REGIONE LAZIO | COMUNE DI CELLENO | COMUNE DI MONTEFIASCONE | COMUNE DI VITERBO | PROVINCIA DI VITERBO

PROGETTO DEFINITIVO

Impianto di produzione di energia elettrica da fonte eolica "Acquaforte" di potenza nominale pari a 47.6 MW e relative opere connesse da realizzarsi nei comuni di Celleno, Montefiascone e Viterbo.

Titolo elaborato

Studio di producibilità

Codice elaborato
F0532BR02A

Scala
-

Progettazione

F4 ingegneria srl
Via Di Giura - Centro direzionale, 85100 Potenza
Tel: +39 0971 1944797 - Fax: +39 0971 55452
www.f4ingegneria.it - f4ingegneria@pec.it

Il Direttore Tecnico
(ing. Giovanni Di Santo)

Società certificata secondo le norme UNI-EN ISO 9001:2015 e UNI-EN ISO 14001:2015 per l'erogazione di servizi di ingegneria nei settori: civile, idraulica, acustica, energia, ambiente (settore IAF: 34).

Gruppo di lavoro
Dott. For. Luigi ZUCCARO
Ing. Giuseppe MANZI
Ing. Alessandro Carmine DE PAOLA
Ing. Mariagrazia LOVALLO
Ing. Gerardo SCAVONE
Ing. jr- Flavio TRIANI
Arch. Gaia TELESCA

Consulenze specialistiche

Committente

APOLLO Wind srl
Via della Stazione 7 39100
Bolzano (Bz)

Data	Descrizione	Redatto	Verificato	Approvato
Maggio 2023	Prima emissione	GDS	GMA	GZU

File sorgente: **F0532BR02A_Studio di producilita'.docx**

Project:

2022-05 Celleno

Licensed user:
Dr. C.P. Beulshausen Wind Consultant
Am Husalsberg 7
DE-30900 Wedemark
49 5130 7054
Dr. C.P. Beulshausen / cp.beulshausen@online.de
Calculated:
17.04.2023 13:17/3.6.366

PARK - Main Result

Calculation: 2023-04-17 Celleno 7x Siemens SG170 6.6MW 115m HH Layout 2023-01

Setup

AEP scaled to a full year based on number of samples
Scaling factor from 23,1 years to 1 year: 0,043

Calculation performed in UTM (north)-WGS84 Zone: 33
At the site centre the difference between grid north and true north is: -1,9°

Wake

Wake Model: N.O. Jensen (RISØ/EMD) Park 2 2018

Wake decay constant
Wake decay constant: 0,070 HH:100m Mixed farmland
Reference WTG: T01

Scaler/wind data

Name	EMD Default Meso Scaler
Terrain scaling	Meso-scale Data Downscaling
Micro terrain flow model	WAsP IBZ from Site Data
Used period	01.01.1999 01:00:00 - 01.02.2022
Meteo object(s)	EMD-WRF ERA5_N42,55_E012,13
	EMD-WRF ERA5_N42,52_E012,13
	EMD-WRF ERA5_N42,54_E012,09
Horizontal interpolation	Distance weighted with selected meteo objects
Displacement height	Omnidirectional from objects
WAsP version	WAsP 12 Version 12.08.0022

Power correction

Power curve correction (adjusted IEC method, improved to match turbine control)

		Min	Max	Avg	Corr. [%]	Neg. corr. [%]	Pos. corr. [%]
Air density							
From air density settings	[°C]	13,1	13,4	13,3			
From air density settings	[hPa]	953,2	959,1	956,5			
Resulting air density	[kg/m³]	1,160	1,166	1,163			
Relative to 15°C at sea level	[%]	94,7	95,2	95,0	-3,0	-3,0	0,0

Scale 1:50.000

New WTG

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK	GROSS (no loss) Free WTGs	Wake loss	Specific results¤) Capacity factor	Mean WTG result	Full load hours	Wind speed free	wake reduced
	[MWh/y]	[MWh/y]	[%]	[%]	[MWh/y]	[Hours/year]	[m/s]	[m/s]
Wind farm	117.268,3	120.770,8	2,9	29,0	16.752,6	2.538	6,0	5,9

¤) Based on wake reduced results and any curtailments.

