



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

F0532BR02B

Scala

-

Riproduzione o consegna a terzi solo dietro specifica autorizzazione.

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)



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



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).

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

PARK - Main Result

Calculation: 2024-03-20|Celleno|7 x SG170-6.6MW 115m HH|Layout 2024-03|EYPA

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|SG 6.6-170 6600 hub: 115.0 m (TOT: 200.0 m)

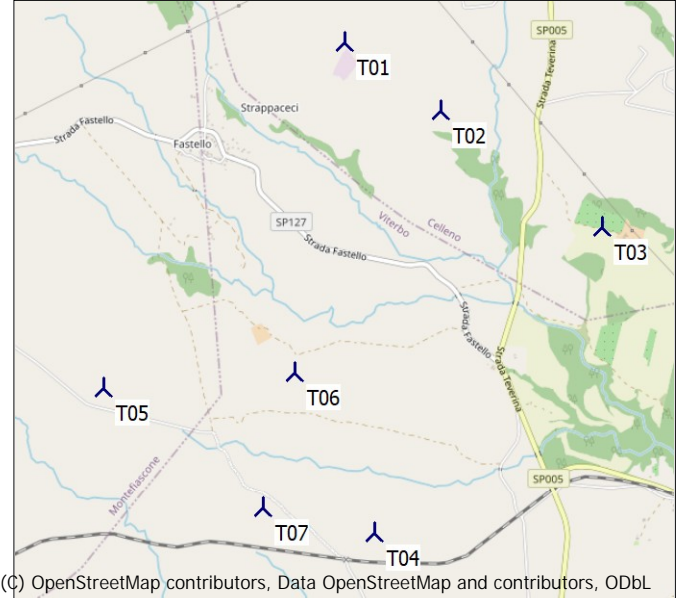
Scaler/wind data

Name: EMD Default Meso Scaler
Terrain scaling: Measured Data Scaling (WASP Stability / A-Parameter)
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 12.09.0010

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	13.5	13.3			
From air density settings [hPa]	953.2	960.0	956.6			
Resulting air density [kg/m³]	1.160	1.167	1.163			
Relative to 15°C at sea level [%]	94.7	95.3	95.0	-2.9	-2.9	0.0



(C) OpenStreetMap contributors, Data OpenStreetMap and contributors, ODbL

Scale 1:50 000

↗ New WTG

Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Wake loss [%]	Specific results ^{a)}		Wind speed		
				Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	free [m/s]	wake [m/s]
Wind farm	116 534.5	120 421.2	3.2	28.8	16 647.8	2 522	6.0	5.9

^{a)} 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		Wind speed	
									Result [MWh/y]	Wake loss [%]	free [m/s]	reduced [m/s]
T01	Yes	Siemens	SG-170-6 600	6 600	170.0	115.0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	17 101.6	2.2	6.12	6.04
T02	Yes	Siemens	SG-170-6 600	6 600	170.0	115.0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16 586.6	2.5	6.01	5.93
T03	Yes	Siemens	SG-170-6 600	6 600	170.0	115.0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16 932.6	1.6	5.96	5.92
T04	Yes	Siemens	SG-170-6 600	6 600	170.0	115.0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16 591.0	2.2	5.99	5.92
T05	Yes	Siemens	SG-170-6 600	6 600	170.0	115.0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16 704.7	1.6	6.01	5.94
T06	Yes	Siemens	SG-170-6 600	6 600	170.0	115.0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16 236.7	6.0	6.07	5.89
T07	Yes	Siemens	SG-170-6 600	6 600	170.0	115.0	USER	Mode 0 - SIEMENS 6,6 MW SG-170	16 381.4	6.3	6.12	5.90

