

Project:

WP A15-Lingewaard

Licensed user:

Solidwinds

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Calculated:

13-12-2017 01:38/3.1.617



PARK - Main Result

Calculation: PARK calculation (5 x V150 @ 166m, + LT CORR + MITIGATION)

Wake Model

N.O. Jensen (RISØ/EMD)

Calculation Settings

Air density calculation mode Individual per WTG
 Result for WTG at hub altitude 1,226 kg/m³ to 1,226 kg/m³
 Air density relative to standard 100,1 % to 100,1 %
 Hub altitude above sea level (asl) 172,5 m to 176,0 m
 Annual mean temperature at hub alt. 8,8 °C to 8,8 °C
 Pressure at WTGs 991,9 hPa to 992,3 hPa

Wake Model Parameters

Terrain type Wake decay constant
 HH:150m Mixed farmland 0,059

Displacement heights from objects

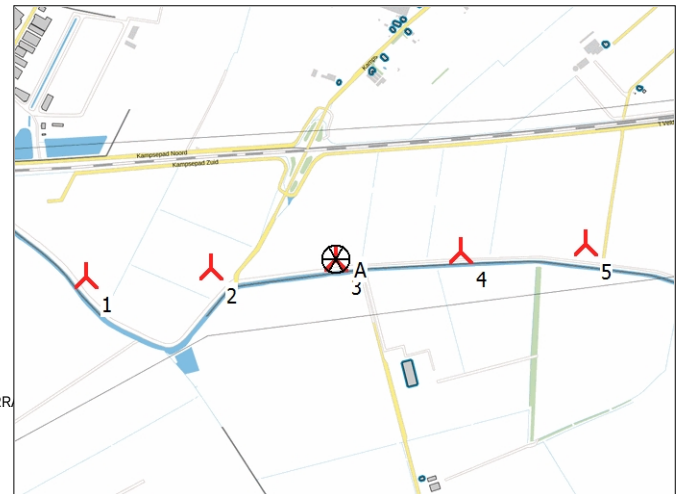
Wake calculation settings
 Angle [°] Wind speed [m/s]
 start end step start end step
 0,5 360,0 1,0 0,5 30,5 1,0

Wind statistics

NL Windmeetmast Ressen (1 yr) (Regression MCP using MERR)

WASP version

WASP 11 Version 11.02.0062



New WTG

Scale 1:25.000
Site Data

Key results for height 166,0 m above ground level

Terrain Dutch Stereo-RD/NAP 2000

X (east) Y (north) Name of wind distribution Type

A 193.147 434.804 WASP object

WASP (WASP 11 Version 11.02.0062)

Wind energy
[kWh/m²]
4.077Mean wind speed
[m/s]
7,7Equivalent roughness
1,7

Calculated Annual Energy for Wind Farm

WTG combination	Result		GROSS (no loss)	Park efficiency	Specific results ^{a)}			Full load hours	Mean wind speed @hub height
	PARK	Result-11,6%			Capacity factor	Mean WTG result			
	[MWh/y]	[MWh/y]	[MWh/y]	[%]	[%]	[MWh/y]	[Hours/year]		[m/s]
Wind farm	87.749,9	77.570,9	94.604,8	92,8	44,2	15.514,2	3.879		7,7

^{a)} Based on Result-11,6%

Calculated Annual Energy for each of 5 new WTGs with total 20,0 MW rated power

WTG type				Power curve			Annual Energy		Park Efficiency	Free mean wind speed
Links	Valid	Manufact.	Type-generator	Power, rated	Rotor diameter	Hub height	Creator	Name		
				[kW]	[m]	[m]			Result	Result-11,6%
									[MWh]	[MWh]
1 A	No	VESTAS	V150-4.20 (SW)-4.000	4.000	150,0	166,0	USER	PC 4.2 MW (mode P01)	18.018,8	15.929
2 A	No	VESTAS	V150-4.20 (SW)-4.000	4.000	150,0	166,0	USER	PC 4.2 MW (mode P01)	17.371,7	15.357
3 A	No	VESTAS	V150-4.20 (SW)-4.000	4.000	150,0	166,0	USER	PC 4.2 MW (mode P01)	17.227,9	15.229
4 A	No	VESTAS	V150-4.20 (SW)-4.000	4.000	150,0	166,0	USER	PC 4.2 MW (mode P01)	17.298,7	15.292
5 A	No	VESTAS	V150-4.20 (SW)-4.000	4.000	150,0	166,0	USER	PC 4.2 MW (mode P01)	17.832,9	15.764

