ENERCON

Site Assessment Report

Energy Yield Estimation

Wind farm:
Ascog Farm (GB)

3 x E-48 800kW with 50m hh

ENERCON
ENERGIE FÜR DIE WELT

Imprint

Publisher

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Project:
Ascog Farm

E_2013_037

Description:
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2013-04-22 11:56/2.8.579

PARK - Main Result

Calculation: Energy Yield Estimation: 3 x ENERCON E-48 800kW with 50m hh

Wake Model N.O. Jensen (RISØ/EMD)

Calculation Settings

Air density calculation mode	Individual per WTG
Result for WTG at hub altitude	1.234 kg/m³ to 1.237 kg/m³
Air density relative to standard	100.8 % to 101.0 %
Hub altitude above sea level (asl)	126.4 m to 150.0 m
Annual mean temperature at hub alt.	7.7 °C to 7.8 °C
Pressure at WTGs	995.0 hPa to 997.8 hPa

Wake Model Parameters

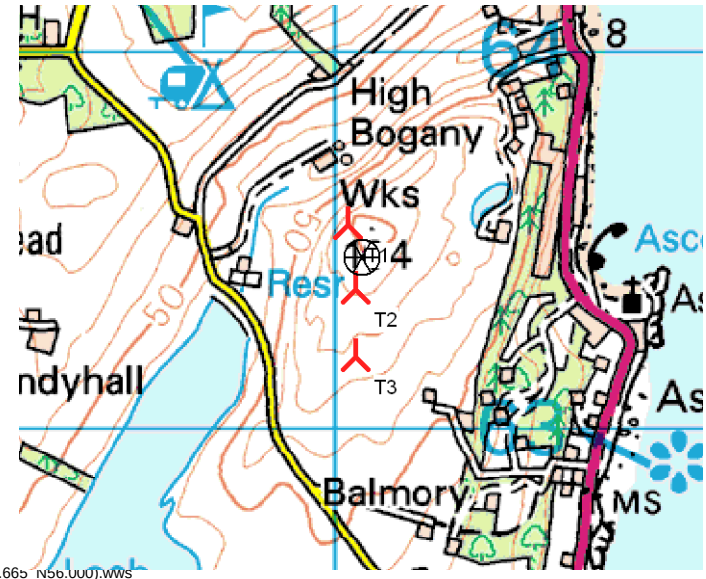
From angle [°]	To angle [°]	Terrain type	Wake Decay Constant
345.0	15.0		0.089
15.0	45.0		0.078
45.0	75.0		0.051
75.0	105.0		0.059
105.0	135.0		0.053
135.0	165.0		0.062
165.0	195.0		0.070
195.0	225.0		0.061
225.0	255.0		0.057
255.0	285.0		0.065
285.0	315.0		0.086
315.0	345.0		0.084

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 GB Ascog WMM (Wind Index MCP using MERRA_basic_W04.665_N56.000).wws

WAsP version WAsP 6-9 2.8.579



Scale 1:20,000

New WTG Site Data

Key results for height 50.0 m above ground level

Terrain **BN (AIRY) (Normal)**

	East	North	Name of wind distribution	Type	Wind energy [kWh/m²]	Mean wind speed [m/s]	Equivalent roughness
A	210,080	663,449	Ascog Farm PARK TDO	WAsP (WAsP 6-9 2.8.579)	5,185	7.9	-0.2

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	Result-12.0% [MWh]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Specific results¤) Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	7,917.8	6,967.6	8,104.2	97.7	33.1	2,322.5	2,903	7.7

¤) *Based on Result-12.0%*

Calculated Annual Energy for each of 3 new WTGs with total 2.4 MW rated power

	Terrain	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Result-12.0% [MWh]	Park Efficiency [%]	Mean wind speed [m/s]
1	A	Yes	ENERCON GmbH	E-48-800	800	48.0	50.0	USER	Power curve Guar. Rev. 2.0	2,754.0	2,424	96.96	7.92
2	A	Yes	ENERCON GmbH	E-48-800	800	48.0	50.0	USER	Power curve Guar. Rev. 2.0	2,642.4	2,325	96.89	7.72
3	A	Yes	ENERCON GmbH	E-48-800	800	48.0	50.0	USER	Power curve Guar. Rev. 2.0	2,521.3	2,219	99.40	7.38

