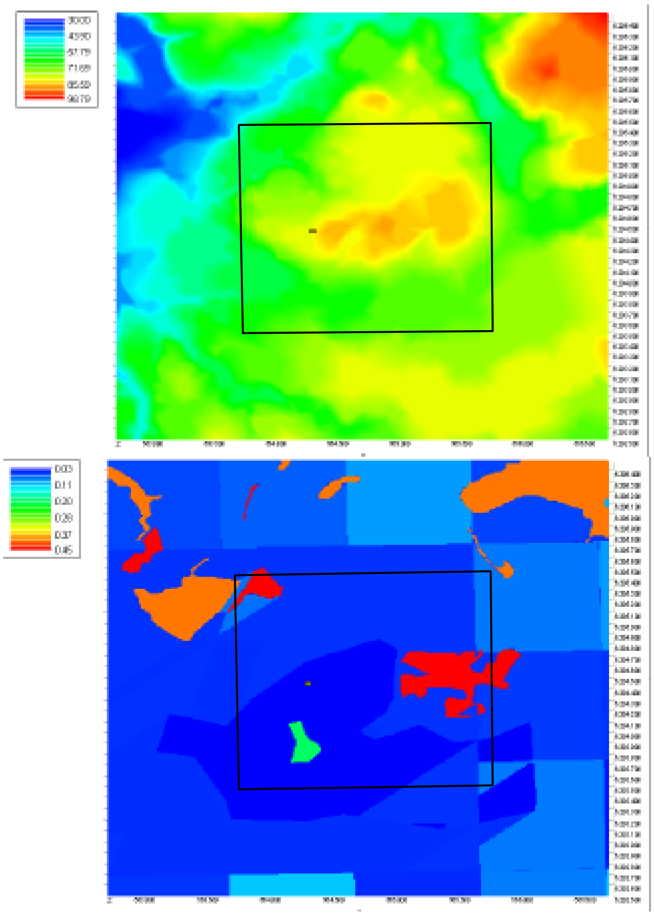

Figure 1 Orography and roughness from the initial extraction (orography in [m], roughness in [m])

Comparing WAsP and WindSim Results

The main statistics of the ratio between the WindSim and WAsP results are shown in Table 1. The mean value of the ration is 97.2%, which mean that the WindSim calculations in general seem to underestimate the mean value of the wind speed distribution. However, this difference may also be due to differences in fitting techniques when fitting the Weibull parameters. The coefficient of variation is 2.4%, which is judged acceptable. When looking at the energy level, the WindSim calculation underestimates approximately – in mean - 9 % as compared to WAsP.

Mean wind speed			Energy level		
m	*s*	*COV=s /m*	*m*	*s*	*COV=s /m*
0.972	0.023	0.024	0.907	0.069	0.076

Table 1: Statistics on the ratio,R, between the mean wind speed or energy level calculated from WindSIM and WAsP.

The dependency on the distance from the meteorological mast and the height above ground is shown in Figure 9. It is obvious, that the WindSim model seems to underestimate increasingly as the distance from the meteorological mast increases. A larger variation is seen as in a distance approximately 1000 meters from the mast. The reason for this larger variation is found by inspecting the Figure 10 and comparing with the roughness map in Figure 8. Here it is seen, that the large ratio comes where the roughness is heigh (a small city is situated). Near the site, the two models predict quite similar, and the difference in mean wind speed is within a few per cent.