WTG siting

Dutch Stereo-RD/NAP 2000

X (east) Y (north) Z Row data/Description

			[m]	
1 New	192.319	434.749	10,0	WT1
2 New	192.733	434.778	8,0	WT2
3 New	193.147	434.804	7,3	WT3
4 New	193.561	434.831	6,5	WT4
5 New	193.975	434.858	7,7	WT5

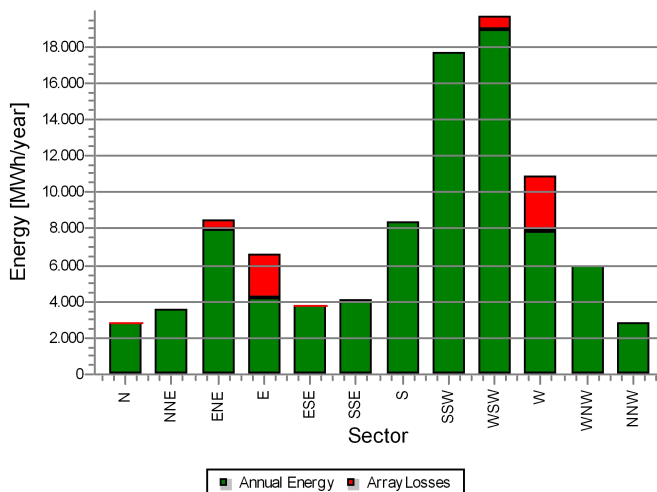


PARK - Production Analysis

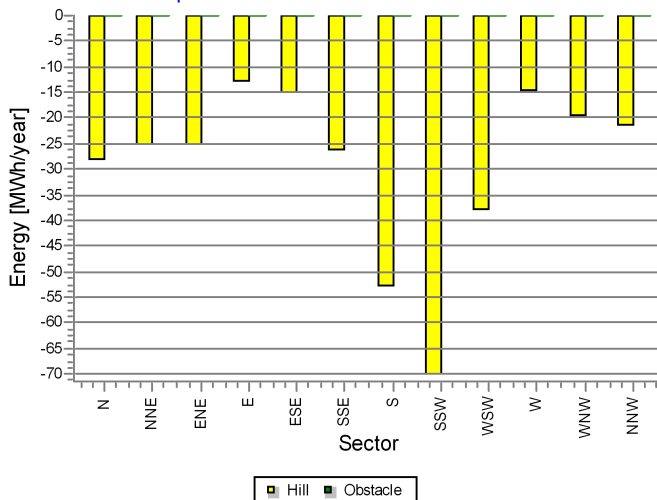
Calculation: PARK calculation (5 x V150 @ 166m, + LT CORR + MITIGATION) WTG: All new WTGs, Air density 1,226 kg/m³
Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	2.832,0	3.560,4	8.506,9	6.641,9	3.759,6	4.127,0	8.452,3	17.672,3	19.665,9	10.924,4	6.000,8	2.814,5	94.958,0
+ Increase due to hills	[MWh]	-28,6	-25,5	-25,6	-13,2	-15,3	-26,6	-53,2	-70,3	-38,2	-14,9	-19,9	-21,8	-353,2
- Decrease due to array losses	[MWh]	0,0	0,0	509,0	2.472,3	8,2	0,0	0,0	0,0	778,9	3.076,2	10,4	0,0	6.854,9
Resulting energy	[MWh]	2.803,5	3.534,8	7.972,3	4.156,4	3.736,1	4.100,4	8.399,1	17.602,0	18.848,8	7.833,3	5.970,5	2.792,7	87.749,9
Specific energy	[kWh/m ²]													993
Specific energy	[kWh/kW]													4.387
Increase due to hills	[%]	-1,0	-0,7	-0,3	-0,2	-0,4	-0,6	-0,6	-0,4	-0,2	-0,1	-0,3	-0,8	-0,37
Decrease due to array losses	[%]	0,0	0,0	6,0	37,3	0,2	0,0	0,0	0,0	4,0	28,2	0,2	0,0	7,25
Utilization	[%]	37,6	36,6	30,3	22,4	37,0	32,9	27,3	22,6	19,9	17,4	29,9	34,9	24,3
Operational	[Hours/year]	393	430	818	642	394	394	717	1.321	1.489	903	589	370	8.459
Full Load Equivalent	[Hours/year]	140	177	399	208	187	205	420	880	942	392	299	140	4.387