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PARK - Main Result

Calculation: Energy Yield Estimation: 3 x ENERCON E-48 800kW with 50m hh

WTG siting

BN (AIRY) (Normal)

		East	North	Z [m]	Row data/Description
1	New	210,043	663,535	100.0	ENERCON GmbH E-48 800 48.0 !O! hub: 50.0 m (TOT: 74.0 m) (8)
2	New	210,063	663,365	90.5	ENERCON GmbH E-48 800 48.0 !O! hub: 50.0 m (TOT: 74.0 m) (9)
3	New	210,063	663,185	76.4	ENERCON GmbH E-48 800 48.0 !O! hub: 50.0 m (TOT: 74.0 m) (10)

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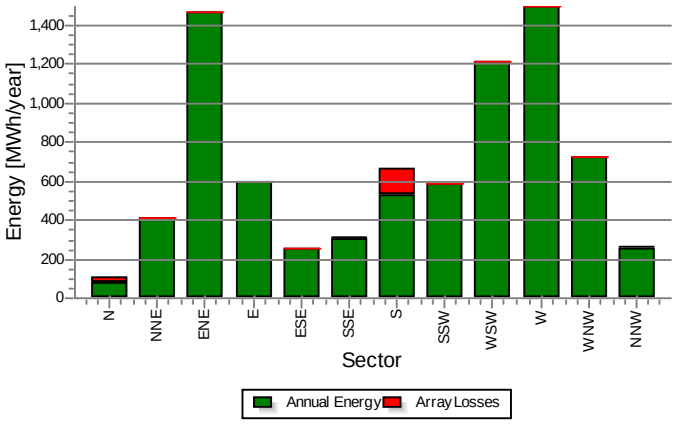
PARK - Production Analysis

Calculation: Energy Yield Estimation: 3 x ENERCON E-48 800kW with 50m hh **WTG:** All new WTGs, Air density varies with WTG position 1.234 kg/m³ - 1.237 kg/m³

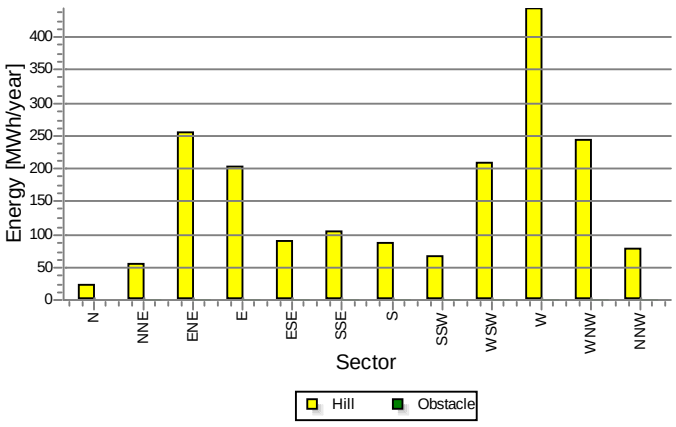
Directional Analysis

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]	80.9	354.2	1,214.6	394.1	167.1	211.6	578.3	521.2	998.5	1,052.5	482.9	183.9	6,239.8
+Increase due to hills	[MWh]	23.5	55.3	256.1	204.3	89.7	105.6	87.2	66.7	209.9	443.9	242.6	79.6	1,864.4
-Decrease due to array losses	[MWh]	25.6	0.6	0.0	0.0	0.0	9.1	141.0	0.4	0.0	0.0	0.0	9.8	186.4
Resulting energy	**[MWh]**	**78.9**	**408.9**	**1,470.7**	**598.4**	**256.8**	**308.1**	**524.4**	**587.5**	**1,208.4**	**1,496.4**	**725.6**	**253.7**	**7,917.8**
Specific energy	[kWh/m²]													1,459
Specific energy	[kWh/kW]													3,299
Increase due to hills	[%]	29.0	15.6	21.1	51.8	53.7	49.9	15.1	12.8	21.0	42.2	50.2	43.3	29.88
Decrease due to array losses	[%]	24.5	0.1	0.0	0.0	0.0	2.9	21.2	0.1	0.0	0.0	0.0	3.7	2.30
Utilization	[%]	33.1	32.9	28.8	30.4	36.4	33.8	24.5	29.1	26.9	30.1	36.5	41.5	30.0
Operational	[Hours/year]	297	542	1,265	638	381	440	645	520	915	1,262	837	506	8,246
Full Load Equivalent	[Hours/year]	33	170	613	249	107	128	218	245	504	624	302	106	3,299

