PARK - Main Result

Calculation: Makromichalis

Wake Model N.O. Jensen (RISO/EMD)

Calculation Settings

Air density calculation mode	Individual per WTG
Result for WTG at hub altitude	1,138 kg/m³
Air density relative to standard	92,9 %
Hub altitude above sea level (asl)	628,9 m
Annual mean temperature at hub alt.	14,8 °C
Pressure at WTGs	940,9 hPa

Wake Model Parameters

Wake decay constant	0,075 HH:50m Mixed farmland

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

Scale 1:25.000

New WTG

WTG siting

Greek GGRS87-GGRS87 (GR)

	Y	X	Z	Row data/Description
			[m]	
1 New	516.054	4.261.560	512,9	ENERCON E-126 EP3 3000 127.0 !O!...

Resource file(s)

C:\Documents\WindPRO Data\Projects\oktwnia2_Res_50_Hub_116,0_0.rsf

Calculated Annual Energy for Wind Farm

					Specific results¤)			
WTG combination	Result PARK [MWh/y]	Result-10,0% [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	14.260,4	12.834,3	14.260,4	100,0	48,8	12.834,3	4.278	8,3

¤) Based on Result-10,0%

Calculated Annual Energy for each of 1 new WTGs with total 3,0 MW rated power

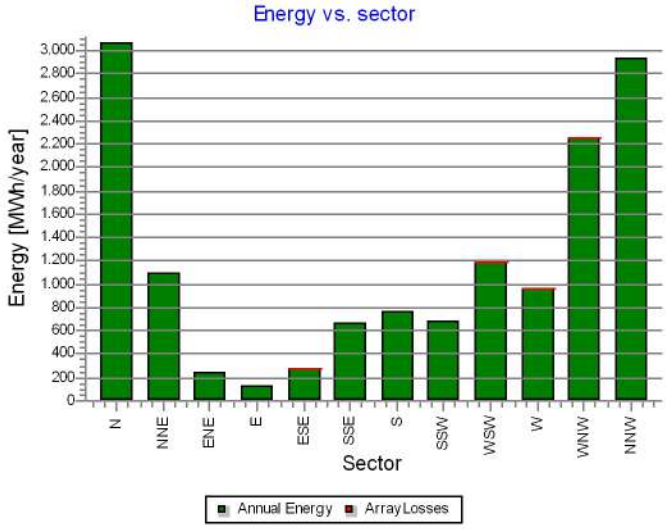
	WTG type						Power curve		Annual Energy		Park	
Links	Valid	Manufact.	Type-generator	Power, rated	Rotor diameter	Hub height	Creator	Name	Result	Result-10,0%	Efficiency	Free mean wind speed
				[kW]	[m]	[m]			[MWh]	[MWh]	[%]	[m/s]
1 A	Yes	ENERCON	E-126 EP3-3.000	3.000	127,0	116,0	EMD	Level 0 - BM 0s - 3000kW - 08/2018	14.260,4	12.834	100,00	8,34

PARK - Production Analysis

Calculation: Makromichalis**WTG:** All new WTGs, Air density 1,138 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]	3.067,4	1.087,7	242,4	133,2	283,0	661,5	766,9	680,4	1.191,6	957,2	2.247,4	2.941,6	14.260,4
Resulting energy	**[MWh]**	**3.067,4**	**1.087,7**	**242,4**	**133,2**	**283,0**	**661,5**	**766,9**	**680,4**	**1.191,6**	**957,2**	**2.247,4**	**2.941,6**	**14.260,4**
Specific energy	[kWh/m²]													1.126
Specific energy	[kWh/kW]													4.753
Utilization	[%]	24,0	24,3	22,4	31,0	23,3	23,3	29,0	26,2	14,8	18,7	25,6	27,7	23,5
Operational	[Hours/year]	1.530	623	259	166	200	396	564	507	617	758	1.409	1.686	8.714
Full Load Equivalent	[Hours/year]	1.022	363	81	44	94	221	256	227	397	319	749	981	4.753