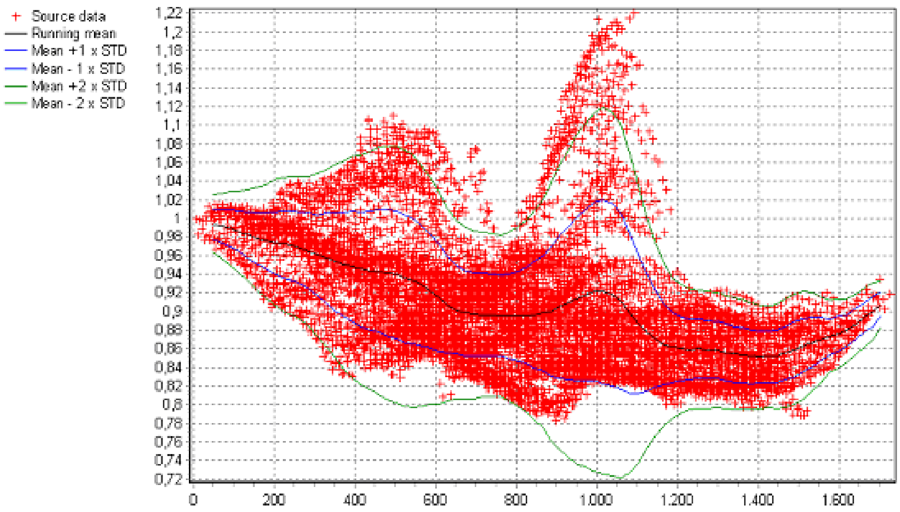

Figure 2 WindSim/ WAsP mean wind speed ratio conditioned on the distance from the met mast

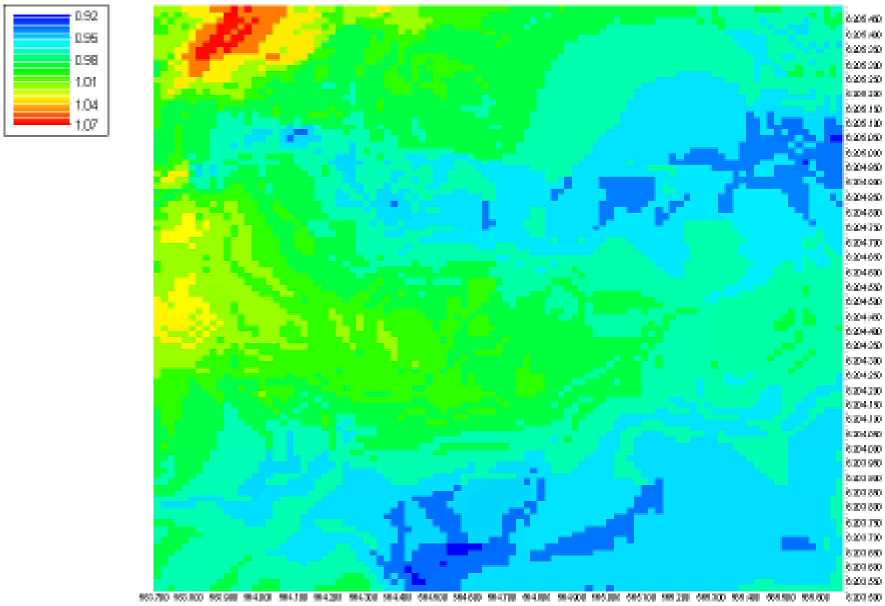

Figure 3 Comparing WindSim/WAsP mean wind speed ratio distributed over the calculation area

Comparing Results at the Meteorological Mast

In order to compare how the different models perform, it is sought to estimate the wind climate at the position of the meteorological mast. I.e. it is possible to compare the model predictions with the original measured data. WAsP v. 5.1 is used to fit the Weibull parameters in all models in order to overcome the known problems of using different Weibull fitting algorithms (see Fitting Weibull Parameters for Wind Energy Applications).

Calculated Weibull A-parameters [m/s]

Model	Height	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
Measured	30 m	4.70	4.50	5.10	6.60	6.70	6.00	6.60	6.80	7.50	6.30	4.10	5.10	6.30
WAsP	30 m	4.73	4.67	5.15	6.59	6.73	6.03	6.57	6.90	7.42	6.35	4.59	5.11	6.34
	70 m	5.59	5.45	6.25	8.26	8.19	7.10	7.78	8.07	8.81	7.79	5.62	6.26	7.65
	100 m	6.08	5.93	6.82	8.95	8.79	7.70	8.48	8.72	9.52	8.43	6.08	6.79	8.28
WindSim	30 m	4.60	4.50	5.10	6.60	6.70	6.00	6.50	6.80	7.50	6.30	4.10	5.10	6.30
	70 m	5.30	5.20	6.00	7.60	7.60	6.60	7.30	7.50	8.30	7.10	4.90	5.90	7.10
	100 m	5.60	5.50	6.20	8.00	8.00	7.00	7.60	7.90	8.60	7.40	5.20	6.20	7.50