Energy vs. sector



Impact of hills and obstacles vs. sector





PARK - Power Curve Analysis

Calculation: PARK calculation (5 x V150 @ 166m, + LT CORR + MITIGATION)WTG: 1 - VESTAS V150-4.20 (SW) 4000 150.0 !O! PC 4.2 MW (mode P01), Hub height: 166,0 m
Name: PC 4.2 MW (mode P01)
Source: Document no.: 0067-7067 V07

Source/Date	Created by	Created	Edited	Stop wind speed [m/s]	Power control	CT curve type	Generator type	Specific power kW/m ²
13-11-2017	USER	12-12-2017	12-12-2017	25,0	Pitch	Standard pitch	Variable	0,23

HP curve comparison - Note: For standard air density and weibull k parameter = 2

Vmean	[m/s]	5	6	7	8	9	10
HP value Pitch, variable speed (2013)	[MWh]	8.424	12.260	15.746	18.708	21.120	22.991
VESTAS V150-4.20 (SW) 4000 150.0 !O! PC 4.2 MW (mode P01)	[MWh]	8.757	12.743	16.376	19.440	21.860	23.623
Check value	[%]	-4	-4	-4	-4	-3	-3

The table shows comparison between annual energy production calculated on basis of simplified "HP-curves" which assume that all WTGs performs quite similar - only specific power loading (kW/m²) and single/dual speed or stall/pitch decides the calculated values. Productions are without wake losses.

For further details, ask at the Danish Energy Agency for project report J.nr. 51171/00-0016 or see windPRO manual chapter 3.5.2.

The method is refined in EMD report "20 Detailed Case Studies comparing Project Design Calculations and actual Energy Productions for Wind Energy Projects worldwide", jan 2003.

Use the table to evaluate if the given power curve is reasonable - if the check value are lower than -5%, the power curve probably is too optimistic due to uncertainty in power curve measurement.

Power curve

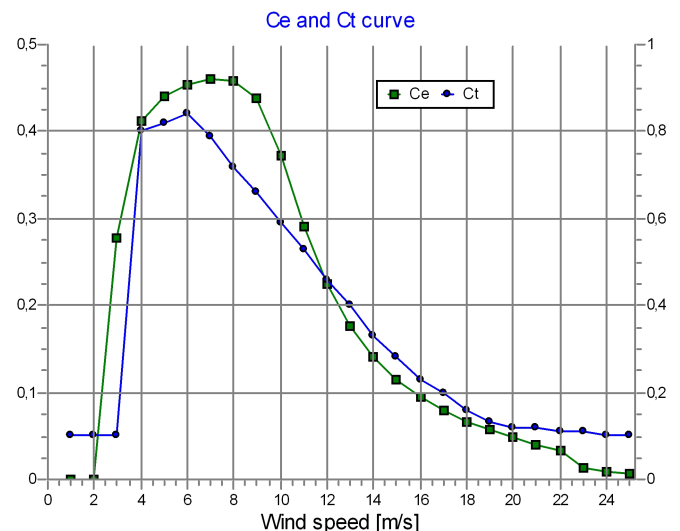
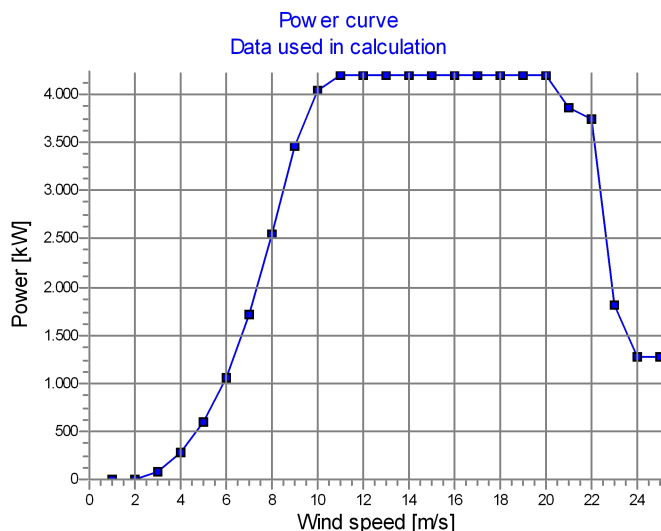
Original data, Air density: 1,225 kg/m³