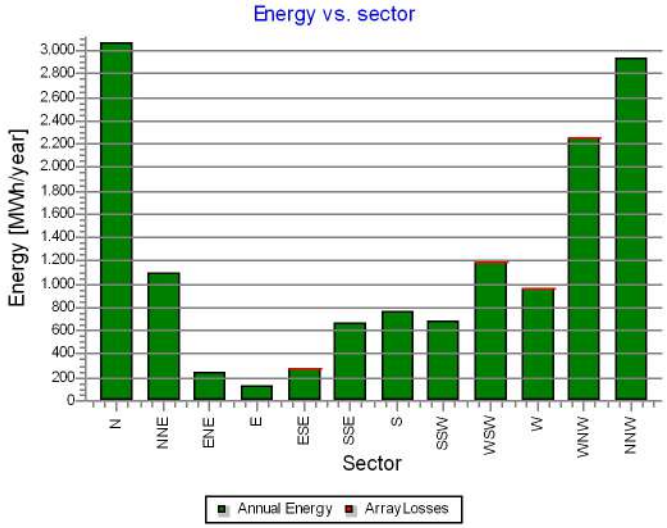
PARK - Production Analysis

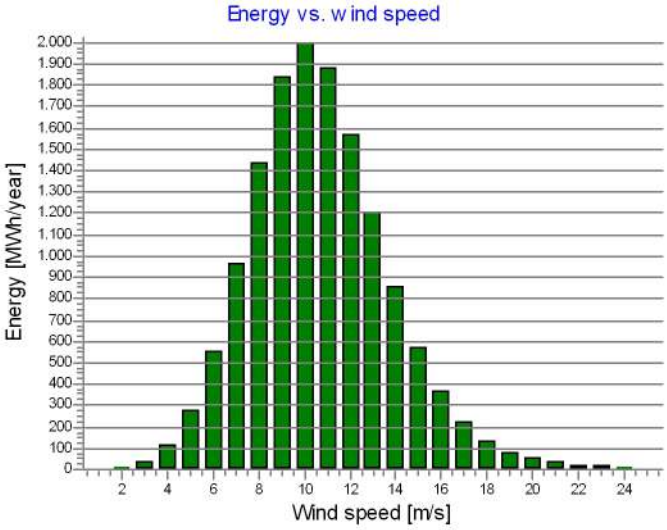
Calculation: Makromichalis**WTG:** 1 - ENERCON E-126 EP3 3000 127.0 !O!, Hub height: 116,0 m, Air density: 1,138 kg/m³

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]	3.067,4	1.087,7	242,4	133,2	283,0	661,5	766,9	680,4	1.191,6	957,2	2.247,4	2.941,6	14.260,4
Resulting energy	**[MWh]**	**3.067,4**	**1.087,7**	**242,4**	**133,2**	**283,0**	**661,5**	**766,9**	**680,4**	**1.191,6**	**957,2**	**2.247,4**	**2.941,6**	**14.260,4**
Specific energy	[kWh/m²]													1.126
Specific energy	[kWh/kW]													4.753
Directional Distribution	[%]	21,5	7,6	1,7	0,9	2,0	4,6	5,4	4,8	8,4	6,7	15,8	20,6	100,0
Utilization	[%]	24,0	24,3	22,4	31,0	23,3	23,3	29,0	26,2	14,8	18,7	25,6	27,7	23,5
Operational	[Hours/year]	1.530	623	259	166	200	396	564	507	617	758	1.409	1.686	8.714
Full Load Equivalent	[Hours/year]	1.022	363	81	44	94	221	256	227	397	319	749	981	4.753
A- parameter*)	[m/s]	10,6	9,8	6,6	6,1	8,6	9,6	8,3	8,3	11,4	8,1	9,2	9,5	9,4
Mean wind speed*)	[m/s]	9,4	8,7	5,9	5,5	7,7	8,5	7,4	7,4	10,1	7,3	8,2	8,5	8,3
k- parameter		3,17	2,64	1,48	1,77	2,05	2,42	2,41	2,16	2,16	1,63	2,50	3,01	2,35
Frequency	[%]	17,6	7,2	3,0	1,9	2,3	4,5	6,5	5,8	7,1	8,7	16,2	19,3	100,0
Power density	[W/m²]													541