Calculated Weibull k-parameters

Model	Height	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
Measured	30 m	1.64	2.04	2.20	2.42	2.53	2.19	1.80	2.19	2.27	2.00	1.54	1.62	2.04
WAsP	30 m	1.72	2.08	2.19	2.44	2.53	2.19	1.87	2.21	2.28	2.04	1.63	1.65	2.06
	70 m	1.94	2.33	2.47	2.72	2.83	2.42	2.06	2.49	2.55	2.31	1.82	1.86	2.30
	100 m	2.02	2.42	2.54	2.80	2.92	2.50	2.15	2.59	2.67	2.42	1.89	1.94	2.30
WindSim	30 m	1.63	2.03	2.19	2.42	2.54	2.17	1.79	2.20	2.28	2.00	1.53	1.61	2.05
	70 m	1.63	2.06	2.24	2.44	2.57	2.14	1.81	2.19	2.30	2.02	1.59	1.63	2.07
	100 m	1.65	2.09	2.18	2.35	2.46	2.19	1.81	2.20	2.21	2.00	1.59	1.61	2.05

Calculated direction probability [%]

Model	Height	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
Measured	30 m	2.00	3.50	8.10	10.6	9.60	8.20	8.40	12.3	15.6	14.9	4.20	2.70	100
WAsP	30 m	2.10	3.80	7.80	10.5	9.70	8.30	8.60	12.4	15.5	14.4	4.60	2.70	100
	70 m	2.00	3.50	7.90	10.8	10.0	8.20	8.20	12.0	15.7	14.7	4.60	2.60	100
	100 m	2.00	3.50	7.90	10.9	9.90	8.10	8.20	12.0	15.7	14.7	4.50	2.60	100
WindSim	30 m	2.00	3.50	8.10	10.6	9.60	8.20	8.40	12.3	15.6	14.9	4.20	2.70	100
	70 m	2.00	3.50	7.90	10.8	9.70	8.00	8.40	12.2	15.5	15.1	4.20	2.60	100
	100 m	2.00	3.50	7.90	10.9	9.70	8.00	8.40	12.1	15.5	15.2	4.20	2.60	100

When comparing the measured and modelled Weibull A-parameters, it seems like the WAsP model has a tendency to slightly over predict the A parameter at the 30 meters height. The WindSim model gives a result that is very close to the measured data (as it is supposed to as the speedups and direction changes are 0). When looking at the A-parameter at 70 meters and 100 meters, then the WindSim model predicts a lower A-parameter than the WAsP model. There are actual plans on substituting the 15 x 150 kW WTGs with a few 2 MW WTGs – if this happen, we will get the chance to see which model that perform best in this matter.

In this test case, the modelled directional probabilities are not very different from the measured ones.

Estimating met. station 5 with met. station 36 data and vice versa

The measured data from station 5 and station 36 has been compared with WindSim modelled data at the same positions but using wind data from the other station. Unfortunately, the data from station 36 is erroneous in long periods, leaving us with only 17 days of good data from February 2000. The analysis of these remaining data is shown below. A WAsP analysis has been made for comparison.

In the Figure 11 the speedup data from the two stations are shown. The actual WindSim data are calculated at one wind speed only (approx. 7-8 m/s), and the data is assumed to have a linear development as shown on the figures – passing through 0.0. If more calculation wind speeds are added, then a speedup-development is assumed stepwise linear. Examining the two figures it is easy to see, that at 10 m/s the maximum speedup is approximately 0.3 m/s, i.e. a change no more than 3%- This means that we should expect only small changes in the modified wind distributions.