Calculated Annual Energy for each of 7 new WTGs with total 46,2 MW rated power

	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy Result [MWh/y]	Wake loss [%]	Wind speed free [m/s]	reduced [m/s]
1	Yes	Siemens	SG-170-6.600	6.600	170,0	115,0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	17.200,1	2,0	6,13	6,06
2	Yes	Siemens	SG-170-6.600	6.600	170,0	115,0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16.688,8	2,3	6,02	5,94
3	Yes	Siemens	SG-170-6.600	6.600	170,0	115,0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	17.061,9	2,0	6,00	5,93
4	Yes	Siemens	SG-170-6.600	6.600	170,0	115,0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16.683,6	1,0	5,87	5,84
5	Yes	Siemens	SG-170-6.600	6.600	170,0	115,0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16.757,7	1,5	6,01	5,95
6	Yes	Siemens	SG-170-6.600	6.600	170,0	115,0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16.308,4	5,8	6,08	5,90
7	Yes	Siemens	SG-170-6.600	6.600	170,0	115,0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16.567,7	5,5	6,13	5,95

Annual Energy result includes shown losses. Additional losses and uncertainty must be considered for an investment decision.

WTG siting

	UTM (north)-WGS84 Zone: 33 Easting	Northing	Z [m]	Row data/Description	Calculation period Start	End
1	New 262.299	4.715.068	399,6	T01	01.01.1999	01.02.2022
2	New 262.915	4.714.600	375,0	T02	01.01.1999	01.02.2022
3	New 263.961	4.713.798	369,7	T03	01.01.1999	01.02.2022
4	New 264.280	4.713.301	348,3	T04	01.01.1999	01.02.2022
5	New 260.617	4.712.849	380,0	T05	01.01.1999	01.02.2022
6	New 261.892	4.712.901	364,7	T06	01.01.1999	01.02.2022
7	New 261.653	4.712.019	360,0	T07	01.01.1999	01.02.2022

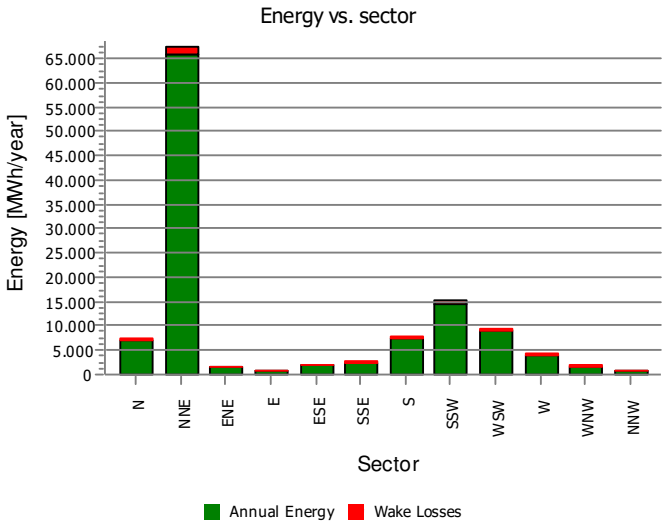
Licensed user:
Dr. C.P. Beulshausen Wind Consultant
Am Husalsberg 7
DE-30900 Wedemark
49 5130 7054
Dr. C.P. Beulshausen / cp.beulshausen@online.de
Calculated:
17.04.2023 13:17/3.6.366

PARK - Production Analysis

Calculation: 2023-04-17 Celleno 7x Siemens SG170 6.6MW 115m HH Layout 2023-01 **WTG:** All new WTGs, Air density varies with WTG position 1,160 kg/m³ - 1,166 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
Model based energy	[MWh]	7.269,6	67.440,8	1.734,4	659,3	2.106,9	2.629,7	7.910,3	15.143,6	9.276,6	4.118,2	1.794,5	686,9	120.770,8
-Decrease due to wake losses	[MWh]	216,1	1.397,2	62,6	32,1	273,5	170,5	276,9	503,8	304,9	143,2	83,4	38,3	3.502,6
Resulting energy	**[MWh]**	**7.053,5**	**66.043,6**	**1.671,8**	**627,2**	**1.833,4**	**2.459,2**	**7.633,3**	**14.639,8**	**8.971,7**	**3.975,0**	**1.711,2**	**648,5**	**117.268,3**
Specific energy	[kWh/m²]													738
Specific energy	[kWh/kW]													2.538
Decrease due to wake losses	[%]	3,0	2,1	3,6	4,9	13,0	6,5	3,5	3,3	3,3	3,5	4,6	5,6	2,90
Full Load Equivalent	[Hours/year]	153	1.430	36	14	40	53	165	317	194	86	37	14	2.538