*) Influence of array losses not included





PARK - Power Curve Analysis

Calculation: Makromichalis**WTG:** 1 - ENERCON E-126 EP3 3000 127.0 !O! Level 0 - BM 0s - 3000kW - 08/2018, Hub height: 116,0 m

Name: Level 0 - BM 0s - 3000kW - 08/2018
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
8/8/2018	EMD	26/5/2017	22/11/2018	25,0	Pitch	User defined	Variable	0,24

D0683590-1_#_de_#_Betriebsmodi_E-126_EP3_3000_kW_mit_TES

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]	6.109	8.955	11.564	13.796	15.623	17.046
ENERCON E-126 EP3 3000 127.0 !O! Level 0 - BM 0s - 3000kW - 08/2018	[MWh]	5.918	8.662	11.214	13.423	15.239	16.649
Check value	[%]	3	3	3	3	3	2

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/m^2) 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

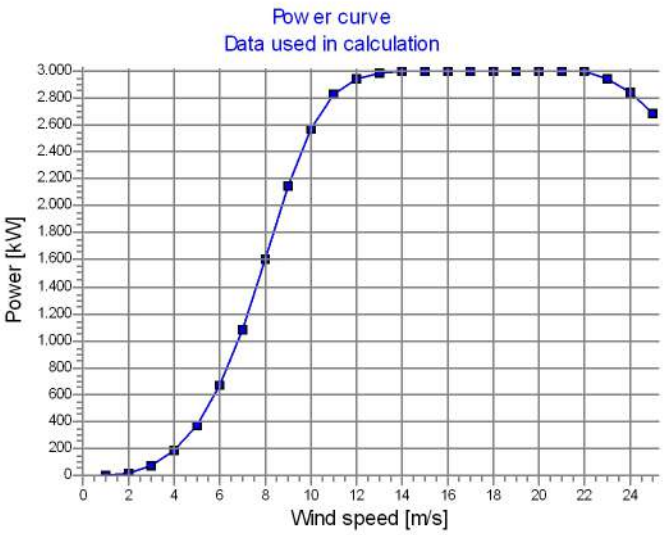
Original data, Air density: 1,225 kg/m³

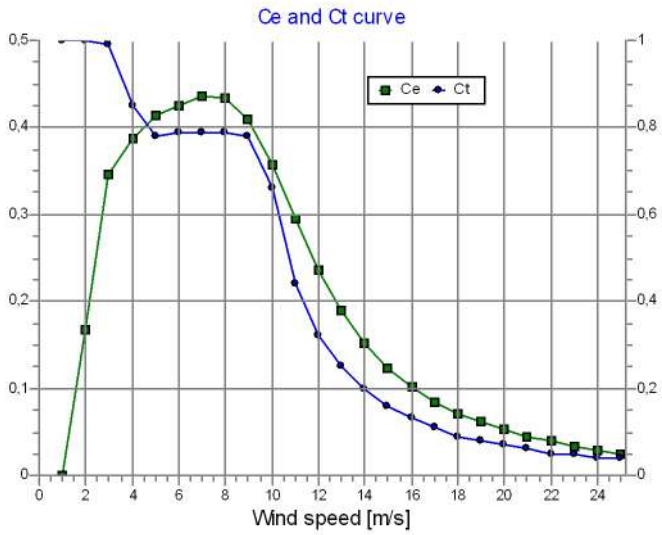
Wind speed [m/s]	Power [kW]	Ce	Wind speed [m/s]	Ct curve
2,0	12,0	0,19	2,0	1,30
2,5	36,0	0,30	2,5	1,11
3,0	73,0	0,35	3,0	0,99
3,5	124,0	0,37	3,5	0,91
4,0	193,0	0,39	4,0	0,85
4,5	287,0	0,41	4,5	0,81
5,0	401,0	0,41	5,0	0,78
5,5	543,0	0,42	5,5	0,79
6,0	715,0	0,43	6,0	0,79
6,5	921,0	0,43	6,5	0,79
7,0	1.160,0	0,44	7,0	0,79
7,5	1.429,0	0,44	7,5	0,79
8,0	1.719,0	0,43	8,0	0,79
8,5	2.010,0	0,42	8,5	0,79
9,0	2.281,0	0,40	9,0	0,78
9,5	2.509,0	0,38	9,5	0,75
10,0	2.687,0	0,35	10,0	0,66
10,5	2.813,0	0,31	10,5	0,53
11,0	2.895,0	0,28	11,0	0,44
11,5	2.945,0	0,25	11,5	0,37
12,0	2.973,0	0,22	12,0	0,32
12,5	2.988,0	0,20	12,5	0,28
13,0	2.996,0	0,18	13,0	0,25
13,5	2.999,0	0,16	13,5	0,22
14,0	3.000,0	0,14	14,0	0,20
14,5	3.000,0	0,13	14,5	0,18
15,0	3.000,0	0,11	15,0	0,16
15,5	3.000,0	0,10	15,5	0,14
16,0	3.000,0	0,09	16,0	0,13
16,5	3.000,0	0,09	16,5	0,12