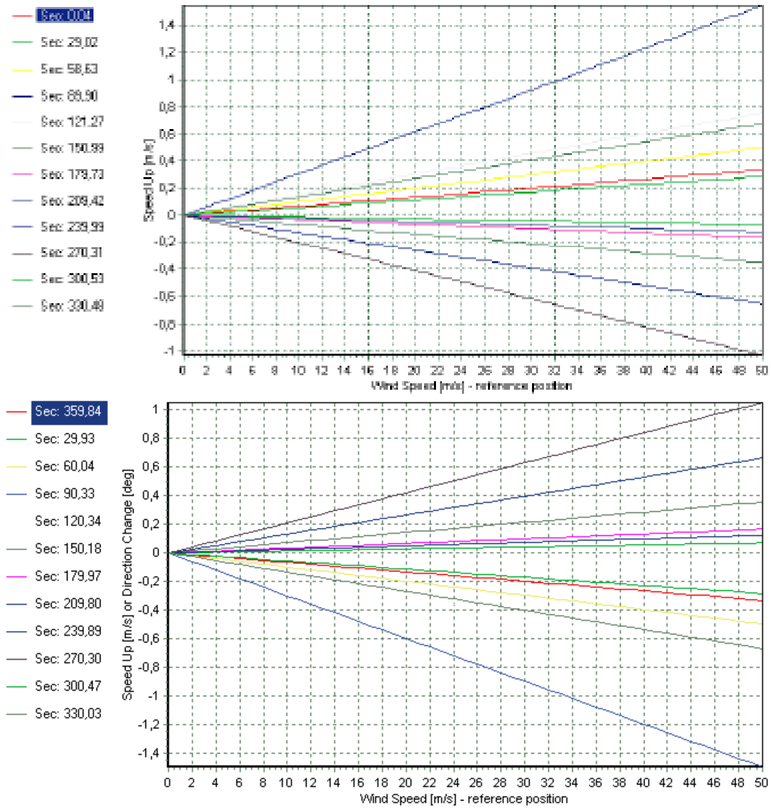

Figure 4 Speedup data from calculated sectors (left=St 36 using St 5, right = St 5 using data from St 36)

WindSim results

The measured distributions for the 17-day period and the estimates of the new wind and directional distributions are shown in Figure 12 and Figure 13. It is obvious that the predicted distributions at the other position looks very much like the one that they are derived from. This is due to the very small modification factors for all dominating sectors (SSW to NNW). It seems, that our model has not been able to capture the large differences in the two measured distributions. However, when over viewing the site, then it is obvious that both of the meteorological masts are operating in wind turbine wakes for long periods. The meteorological mast number 36 is placed only 70 meters from the nearmost turbine. Making a park analysis in WindPRO the ‘park efficiency’ is found to 92.2% for station 5 and station 36 is at 87.7% (park efficiency is calculated relative to energy levels). Interpreting the park efficiency in terms of wind speeds, approximate calculations shows that the omni directional mean wind speed at the sites is lowered with 0.19 m/s (station 5) and 0.30 m/s (station 36) relative to the free wind speed. Thus, it is concluded, that the WindSim model performs as expected and the main difference in measured wind statistics is due to wind farm wake effects. In addition, differences in anemometer calibration and/or type may cause differences in wind statistics, but this issue is not investigated further here.