Wind speed [m/s]	Power [kW]	Ce	Wind speed [m/s]	Ct curve
3,0	81,0	0,28	1,0	0,10
4,0	285,0	0,41	2,0	0,10
5,0	597,0	0,44	3,0	0,10
6,0	1.062,0	0,45	4,0	0,80
7,0	1.709,0	0,46	5,0	0,82
8,0	2.545,0	0,46	6,0	0,84
9,0	3.458,0	0,44	7,0	0,79
10,0	4.038,0	0,37	8,0	0,72
11,0	4.191,0	0,29	9,0	0,66
12,0	4.200,0	0,22	10,0	0,59
13,0	4.200,0	0,18	11,0	0,53
14,0	4.200,0	0,14	12,0	0,46
15,0	4.200,0	0,11	13,0	0,40
16,0	4.200,0	0,09	14,0	0,33
17,0	4.200,0	0,08	15,0	0,28
18,0	4.200,0	0,07	16,0	0,23
19,0	4.200,0	0,06	17,0	0,20
20,0	4.200,0	0,05	18,0	0,16
21,0	3.870,0	0,04	19,0	0,13
22,0	3.745,0	0,03	20,0	0,12
23,0	1.805,0	0,01	21,0	0,12
24,0	1.283,0	0,01	22,0	0,11
			23,0	0,11
			24,0	0,10

Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 1,226 kg/m³ New windPRO method (adjusted IEC method, improved to match turbine control) <RECOMMENDED>

Wind speed [m/s]	Power [kW]	Ce	Interval [m/s]	Energy [MWh]	Acc. Energy [MWh]	Relative [%]
1,0	0,0	0,00	0,50- 1,50	0,0	0,0	0,0
2,0	0,0	0,00	1,50- 2,50	0,0	0,0	0,0
3,0	81,0	0,28	2,50- 3,50	54,9	54,9	0,3
4,0	285,0	0,41	3,50- 4,50	226,2	281,1	1,6
5,0	597,0	0,44	4,50- 5,50	545,0	826,1	4,6
6,0	1.062,0	0,45	5,50- 6,50	1.034,7	1.860,8	10,3
7,0	1.709,0	0,46	6,50- 7,50	1.653,8	3.514,6	19,5
8,0	2.545,0	0,46	7,50- 8,50	2.267,8	5.782,4	32,1
9,0	3.458,0	0,44	8,50- 9,50	2.631,3	8.413,7	46,7
10,0	4.038,0	0,37	9,50-10,50	2.551,0	10.964,8	60,9
11,0	4.191,0	0,29	10,50-11,50	2.122,4	13.087,1	72,6
12,0	4.200,0	0,22	11,50-12,50	1.603,5	14.690,6	81,5
13,0	4.200,0	0,18	12,50-13,50	1.149,5	15.840,1	87,9
14,0	4.200,0	0,14	13,50-14,50	794,5	16.634,6	92,3
15,0	4.200,0	0,11	14,50-15,50	531,8	17.166,3	95,3
16,0	4.200,0	0,09	15,50-16,50	345,1	17.511,4	97,2
17,0	4.200,0	0,08	16,50-17,50	216,9	17.728,3	98,4
18,0	4.200,0	0,07	17,50-18,50	131,9	17.860,2	99,1
19,0	4.200,0	0,06	18,50-19,50	77,5	17.937,7	99,5
20,0	4.200,0	0,05	19,50-20,50	43,2	17.980,9	99,8
21,0	3.870,0	0,04	20,50-21,50	22,5	18.003,5	99,9
22,0	3.745,0	0,03	21,50-22,50	10,3	18.013,8	100,0
23,0	1.805,0	0,01	22,50-23,50	3,6	18.017,4	100,0
24,0	1.283,0	0,01	23,50-24,50	1,1	18.018,5	100,0
25,0	1.283,0	0,01	24,50-25,50	0,3	18.018,8	100,0



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PARK - Terrain

Calculation: PARK calculation (5 x V150 @ 166m, + LT CORR + MITIGATION)Site Data: A - WAsP object

Obstacles:

0 Obstacles used

Roughness:

Terrain data files used in calculation:

C:\WindPro 3.1\Projects\WP A15-Lingewaard\ROUGHNESSLINE_WP A15-Lingewaard_0.wpo

Min X: 161.365, Max X: 224.143, Min Y: 402.877, Max Y: 466.578, Width: 62.777 m, Height: 63.701 m

Orography:

Terrain data files used in calculation:

C:\WindPro 3.1\Projects\WP A15-Lingewaard\WP A15-Lingewaard_EMDGrid_0.wpg

Min X: 178.026, Max X: 208.346, Min Y: 419.705, Max Y: 449.942, Width: 30.320 m, Height: 30.237 m



PARK - Wind Data Analysis

Calculation: PARK calculation (5 x V150 @ 166m, + LT CORR + MITIGATION) Wind data: A - WASP object; Hub height: 166,0

Site coordinates

Dutch Stereo-RD/NAP 2000

East: 193.147 North: 434.804

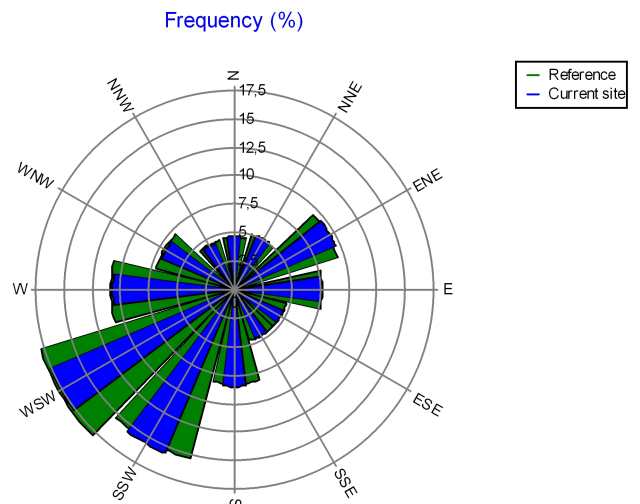
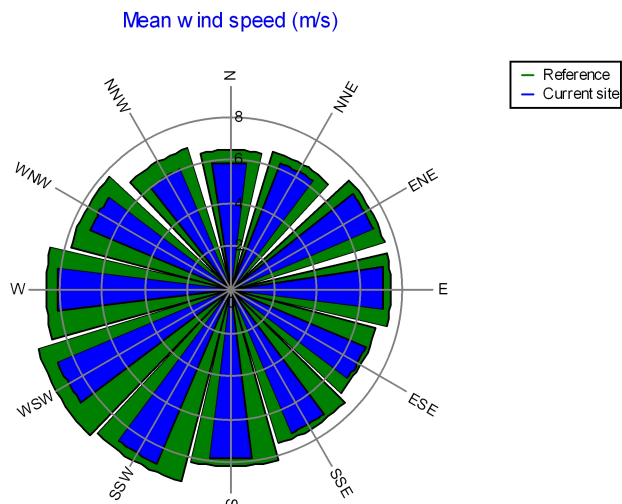
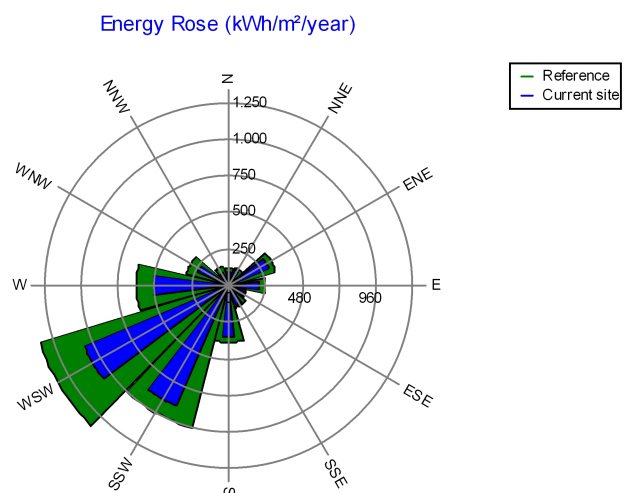
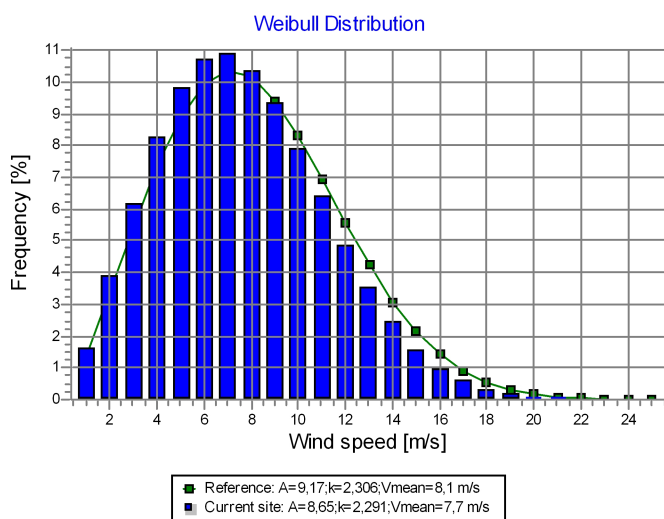
WT3