17,0	3.000,0	0,08	17,0	0,11
17,5	3.000,0	0,07	17,5	0,10
18,0	3.000,0	0,07	18,0	0,09
18,5	3.000,0	0,06	18,5	0,09
19,0	3.000,0	0,06	19,0	0,08
19,5	3.000,0	0,05	19,5	0,07
20,0	3.000,0	0,05	20,0	0,07
20,5	3.000,0	0,04	20,5	0,06
21,0	2.998,0	0,04	21,0	0,06
21,5	2.994,0	0,04	21,5	0,06
22,0	2.985,0	0,04	22,0	0,05
22,5	2.969,0	0,03	22,5	0,05
23,0	2.943,0	0,03	23,0	0,05
23,5	2.901,0	0,03	23,5	0,04
24,0	2.847,0	0,03	24,0	0,04
24,5	2.777,0	0,02	24,5	0,04
25,0	2.692,0	0,02	25,0	0,04

Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 1,138 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	9,6	0,17	1,50- 2,50	5,6	5,6	0,0
3,0	67,4	0,35	2,50- 3,50	33,9	39,6	0,3
4,0	179,2	0,39	3,50- 4,50	112,8	152,4	1,1
5,0	372,5	0,41	4,50- 5,50	276,5	428,8	3,0
6,0	663,4	0,43	5,50- 6,50	556,7	985,5	6,9
7,0	1.076,3	0,44	6,50- 7,50	962,8	1.948,3	13,7
8,0	1.602,2	0,43	7,50- 8,50	1.440,0	3.388,3	23,8
9,0	2.150,0	0,41	8,50- 9,50	1.839,1	5.227,4	36,7
10,0	2.578,2	0,36	9,50-10,50	1.998,0	7.225,4	50,7
11,0	2.830,2	0,29	10,50-11,50	1.879,2	9.104,7	63,8
12,0	2.944,6	0,24	11,50-12,50	1.574,3	10.678,9	74,9
13,0	2.985,6	0,19	12,50-13,50	1.205,2	11.884,1	83,3
14,0	2.998,2	0,15	13,50-14,50	858,0	12.742,1	89,4
15,0	3.000,0	0,12	14,50-15,50	574,8	13.316,9	93,4
16,0	3.000,0	0,10	15,50-16,50	366,5	13.683,4	96,0
17,0	3.000,0	0,08	16,50-17,50	225,7	13.909,1	97,5
18,0	3.000,0	0,07	17,50-18,50	136,7	14.045,8	98,5
19,0	3.000,0	0,06	18,50-19,50	83,1	14.128,9	99,1
20,0	3.000,0	0,05	19,50-20,50	51,5	14.180,4	99,4
21,0	3.000,0	0,04	20,50-21,50	32,8	14.213,2	99,7
22,0	2.997,8	0,04	21,50-22,50	21,3	14.234,4	99,8
23,0	2.943,0	0,03	22,50-23,50	13,8	14.248,2	99,9
24,0	2.847,0	0,03	23,50-24,50	8,8	14.257,0	100,0
25,0	2.692,0	0,02	24,50-25,50	3,4	14.260,4	100,0