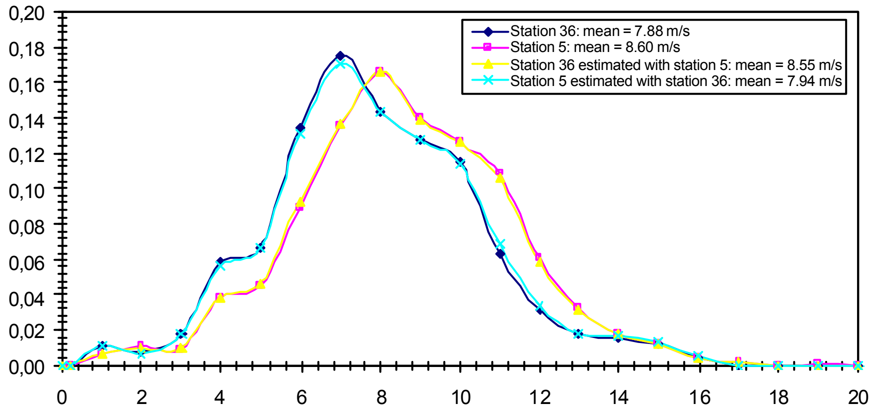

Figure 5 Sample and modified distributions for Stations 5 and 36

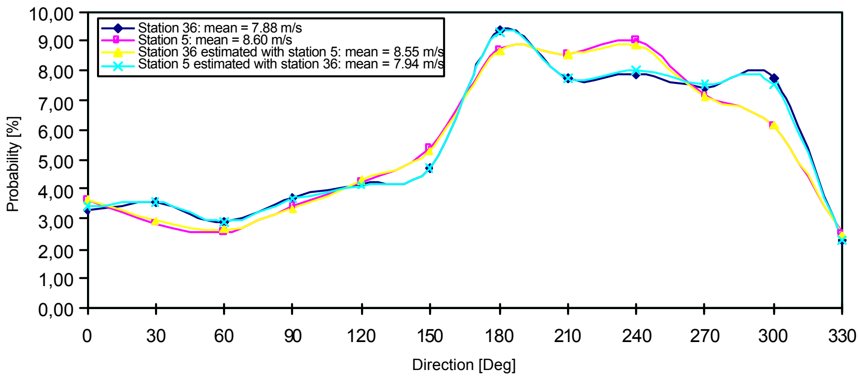

Figure 6 Directional distribution for stations 5 and 36 and the model data

WAsP results

In order to support the conclusions regarding the main differences in measured wind distributions a WAsP analysis has been performed, analysing differences in the two meteorological stations by using the 'long term' data from station 5. Only the Weibull A-parameter is reported below in Table 2. It is seen, that the differences at the two sites are almost negligible, supporting the conclusion that the main differences in the measured wind statistics comes from the wake effects.

Station	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	All
St 5 measured (long)	4.70	4.50	5.10	6.60	6.70	6.00	6.60	6.80	7.50	6.30	4.10	5.10	6.30
St 5 with 5 long term	4.73	4.67	5.15	6.59	6.73	6.03	6.57	6.90	7.42	6.35	4.59	5.11	6.34
St 36 with 5 long term	4.68	4.53	5.10	6.75	6.84	5.98	6.50	6.83	7.67	6.74	4.68	5.17	6.45

Table 2: Weibull A-parameters for estimated with different meteorological stations (5 and 36).

Comparing with production data

The production data from the turbines have been analysed in [i], and the results from this reference is used here. The WindSim results have been save in a rsf-file and processed using the PARK module in WindPRO in order to include wake effects. The results from the analysis are shown in the Figure 14 where data from the 'Goodness' indexes for all turbines on site is plotted. The 'Goodness' is defined as the ratio between the actual measured production and the calculated (modelled) production, i.e. a 'Goodness' larger than 1.0 is an underestimation of the actual measured production.

When inspecting the Figure 14 it is obvious that both models seem to underestimate the actual measured production. As stated before in 3.3, the WAsP model over-estimates the wind climate even if the same position is estimated. This may account for some of the difference between the two models. Also, results from the WAsP model seems to somewhat correlate to the height (green line in graph below), i.e. 'high' altitudes may also be followed by a relative large 'Goodness'. The WindSim model does not have the same trend, but seems to increase in 'Goodness' as the distance from the meteorological mast increases.

So a promising thing about WindSim is that is seem to "catch" the lower sited WTGs much better (WTG 5 and 9), which indeed is a positive trend. Thus, this may invoke much improvement at sites with more complex terrain. WindSim predicts the WTGs farther away from met mast worse. This may be caused by the fact that a WindSim micro siting analysis does not take roughness at longer distance into the calculation (except in cases where the analysis has been run as a nested analysis). In general, it seems that the 'physical' roughness description used in WindSim does not capture the effect of the complex roughness as well as the more refined (but experience based) treatment of roughness in WAsP. This lead to conclusion, that WindSim performs its optimum at sites with more simple roughness and complex orography.