Energy vs. sector



Impact of hills and obstacles vs. sector



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PARK - Power Curve Analysis

Calculation: Energy Yield Estimation: 3 x ENERCON E-48 800kW with 50m hh**WTG:** 1 - ENERCON GmbH E-48 800 48.0 !O! Power curve Guar. Rev. 2.0, Hub height: 50.0 m

Name: Power curve Guar. Rev. 2.0
Source: ENERCON GmbH

Source/Date	Created by	Created	Edited	Stop wind speed [m/s]	Power control	CT curve type	Generator type	Specific power kW/m²
2009-11-25	USER	2001-11-27	2010-03-04	25.0	Pitch	User defined	One generator	0.44

Ct-curve Rev. 2.0 (03.03.2010)

Power curve

Original data from Windcat, Air density: 1.225 kg/m³

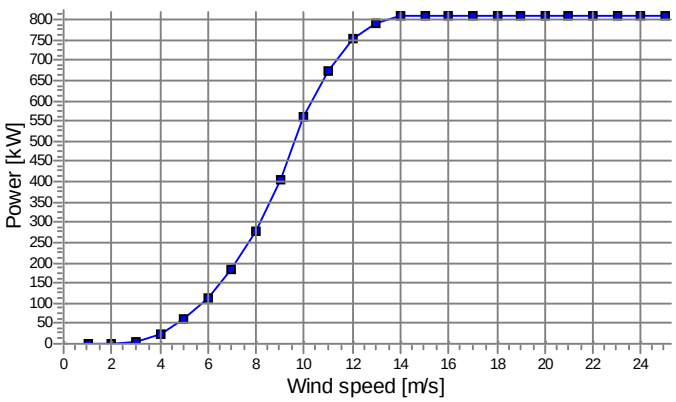
Wind speed [m/s]	Power [kW]	Ce	Wind speed [m/s]	Ct curve
1.0	0.0	0.00	1.0	0.00
2.0	0.0	0.00	2.0	0.00
3.0	5.0	0.17	3.0	0.87
4.0	25.0	0.35	4.0	0.89
5.0	60.0	0.43	5.0	0.89
6.0	110.0	0.46	6.0	0.89
7.0	180.0	0.47	7.0	0.89
8.0	275.0	0.48	8.0	0.89
9.0	400.0	0.50	9.0	0.88
10.0	555.0	0.50	10.0	0.89
11.0	671.0	0.45	11.0	0.89
12.0	750.0	0.39	12.0	0.60
13.0	790.0	0.32	13.0	0.43
14.0	810.0	0.27	14.0	0.33
15.0	810.0	0.22	15.0	0.27
16.0	810.0	0.18	16.0	0.22
17.0	810.0	0.15	17.0	0.18
18.0	810.0	0.13	18.0	0.15
19.0	810.0	0.11	19.0	0.13
20.0	810.0	0.09	20.0	0.11
21.0	810.0	0.08	21.0	0.10
22.0	810.0	0.07	22.0	0.09
23.0	810.0	0.06	23.0	0.08
24.0	810.0	0.05	24.0	0.07
25.0	810.0	0.05	25.0	0.06