PARK - Wind Data Analysis

Calculation: Makromichalis**Wind data:** A - Resource file(s); Hub height: 116,0

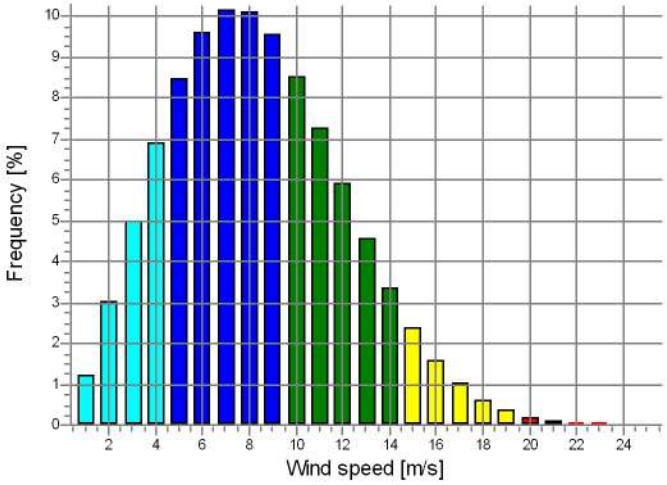
Site coordinates
Greek GGRS87-GGRS87 (GR)
East: 515.856 North: 4.261.461
ENERCON E-126 EP3 3000 127.0 !O! hub: 116,0 m (TOT: 179,5 m) (3)

Resource file
C:\Documents\WindPRO Data\Projects\oktwnia2_Res_50_Hub_116,0_0.rsf

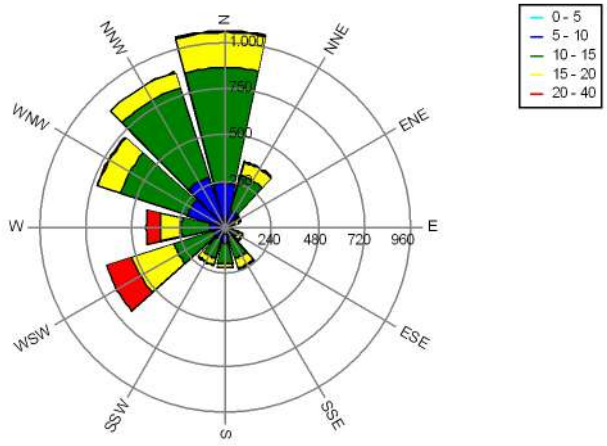
Weibull Data

Sector	A- parameter [m/s]	Wind speed [m/s]	k- parameter	Frequency [%]
0 N	10,56	9,45	3,166	17,6
1 NNE	9,76	8,67	2,640	7,2
2 ENE	6,56	5,93	1,480	3,0
3 E	6,14	5,47	1,766	1,9
4 ESE	8,64	7,66	2,051	2,3
5 SSE	9,58	8,50	2,420	4,5
6 S	8,30	7,36	2,410	6,5
7 SSW	8,30	7,35	2,160	5,8
8 WSW	11,38	10,08	2,163	7,1
9 W	8,14	7,29	1,630	8,7
10 WNW	9,20	8,17	2,502	16,2
11 NNW	9,55	8,53	3,007	19,3
All	9,41	8,34	2,348	100,0