Wind statistics

NL Windmeetmast Ressen (1 yr) (Regression MCP using MERRA_basic_E06.001 N52.000 E006.188)

Weibull Data

Sector	Current site		Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]		A- parameter [m/s]	k- parameter	Frequency [%]
1 NNE	7,10	6,30	2,318	7,32	2,282	4,6
2 ENE	8,09	7,18	2,475	7,53	2,471	5,0
3 E	7,99	7,13	2,561	8,41	2,554	9,5
4 ESE	7,63	6,80	2,908	8,37	2,886	7,7
5 SSE	7,63	6,80	2,854	7,84	2,870	4,7
6 S	8,10	7,19	2,627	8,38	2,629	4,6
7 SSW	8,81	7,81	2,455	9,22	2,456	8,2
8 WSW	9,85	8,73	2,451	10,30	2,455	15,3
9 W	9,84	8,72	2,291	10,60	2,297	17,8
10 WNW	9,13	8,09	2,307	9,71	2,309	10,9
11 NNW	8,03	7,11	2,326	8,70	2,309	7,1
All	6,83	6,04	2,170	7,71	2,167	4,5
	8,65	7,66	2,291	9,17	2,306	100,0





PARK - Park power curve

Calculation: PARK calculation (5 x V150 @ 166m, + LT CORR + MITIGATION)

Wind speed	Free WTGs	Park WTGs	N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW
[m/s]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
0,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5	915	850	915	915	862	638	913	915	915	915	862	638	913	915
4,5	2.205	1.963	2.205	2.205	1.972	1.235	2.196	2.205	2.205	2.205	1.973	1.235	2.196	2.205
5,5	4.148	3.658	4.148	4.148	3.690	2.159	4.130	4.148	4.148	4.148	3.690	2.160	4.130	4.148
6,5	6.928	6.098	6.928	6.928	6.174	3.531	6.900	6.928	6.928	6.928	6.173	3.531	6.900	6.928
7,5	10.635	9.405	10.635	10.635	9.554	5.538	10.598	10.635	10.635	10.635	9.553	5.538	10.598	10.635
8,5	15.008	13.414	15.008	15.008	13.706	8.254	14.967	15.008	15.008	15.008	13.705	8.255	14.967	15.008
9,5	18.740	17.105	18.740	18.740	17.622	11.470	18.715	18.740	18.740	18.740	17.623	11.470	18.715	18.740
10,5	20.573	19.321	20.572	20.572	20.001	14.573	20.566	20.572	20.572	20.572	20.003	14.572	20.566	20.572
11,5	20.978	20.240	20.978	20.978	20.832	17.154	20.977	20.978	20.978	20.978	20.834	17.152	20.977	20.978
12,5	21.000	20.642	21.000	21.000	20.986	19.060	21.000	21.000	21.000	21.000	20.986	19.061	21.000	21.000
13,5	21.000	20.876	21.000	21.000	21.000	20.322	21.000	21.000	21.000	21.000	21.000	20.322	21.000	21.000
14,5	21.000	20.981	21.000	21.000	21.000	20.898	21.000	21.000	21.000	21.000	21.000	20.898	21.000	21.000
15,5	21.000	21.000	21.000	21.000	21.000	20.998	21.000	21.000	21.000	21.000	21.000	20.998	21.000	21.000
16,5	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000
17,5	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000
18,5	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000
19,5	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000
20,5	20.175	20.321	20.175	20.175	20.330	20.737	20.180	20.175	20.175	20.175	20.330	20.737	20.180	20.175
21,5	19.038	19.190	19.038	19.038	19.110	19.765	19.039	19.038	19.038	19.038	19.110	19.765	19.039	19.038
22,5	13.875	14.779	13.875	13.875	14.791	17.438	13.904	13.875	13.875	13.875	14.793	17.436	13.904	13.875
23,5	7.720	8.528	7.720	7.720	8.048	11.651	7.728	7.720	7.720	7.720	8.046	11.652	7.728	7.720
24,5	6.415	6.628	6.415	6.415	6.433	7.556	6.415	6.415	6.415	6.415	6.432	7.557	6.415	6.415
25,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Description:

The park power curve is similar to a WTG power curve, meaning that when a given wind speed appears in front of the park with same speed in the entire wind farm area (before influence from the park), the output from the park can be found in the park power curve. Another way to say this: The park power curve includes array losses, but do NOT include terrain given variations in the wind speed over the park area.