Power, Efficiency and energy vs. wind speed

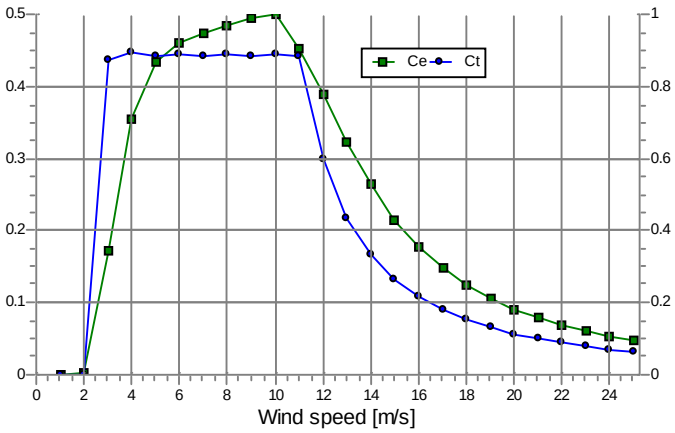
Data used in calculation, Air density: 1.234 kg/m³ New WindPRO method (adjusted IEC method, improved to match turbine control) <RECOMMENDED>

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	0.6	0.6	0.0
3.0	5.1	0.17	2.50- 3.50	5.6	6.2	0.2
4.0	25.3	0.35	3.50- 4.50	21.0	27.2	1.0
5.0	60.6	0.43	4.50- 5.50	50.0	77.2	2.8
6.0	111.0	0.46	5.50- 6.50	92.4	169.7	6.2
7.0	181.6	0.47	6.50- 7.50	146.4	316.0	11.5
8.0	277.5	0.49	7.50- 8.50	208.5	524.5	19.0
9.0	403.7	0.50	8.50- 9.50	272.4	797.0	28.9
10.0	558.4	0.50	9.50-10.50	319.7	1,116.7	40.5
11.0	674.0	0.45	10.50-11.50	330.1	1,446.8	52.5
12.0	751.8	0.39	11.50-12.50	305.1	1,751.9	63.6
13.0	791.0	0.32	12.50-13.50	259.8	2,011.7	73.0
14.0	810.0	0.26	13.50-14.50	208.2	2,219.9	80.6
15.0	810.0	0.21	14.50-15.50	159.4	2,379.4	86.4
16.0	810.0	0.18	15.50-16.50	118.2	2,497.5	90.7
17.0	810.0	0.15	16.50-17.50	85.3	2,582.9	93.8
18.0	810.0	0.12	17.50-18.50	60.1	2,643.0	96.0
19.0	810.0	0.11	18.50-19.50	41.2	2,684.2	97.5
20.0	810.0	0.09	19.50-20.50	27.5	2,711.7	98.5
21.0	810.0	0.08	20.50-21.50	18.0	2,729.7	99.1
22.0	810.0	0.07	21.50-22.50	11.4	2,741.1	99.5
23.0	810.0	0.06	22.50-23.50	7.1	2,748.1	99.8
24.0	810.0	0.05	23.50-24.50	4.3	2,752.4	99.9
25.0	810.0	0.05	24.50-25.50	1.6	2,754.0	100.0

Power curve
Data used in calculation



Ce and Ct curve



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PARK - Wind Data Analysis

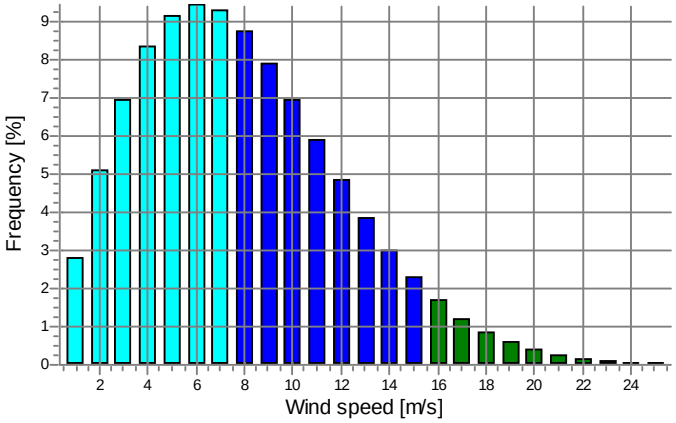
Calculation: Energy Yield Estimation: 3 x ENERCON E-48 800kW with 50m hh**Wind data:** A - Ascog Farm PARK TDO; Hub height: 50.0