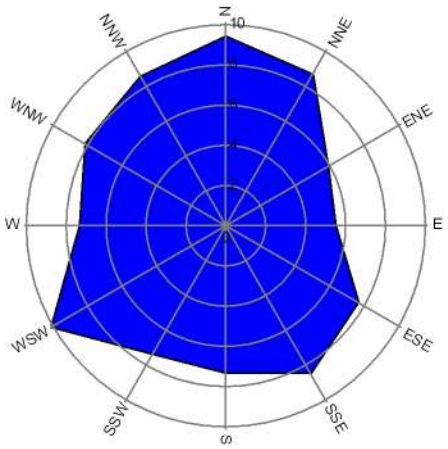
Weibull Distribution



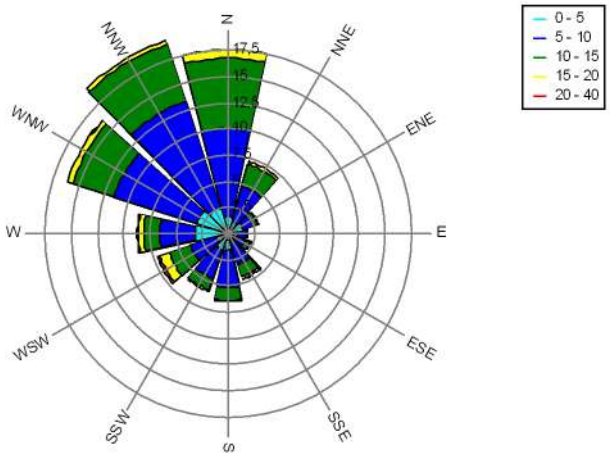
Energy Rose (kWh/m²/year)



Mean wind speed (m/s)



Frequency (%)



PARK - Park power curve

Calculation: Makromichalis

	Power													
Wind speed [m/s]	Free WTGs [kW]	Park WTGs [kW]	N [kW]	NNE [kW]	ENE [kW]	E [kW]	ESE [kW]	SSE [kW]	S [kW]	SSW [kW]	WSW [kW]	W [kW]	WNW [kW]	NNW [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	33	33	33	33	33	33	33	33	33	33	33	33	33	33
3,5	115	115	115	115	115	115	115	115	115	115	115	115	115	115
4,5	266	266	266	266	266	266	266	266	266	266	266	266	266	266
5,5	504	504	504	504	504	504	504	504	504	504	504	504	504	504
6,5	854	854	854	854	854	854	854	854	854	854	854	854	854	854
7,5	1.328	1.328	1.328	1.328	1.328	1.328	1.328	1.328	1.328	1.328	1.328	1.328	1.328	1.328
8,5	1.883	1.883	1.883	1.883	1.883	1.883	1.883	1.883	1.883	1.883	1.883	1.883	1.883	1.883
9,5	2.386	2.386	2.386	2.386	2.386	2.386	2.386	2.386	2.386	2.386	2.386	2.386	2.386	2.386
10,5	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725	2.725
11,5	2.900	2.900	2.900	2.900	2.900	2.900	2.900	2.900	2.900	2.900	2.900	2.900	2.900	2.900
12,5	2.970	2.970	2.970	2.970	2.970	2.970	2.970	2.970	2.970	2.970	2.970	2.970	2.970	2.970
13,5	2.994	2.994	2.994	2.994	2.994	2.994	2.994	2.994	2.994	2.994	2.994	2.994	2.994	2.994
14,5	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
15,5	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
16,5	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
17,5	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
18,5	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
19,5	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
20,5	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
21,5	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
22,5	2.993	2.993	2.993	2.993	2.993	2.993	2.993	2.993	2.993	2.993	2.993	2.993	2.993	2.993
23,5	2.901	2.901	2.901	2.901	2.901	2.901	2.901	2.901	2.901	2.901	2.901	2.901	2.901	2.901
24,5	2.777	2.777	2.777	2.777	2.777	2.777	2.777	2.777	2.777	2.777	2.777	2.777	2.777	2.777
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.