Measuring a park power curve is not as simple as measuring a WTG power curve due to the fact that the park power curve depends on the wind direction and that the same wind speed normally will not appear for the entire park area at the same time (only in very flat non-complex terrain). The idea with this version of the park power curve is not to use it for validation based on measurements. This would require at least 2 measurement masts at two sides of the park, unless only a few direction sectors should be tested, AND non complex terrain (normally only useable off shore). Another park power curve version for complex terrain is available in windPRO.

The park power curve can be used for:

1. Forecast systems, based on more rough (approximated) wind data, the park power curve would be an efficient way to make the connection from wind speed (and direction) to power.
2. Construction of duration curves, telling how often a given power output will appear, the park power curve can be used together with the average wind distribution for the Wind farm area in hub height. The average wind distribution can eventually be obtained based on the Weibull parameters for each WTG position. These are found at print menu: >Result to file< in the >Park result< which can be saved to file or copied to clipboard and pasted in Excel.
3. Calculation of wind energy index based on the PARK production (see below).
4. Estimation of the expected PARK production for an existing wind farm based on wind measurements at minimum 2 measurement masts at two sides of wind farm. The masts must be used for obtaining the free wind speed. The free wind speed is used in the simulation of expected energy production with the PARK power curve. This procedure will only work suitable in non complex terrains. For complex terrain another park power curve calculation is available in windPRO (PPV-model).

Note:

From the >Result to file< the >Wind Speeds Inside Wind farm< is also available. These can (e.g. via Excel) be used for extracting the wake induced reductions in measured wind speed.



PARK - WTG distances

Calculation: PARK calculation (5 x V150 @ 166m, + LT CORR + MITIGATION)

WTG distances

	Z	Nearest WTG	Z	Horizontal distance	Distance in
	[m]		[m]	[m]	rotor diameters
1	10,0	2	8,0	415	2,8
2	8,0	3	7,3	415	2,8
3	7,3	4	6,5	415	2,8
4	6,5	3	7,3	415	2,8
5	7,7	4	6,5	415	2,8
Min	6,5		6,5	415	2,8
Max	10,0		8,0	415	2,8



Scale 1:25.000

New WTG



PARK - Wind statistics info

Calculation: PARK calculation (5 x V150 @ 166m, + LT CORR + MITIGATION)

Main data for wind statistic

File C:\WindPro 3.1\Projects\WP A15-Lingewaard\NL Windmeetmast Ressen (1 yr) (Regression MCP using MERRA_basic_E06.001_N52.000 (50) (1)).wws
 Name Windmeetmast Ressen (1 yr) (Regression MCP using MERRA_basic_E06.001_N52.000 (50) (1))
 Country Netherlands
 Source USER
 Mast coordinates Dutch Stereo-RD/NAP 2000 East: 186.106 North: 433.970
 Created 12-12-2017
 Edited 12-12-2017
 Sectors 12
 WAsP version WAsP 11 Version 11.02.0062
 Displacement height None

Comments

From MCP

Additional info for wind statistic

Based on measurement height 70,0 m
 Base elevation for measurement mast 8,9 m

Long term correction information

Method Regression MCP
 Source data MERRA_basic_E06.001_N52.000 (50) (1)
 Distance to source data 16,3 km
 Long term period from 1-1-1984
 Long term period to 1-8-2014
 Concurrent period from 13-4-2013
 Concurrent period to 13-4-2014
 Concurrent data records 8569
 Concurrent record interval 60 minutes
 Concurrent data recovery 98,9 %

Number of years with long term data 30,6 years
 Number of months with concurrent data 11,7 Months

Correlation test based on Concurrent monthly wind indices

Power curve used for index Simple power curve truncated at: 14,0 m/s
 Data availability demand for inclusion of month 60 %
 Number of months 11
 r^2 - wind index 0,9896
 r - wind index 0,9948
 s - wind index 3,2633