Site coordinates
BN (AIRY) (Normal) East: 210,080 North: 663,449
Wind statistics
GB Ascog WMM (Wind Index MCP using MERRA_basic_W04.665_N56.000).wws

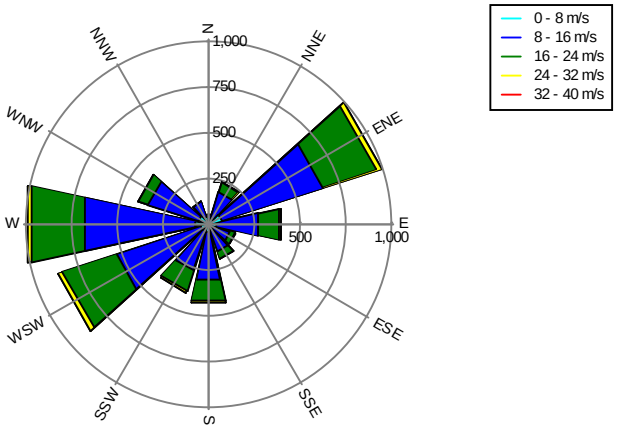
Weibull Data

Sector	Current site A- parameter [m/s]	Wind speed [m/s]	k- parameter	Frequency [%]
0 N	5.55	4.93	1.842	3.6
1 NNE	7.56	6.73	1.732	6.5
2 ENE	9.82	8.70	2.084	15.1
3 E	8.70	7.73	1.854	7.9
4 ESE	7.30	6.50	1.783	4.7
5 SSE	7.59	6.76	1.779	5.5
6 S	9.21	8.16	2.045	7.8
7 SSW	9.68	8.57	2.068	6.2
8 WSW	10.63	9.42	2.201	10.9
9 W	10.01	8.86	2.197	15.3
10 WNW	8.30	7.36	2.092	10.3
11 NNW	6.72	5.95	2.080	6.2
All	8.90	7.89	1.936	100.0

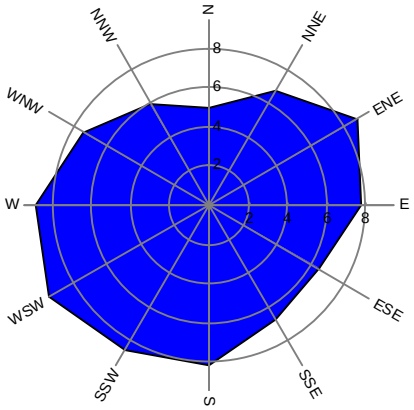
Weibull Distribution



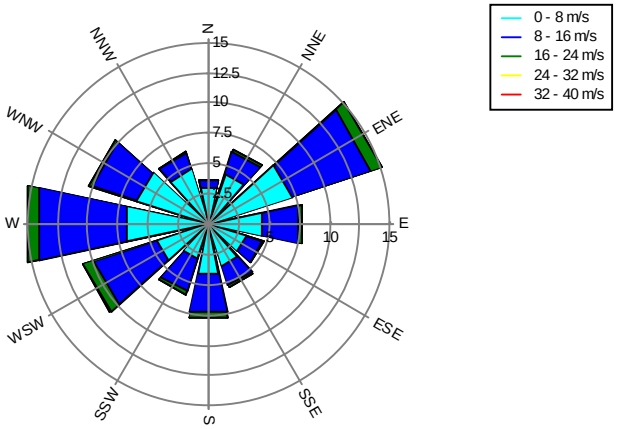
Energy Rose (kWh/m²/year)



Mean wind speed (m/s)



Frequency (%)