Licensed user:
Dr. C.P. Beulshausen Wind Consultant
Am Husalsberg 7
DE-30900 Wedemark
49 5130 7054
Dr. C.P. Beulshausen / cp.beulshausen@online.de
Calculated:
17.04.2023 13:17/3.6.366

PARK - Power Curve Analysis

Calculation: 2023-04-17 Celleno 7x Siemens SG170 6.6MW 115m HH Layout 2023-01 **WTG:** 1 - Siemens SG-170 6600 170.0 !O!, Hub height: 115,0 m

Name: Mode 0 - SIEMENS 6,6 MW SG-170
Source: SIEMENS

Source/Date	Created by	Created	Edited	Stop wind speed [m/s]	Power control	CT curve type	Generator type	Specific power kW/m²
16.07.2021	USER	07.10.2004	16.09.2021	23,0	Pitch	User defined	Variable	0,29

based on document: D2849164-001 SGRE ON SG 6.6-170 Standard Ct and Power Curve Rev.0 Mode AM 0
edited by cpb 2021.09.16

HP curve comparison - Note: For standard air density

Vmean	[m/s]	5	6	7	8	9	10
HP value Pitch, variable speed (2013)	[MWh]	11.445	17.316	22.937	27.907	32.074	35.390
Siemens SG-170 6600 170.0 !O! Mode 0 - SIEMENS 6,6 MW SG-170	[MWh]	11.609	17.472	23.042	27.872	31.748	34.592
Check value	[%]	-1	-1	0	0	1	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 the windPRO manual.
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

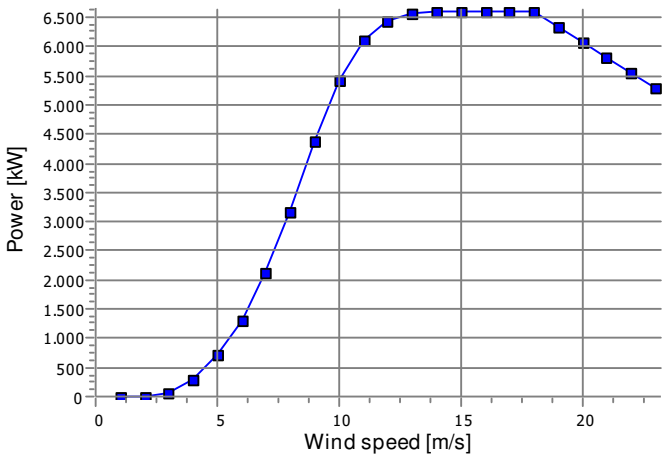
Wind speed [m/s]	Power [kW]	Cp	Wind speed [m/s]	Ct curve
3,0	89,0	0,24	3,0	0,95
3,5	178,0	0,30	3,5	0,88
4,0	328,0	0,37	4,0	0,85
4,5	522,0	0,41	4,5	0,83
5,0	758,0	0,44	5,0	0,82
5,5	1.040,0	0,45	5,5	0,83
6,0	1.376,0	0,46	6,0	0,83
6,5	1.771,0	0,46	6,5	0,84
7,0	2.230,0	0,47	7,0	0,84
7,5	2.757,0	0,47	7,5	0,84
8,0	3.346,0	0,47	8,0	0,83
8,5	3.974,0	0,47	8,5	0,80
9,0	4.600,0	0,45	9,0	0,77
9,5	5.177,0	0,43	9,5	0,71
10,0	5.660,0	0,41	10,0	0,65
10,5	6.024,0	0,37	10,5	0,58
11,0	6.272,0	0,34	11,0	0,51
11,5	6.424,0	0,30	11,5	0,44
12,0	6.510,0	0,27	12,0	0,38
12,5	6.556,0	0,24	12,5	0,34
13,0	6.579,0	0,22	13,0	0,29
13,5	6.590,0	0,19	13,5	0,26
14,0	6.596,0	0,17	14,0	0,23
14,5	6.598,0	0,16	14,5	0,21
15,0	6.599,0	0,14	15,0	0,19
15,5	6.600,0	0,13	15,5	0,17
16,0	6.600,0	0,12	16,0	0,16
16,5	6.600,0	0,11	16,5	0,14
17,0	6.600,0	0,10	17,0	0,13
17,5	6.600,0	0,09	17,5	0,12
18,0	6.600,0	0,08	18,0	0,12
18,5	6.468,0	0,07	18,5	0,10
19,0	6.336,0	0,07	19,0	0,09
19,5	6.204,0	0,06	19,5	0,08
20,0	6.072,0	0,05	20,0	0,07
20,5	5.940,0	0,05	20,5	0,07
21,0	5.808,0	0,05	21,0	0,06
21,5	5.676,0	0,04	21,5	0,06
22,0	5.544,0	0,04	22,0	0,05
22,5	5.412,0	0,03	22,5	0,05
23,0	5.280,0	0,03	23,0	0,04