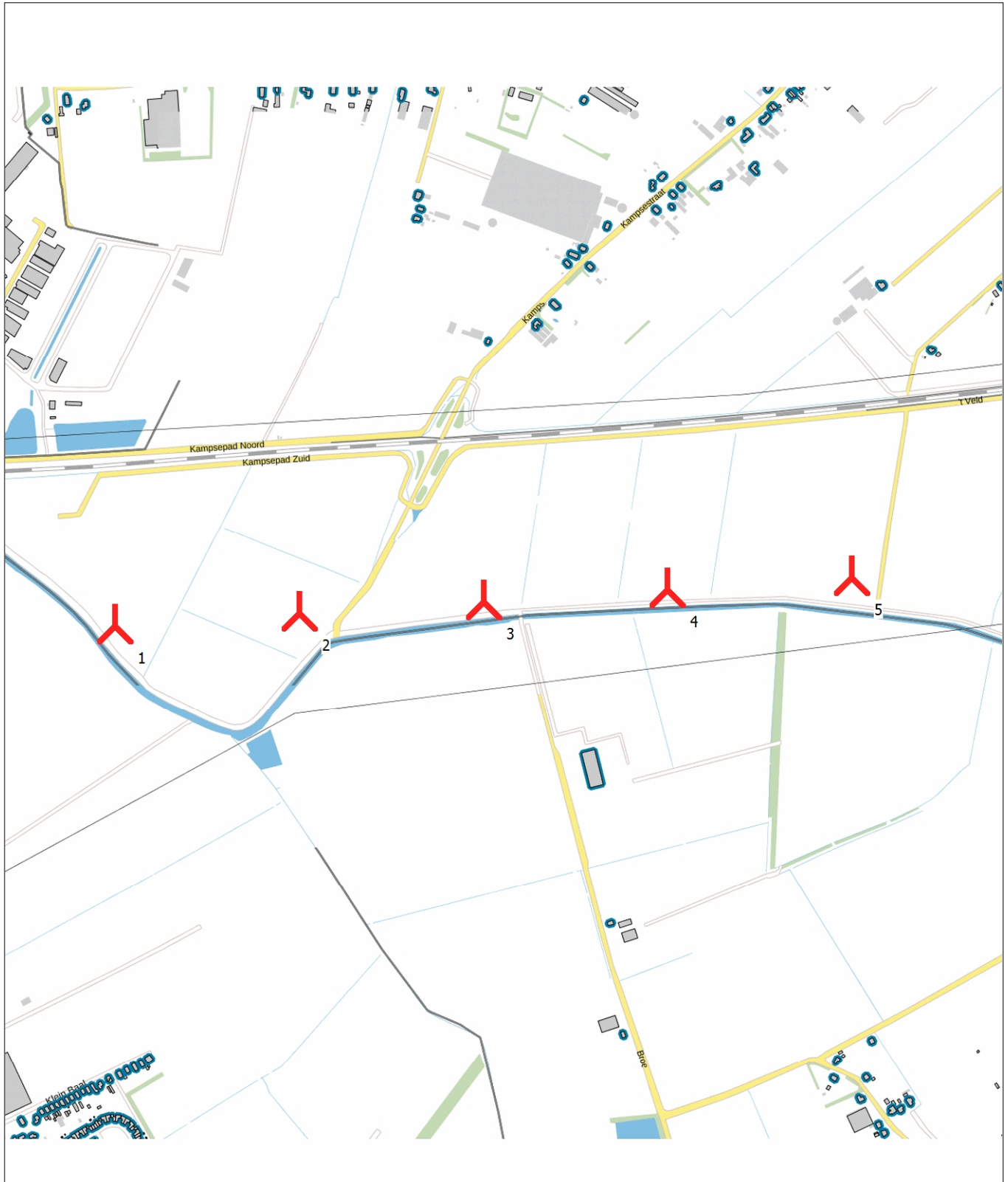
Note

To get the most correct calculation results, wind statistics shall be calculated with the SAME model and model parameters, as currently chosen in calculation. For WAsP versions before 10.0, the model is unchanged, but thereafter more model changes affecting the wind statistic is seen. Likewise WAsP CFD should always use WAsP CFD calculated wind statistics.



PARK - Map

Calculation: PARK calculation (5 x V150 @ 166m, + LT CORR + MITIGATION)



Map: BAG kaart groot , Print scale 1:12.500, Map center Dutch Stereo-RD/NAP 2000 East: 193.147 North: 434.803

New WTG