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PARK - Park power curve

Calculation: Energy Yield Estimation: 3 x ENERCON E-48 800kW with 50m hh

	Power													
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	8	7	6	8	8	8	8	7	6	8	8	8	8	7
3.5	46	43	27	45	46	46	46	43	26	45	46	46	46	42
4.5	129	122	81	128	129	129	129	122	78	129	129	129	129	122
5.5	257	245	170	257	257	257	257	246	165	257	257	257	257	245
6.5	439	420	298	438	439	439	439	420	289	438	439	439	439	418
7.5	688	659	473	687	688	688	688	659	459	687	688	688	688	656
8.5	1,022	978	703	1,019	1,022	1,022	1,022	979	683	1,020	1,022	1,022	1,022	974
9.5	1,447	1,385	996	1,443	1,447	1,447	1,447	1,387	968	1,444	1,447	1,447	1,447	1,380
10.5	1,852	1,780	1,316	1,849	1,852	1,852	1,852	1,787	1,277	1,851	1,852	1,852	1,852	1,782
11.5	2,143	2,083	1,704	2,141	2,143	2,143	2,143	2,097	1,655	2,142	2,143	2,143	2,143	2,099
12.5	2,316	2,284	2,092	2,316	2,316	2,316	2,316	2,301	2,034	2,316	2,316	2,316	2,316	2,301
13.5	2,403	2,394	2,340	2,403	2,403	2,403	2,403	2,398	2,320	2,403	2,403	2,403	2,403	2,398
14.5	2,430	2,428	2,418	2,430	2,430	2,430	2,430	2,430	2,412	2,430	2,430	2,430	2,430	2,430
15.5	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430
16.5	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430
17.5	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430
18.5	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430
19.5	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430
20.5	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430
21.5	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430
22.5	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430
23.5	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430
24.5	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430	2,430
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.

Project:
Ascog Farm

E_2013_037

Description:
Please see special notes and disclaimer in the attachment.

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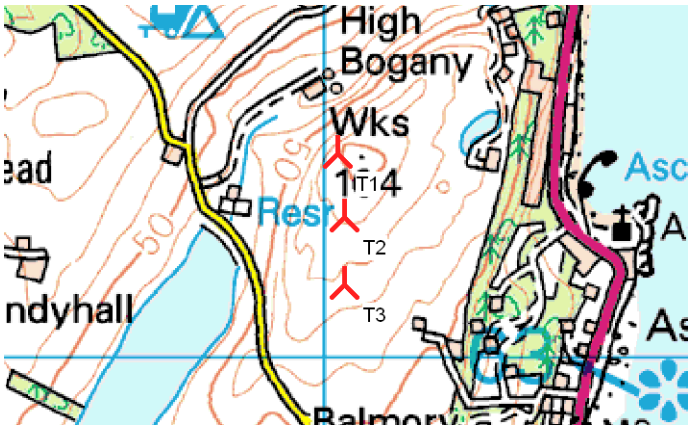
2013-04-22 11:56/2.8.579

PARK - WTG distances

Calculation: Energy Yield Estimation: 3 x ENERCON E-48 800kW with 50m hh

WTG distances

	Z	Nearest WTG	Z	Horizontal distance	Distance in rotor diameters
	[m]		[m]	[m]	
1	100.0	2	90.5	171	3.6
2	90.5	1	100.0	171	3.6
3	76.4	2	90.5	180	3.7
Min	**76.4**		**90.5**	**171**	**3.6**
Max	**100.0**		**100.0**	**180**	**3.7**