Power and efficiency vs. wind speed

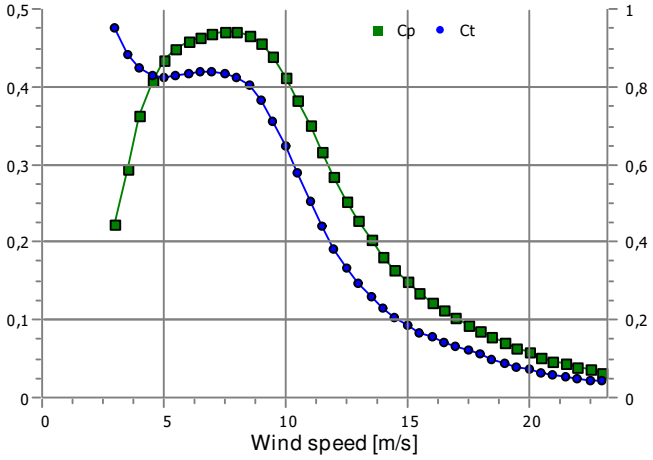
Data used in calculation, Mean air density: 1,160 kg/m³

Wind speed [m/s]	Power [kW]	Cp
1,0	0,0	0,00
2,0	0,0	0,00
3,0	79,1	0,22
4,0	305,7	0,36
5,0	714,1	0,43
6,0	1.301,1	0,46
7,0	2.110,6	0,47
8,0	3.169,5	0,47
9,0	4.373,6	0,46
10,0	5.437,6	0,41
11,0	6.123,4	0,35
12,0	6.445,0	0,28
13,0	6.559,0	0,23
14,0	6.590,4	0,18
15,0	6.598,0	0,15
16,0	6.599,9	0,12
17,0	6.600,0	0,10
18,0	6.600,0	0,09
19,0	6.336,0	0,07
20,0	6.072,0	0,06
21,0	5.808,0	0,05
22,0	5.544,0	0,04
23,0	5.280,0	0,03

Power curve
For air density: 1,160 kg/m³ and reference climate data



Cp and Ct curve
For air density: 1,160 kg/m³ and reference climate data



Licensed user:
Dr. C.P. Beulshausen Wind Consultant
Am Husalsberg 7
DE-30900 Wedemark
49 5130 7054
Dr. C.P. Beulshausen / cp.beulshausen@online.de
Calculated:
17.04.2023 13:17/3.6.366

PARK - Wind Data Analysis

Calculation: 2023-04-17 Celleno 7x Siemens SG170 6.6MW 115m HH Layout 2023-01 **Wind data:** 3 - T03; Hub height: 115,0

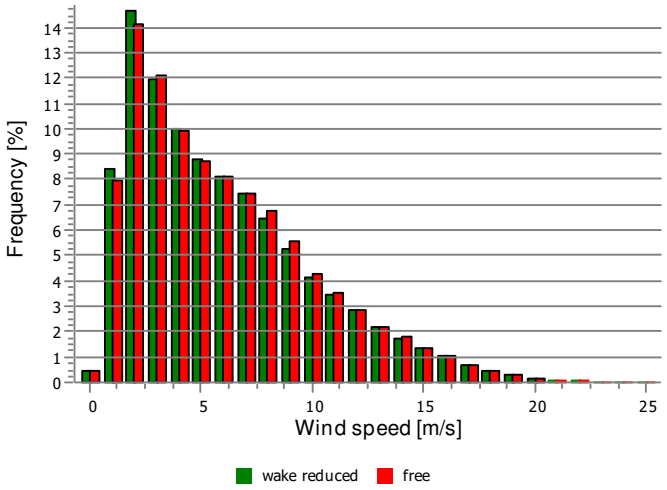
Site coordinates
UTM (north)-WGS84 Zone: 33
East: 263.961 North: 4.713.798
T03