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

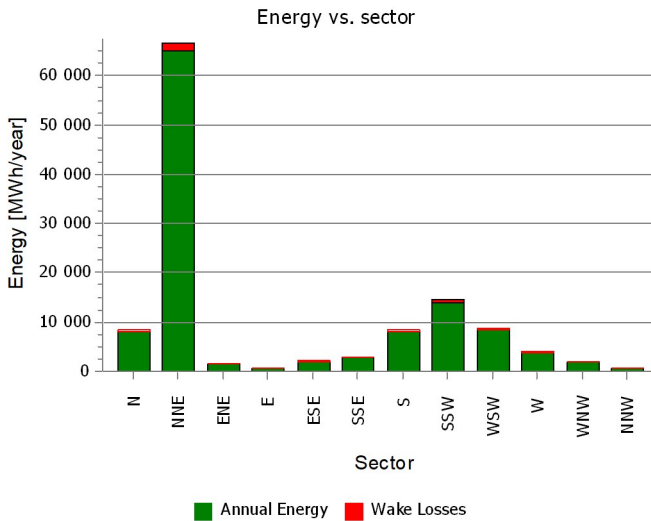
WTG siting

		UTM (north)-WGS84 Zone: 32				Row data/Description	Calculation period	
		Easting	Northing	Z	Start		End	
T01	New	754 911	4 715 678	399.6	T01 SG 6.6-170 6600 hub: 115.0 m (TOT: 200.0 m)	01/01/1999	01/02/2022	
T02	New	755 559	4 715 255	375.0	T02 SG 6.6-170 6600 hub: 115.0 m (TOT: 200.0 m)	01/01/1999	01/02/2022	
T03	New	756 659	4 714 529	369.7	T03 SG 6.6-170 6600 hub: 115.0 m (TOT: 200.0 m)	01/01/1999	01/02/2022	
T04	New	755 223	4 712 450	340.2	T04 SG 6.6-170 6600 hub: 115.0 m (TOT: 200.0 m)	01/01/1999	01/02/2022	
T05	New	753 390	4 713 345	380.0	T05 SG 6.6-170 6600 hub: 115.0 m (TOT: 200.0 m)	01/01/1999	01/02/2022	
T06	New	754 659	4 713 487	364.7	T06 SG 6.6-170 6600 hub: 115.0 m (TOT: 200.0 m)	01/01/1999	01/02/2022	
T07	New	754 483	4 712 591	360.0	T07 SG 6.6-170 6600 hub: 115.0 m (TOT: 200.0 m)	01/01/1999	01/02/2022	

PARK - Production Analysis

Calculation: 2024-03-20|Celleno|7 x SG170-6.6MW 115m HH|Layout 2024-03|EYPA WTG: All new WTGs, Air density varies with WTG position 1.160 kg/m³ - 1.167 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]	8 297.4	66 583.2	1 611.2	670.2	2 230.5	2 736.8	8 381.8	14 592.7	8 610.1	3 951.7	2 001.7	753.9	120 421.2
-Decrease due to wake losses	[MWh]	294.9	1 553.3	50.5	51.8	327.3	80.1	364.7	576.6	230.2	171.7	165.4	20.2	3 886.7
Resulting energy	[MWh]	8 002.4	65 029.9	1 560.7	618.4	1 903.2	2 656.7	8 017.1	14 016.1	8 379.9	3 780.0	1 836.2	733.8	116 534.5
Specific energy	[kWh/m ²]													733
Specific energy	[kWh/kW]													2 522
Decrease due to wake losses	[%]	3.6	2.3	3.1	7.7	14.7	2.9	4.4	4.0	2.7	4.3	8.3	2.7	3.23
Full Load Equivalent	[Hours/year]	173	1 408	34	13	41	58	174	303	181	82	40	16	2 522



PARK - Power Curve Analysis

Calculation: 2024-03-20|Celleno|7 x SG170-6.6MW 115m HH|Layout 2024-03|EYPA WTG: T06 - 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/m ²
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/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 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