Scale 1:20,000

New WTG

Project:
Ascog Farm

E_2013_037

Description:
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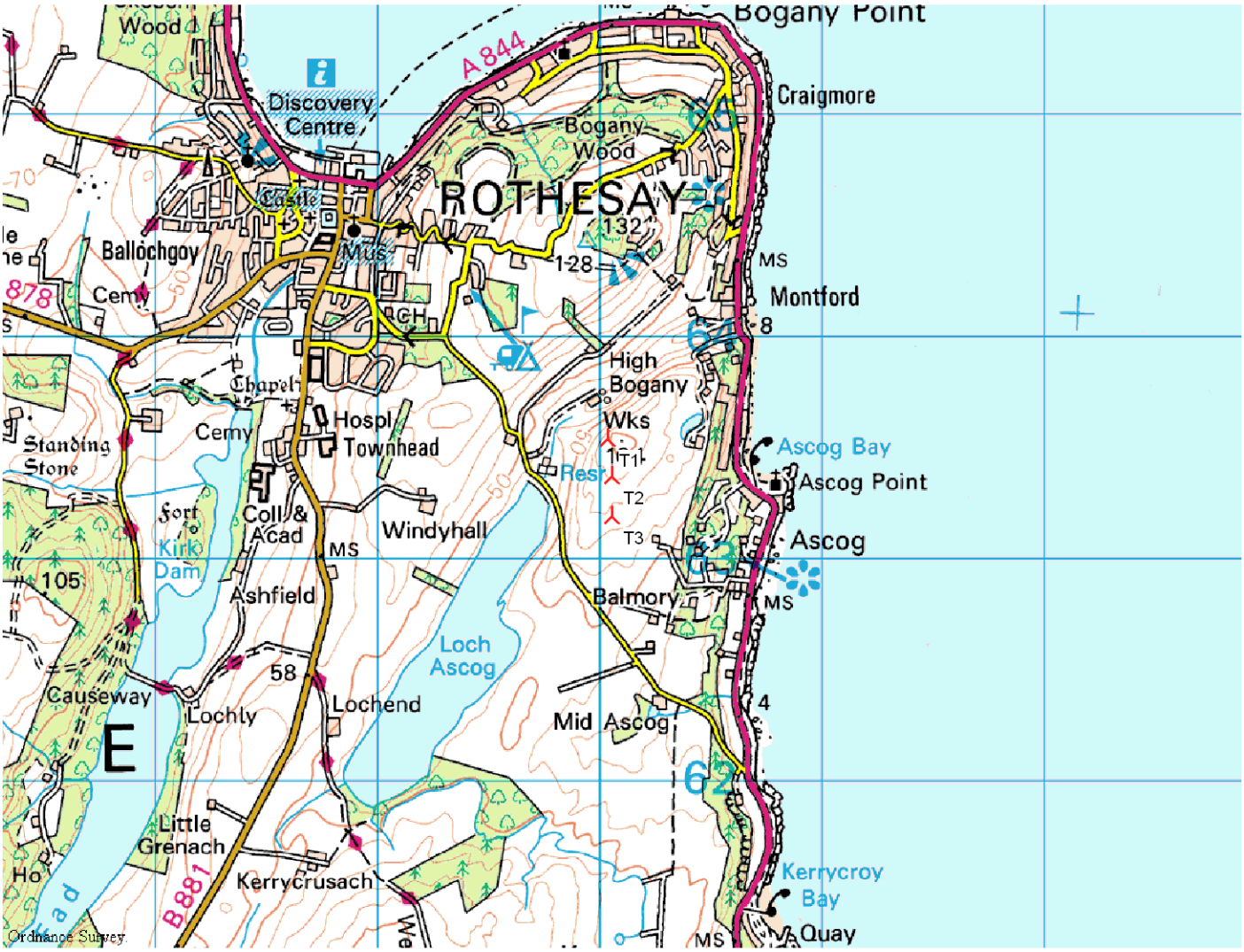
PARK - Map

Calculation: Energy Yield Estimation: 3 x ENERCON E-48 800kW with 50m hh



0 500 1000 1500 2000 m

Map: WindPRO map , Print scale 1:30,000, Map center BN (AIRY) (Normal) East: 210,053 North: 663,360

New WTG

Special notes and disclaimer:

Energy yield estimations with met masts

The energy yield was estimated using wind data achieved by wind measurements. The wind data was long-term correlated by means of MERRA reanalysis data (provided by EMD). The modelled wind conditions of the WEC locations have been transferred from the met mast using WAsP.

The annual energy production (AEP) is measured at the WEC reference point (at the 400V AC terminals behind the power cabinets). The AEP takes wake losses into account. If not expressly stated below, any other losses were not considered (e.g. electrical losses after WEC reference point, losses due to lack of availability or operation outside design parameters, blade icing events, grid curtailment, noise or shadow shut-downs or sector management, etc.). For the definition of wind class the air density of the site has to be taken into account.

Note: Energy yield estimations are affected by uncertainties (in the calculation model or in the information on landscape roughness and obstacles or due to inaccuracy of available maps). Therefore, it is strongly recommended to apply the safety margin as stated in the report.

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