Masts used
Distance weighted with selected meteo objects
EMD-WRF ERA5_N42,55_E012,13

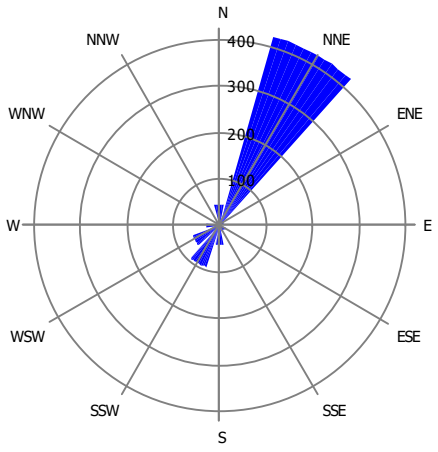
Winddata for site

Sector	Free mean wind speed [m/s]	Wake reduced mean wind speed [m/s]	Frequency [%]
0 N	7,0	7,0	4,7
1 NNE	8,9	8,9	30,3
2 ENE	3,2	3,2	7,4
3 E	2,6	2,6	6,7
4 ESE	3,4	3,3	7,6
5 SSE	3,8	3,2	5,7
6 S	4,8	4,8	7,7
7 SSW	6,4	6,4	11,1
8 WSW	6,2	5,9	9,3
9 W	5,3	5,3	5,4
10 WNW	4,4	4,2	2,7
11 NNW	3,9	3,9	1,3
All	6,0	5,9	100,0

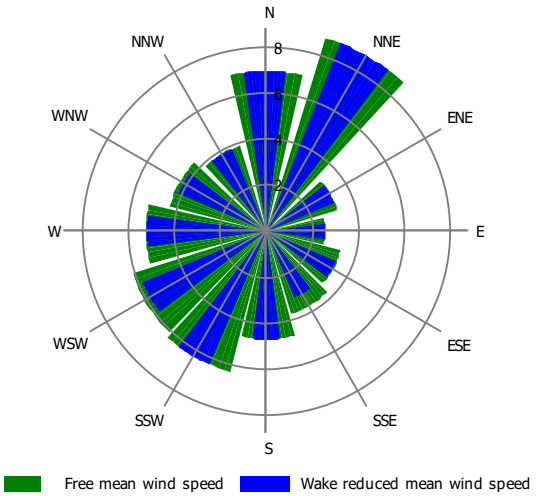
Wind distribution



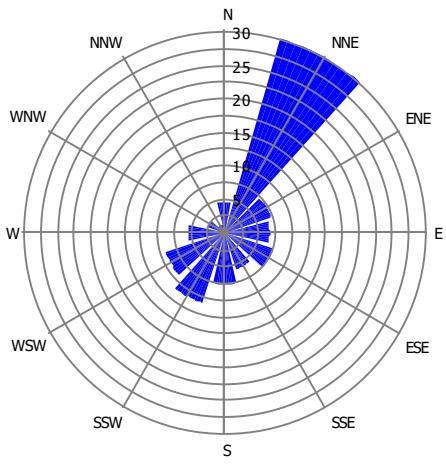
Energy Rose (WTG) (kWh/m²/year)



Mean wind speed (m/s)



Frequency (%)



Licensed user:
Dr. C.P. Beulshausen Wind Consultant
Am Husalsberg 7
DE-30900 Wedemark
49 5130 7054
Dr. C.P. Beulshausen / cp.beulshausen@online.de
Calculated:
17.04.2023 13:17/3.6.366

PARK - Map

Calculation: 2023-04-17 Celleno 7x Siemens SG170 6.6MW 115m HH Layout 2023-01

0 500 1000 1500 2000 m

Map: Air detail , Print scale 1:50.000, Map center UTM (north)-WGS84 Zone: 33 East: 262.448 North: 4.713.544

New WTG