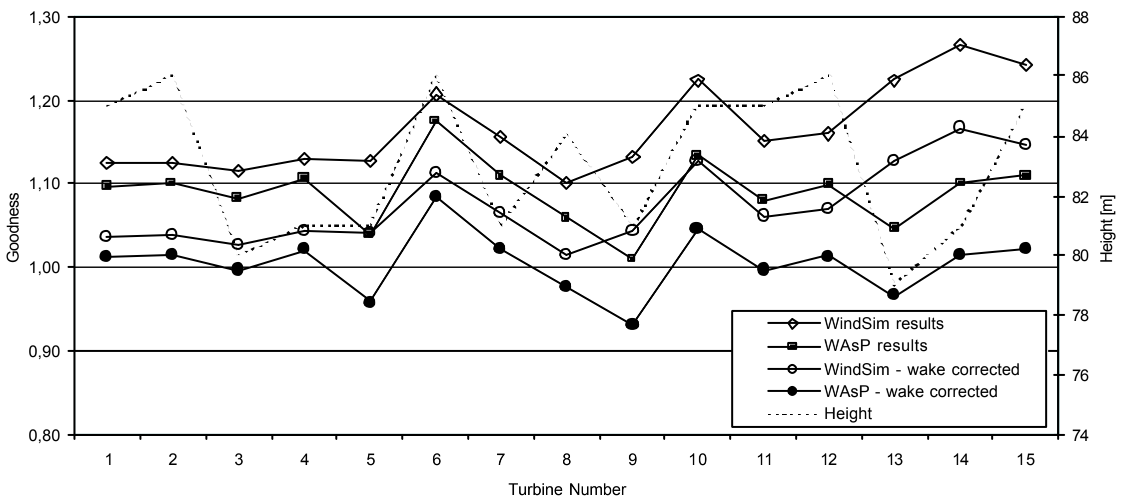

Figure 7 Comparing energy production calculated from WindSim with those calculated with WAsP.

When finding that both initial WindSim and WAsP calculation as well underestimate the actual measured production, then we may look for other sources of error than pure model errors. This may be a too conservative power curve, however the power curve seems fine when compared to the HP generic power curves, see [i]. Another obvious source of error could be wind speeds measured too low. This may be initiated by:

- Boom effects
- Wake effects from the nearby turbines (which may be the most probable cause)

- Anemometer errors (e.g. from wear and tear) – calibration required
- False positioning of met mast relative to height contours (or 'disturbances' in the actual wind profile – e.g. a zero displacement height)

As stated in Section 3.3.4, the wakes from nearby turbines influences the measured wind speeds significantly. When making a rough correction of the wake influence (simply by adjusting the calculated wind energy with the 'park efficiency' factors as stated in Section 3.3.4), then the WAsP results are now within ±9%. The WindSim calculations still – in mean - underestimate the actual production, but within a reasonable margin, see Figure 14 and Table 3. One main reason for the underestimation of the energy is believed to rise from lack of a good/validated free wind distribution. In new wind farm projects, this issue does not occur, but in validation cases, it is of outmost importance to have tools for analysing and 'cleaning' the data from wake effects. This feature is currently being implemented in an upcoming version of WindPRO – expected release in winter 2002 / spring 2003.

Statistic	Goodness from	
	WindSim	WAsP
Max	1.167	1.083
Min	1.014	0.931
Mean	1.075	1.005
Standard deviation	0.048	0.037

Table 3: Goodness - Wake Corrected.

Discussion/Conclusion

The case study has demonstrated the application of the new tools available in WindPRO for linking existing data into a WindSim/WindPRO joint analysis. The ease of extracting the WindSim input files enables the user to gain the benefit of a second opinion analysis based on an alternative model to WAsP.

The actual case study from Torrild shows, that the site fits the WAsP model best – it is a typical Danish site – event if the orography is some of the 'roughest' that we may find in Denmark. The WindSim model seem to have problems with taking complex roughness into account, but it also seem to improve handling of the orography. In addition, it must be noted that the WindSim model has its strengths in sites with complex orography and not sites with complex roughness - as the current site.