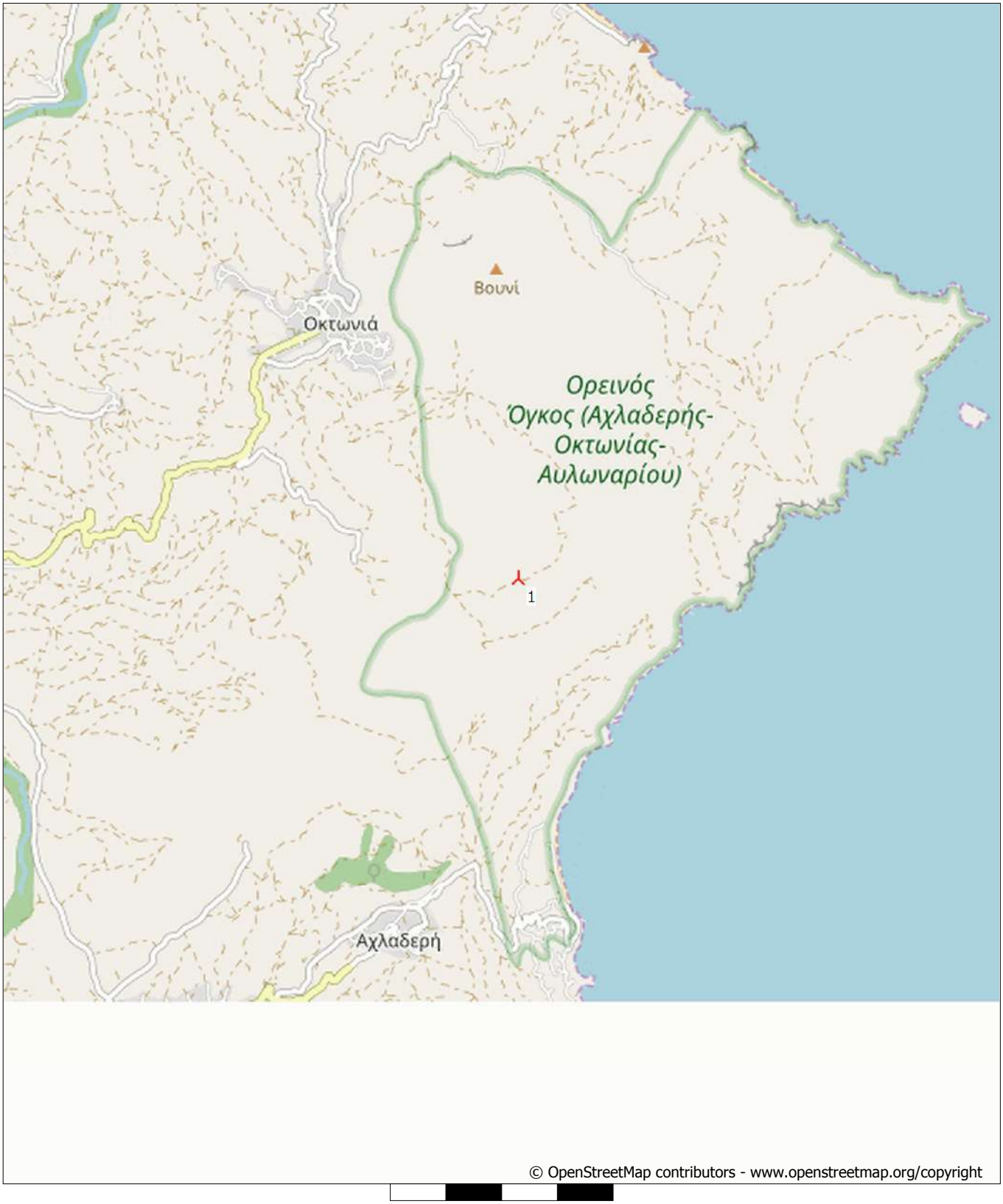
The park power curve can be used for:

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 - Map

Calculation: Makromichalis



0 500 1000 1500 2000 m

Map: Open Street Map 010 , Print scale 1:50.000, Map center Greek GGRS87-GGRS87 (GR) East: 515.856 North: 4.261.461

New WTG