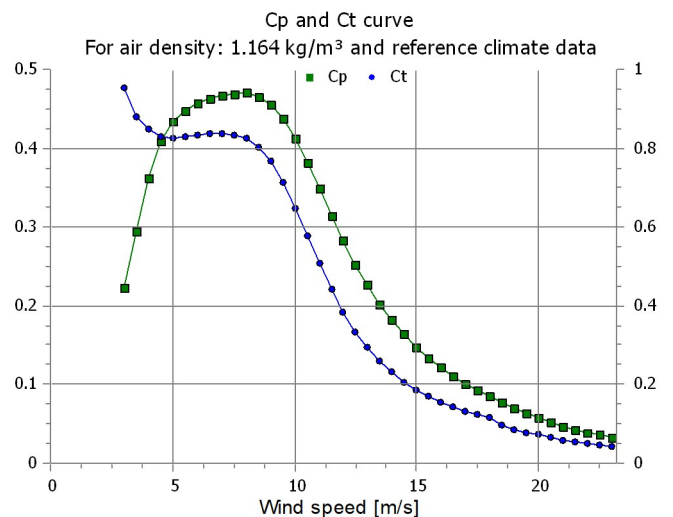
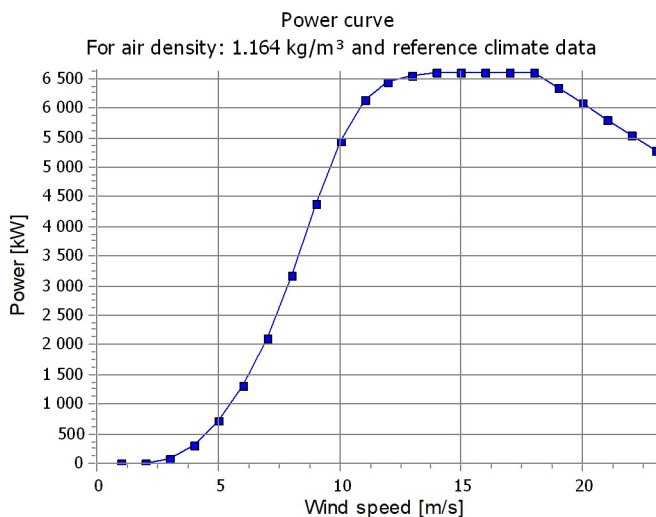
Original data, Air density: 1.225 kg/m³

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	1040.0	0.45	5.5	0.83
6.0	1376.0	0.46	6.0	0.83
6.5	1771.0	0.46	6.5	0.84
7.0	2230.0	0.47	7.0	0.84
7.5	2757.0	0.47	7.5	0.84
8.0	3346.0	0.47	8.0	0.83
8.5	3974.0	0.47	8.5	0.80
9.0	4600.0	0.45	9.0	0.77
9.5	5177.0	0.43	9.5	0.71
10.0	5660.0	0.41	10.0	0.65
10.5	6024.0	0.37	10.5	0.58
11.0	6272.0	0.34	11.0	0.51
11.5	6424.0	0.30	11.5	0.44
12.0	6510.0	0.27	12.0	0.38
12.5	6556.0	0.24	12.5	0.34
13.0	6579.0	0.22	13.0	0.29
13.5	6590.0	0.19	13.5	0.26
14.0	6596.0	0.17	14.0	0.23
14.5	6598.0	0.16	14.5	0.21
15.0	6599.0	0.14	15.0	0.19
15.5	6600.0	0.13	15.5	0.17
16.0	6600.0	0.12	16.0	0.16
16.5	6600.0	0.11	16.5	0.14
17.0	6600.0	0.10	17.0	0.13
17.5	6600.0	0.09	17.5	0.12
18.0	6600.0	0.08	18.0	0.12
18.5	6468.0	0.07	18.5	0.10
19.0	6336.0	0.07	19.0	0.09
19.5	6204.0	0.06	19.5	0.08
20.0	6072.0	0.05	20.0	0.07
20.5	5940.0	0.05	20.5	0.07
21.0	5808.0	0.05	21.0	0.06
21.5	5676.0	0.04	21.5	0.06
22.0	5544.0	0.04	22.0	0.05
22.5	5412.0	0.03	22.5	0.05
23.0	5280.0	0.03	23.0	0.04

Power and efficiency vs. wind speed

Data used in calculation, Mean air density: 1.164 kg/m³

Wind speed [m/s]	Power [kW]	Cp
1.0	0.0	0.00
2.0	0.0	0.00
3.0	79.7	0.22
4.0	307.1	0.36
5.0	716.8	0.43
6.0	1305.7	0.46
7.0	2117.9	0.47
8.0	3180.3	0.47
9.0	4387.3	0.46
10.0	5450.8	0.41
11.0	6132.1	0.35
12.0	6448.8	0.28
13.0	6560.2	0.23
14.0	6590.7	0.18
15.0	6598.1	0.15
16.0	6600.0	0.12
17.0	6600.0	0.10
18.0	6600.0	0.09
19.0	6336.0	0.07
20.0	6072.0	0.06
21.0	5808.0	0.05
22.0	5544.0	0.04
23.0	5280.0	0.03



PARK - Wind Data Analysis

Calculation: 2024-03-20|Celleno|7 x SG170-6.6MW 115m HH|Layout 2024-03|EYPA Wind data: T06 - T06|SG 6.6-170 6600 hub: 115.0 m (TOT: 200.0 m); Hub height: 115.0

Site coordinates

UTM (north)-WGS84 Zone: 32

East: 754 659 North: 4 713 487

T06 - T06|SG 6.6-170 6600 hub: 115.0 m (TOT: 200.0 m)

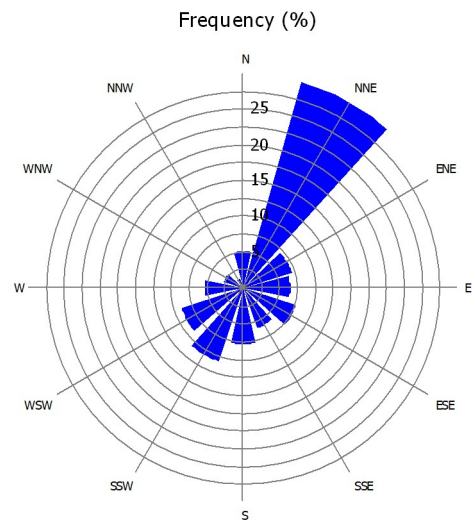
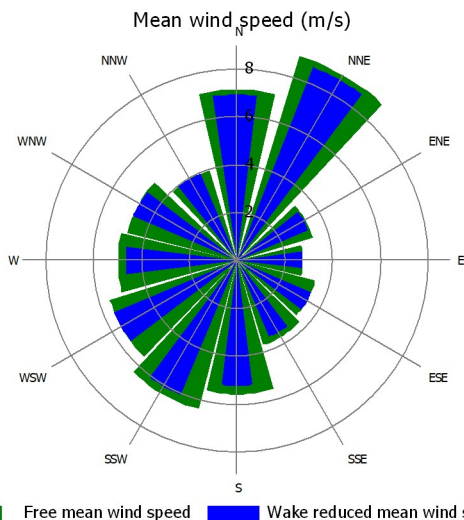
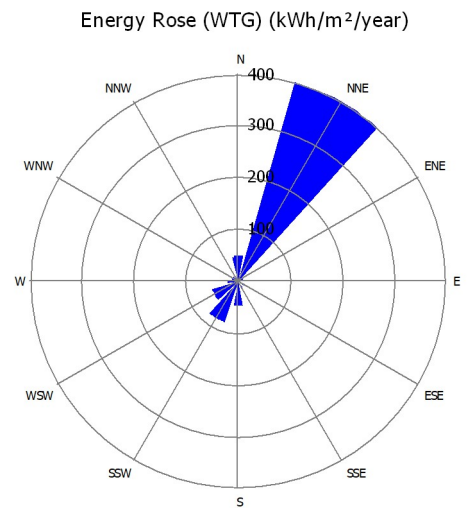
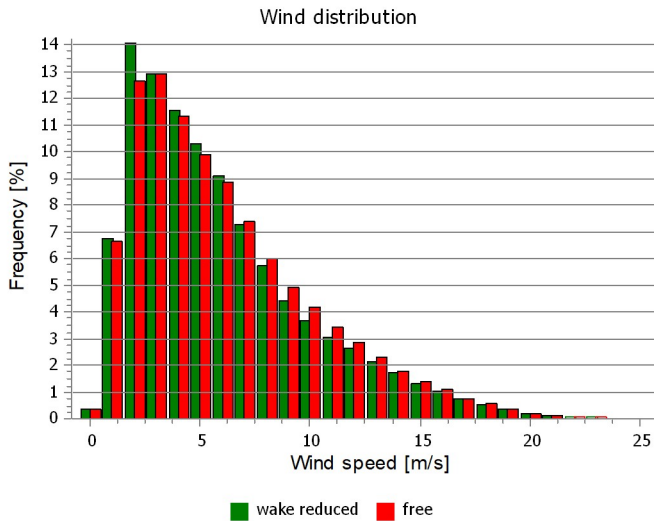
Masts used

Distance weighted with selected meteo objects

EMD-WRF ERA5_N42,54_E012,09

Winddata for site

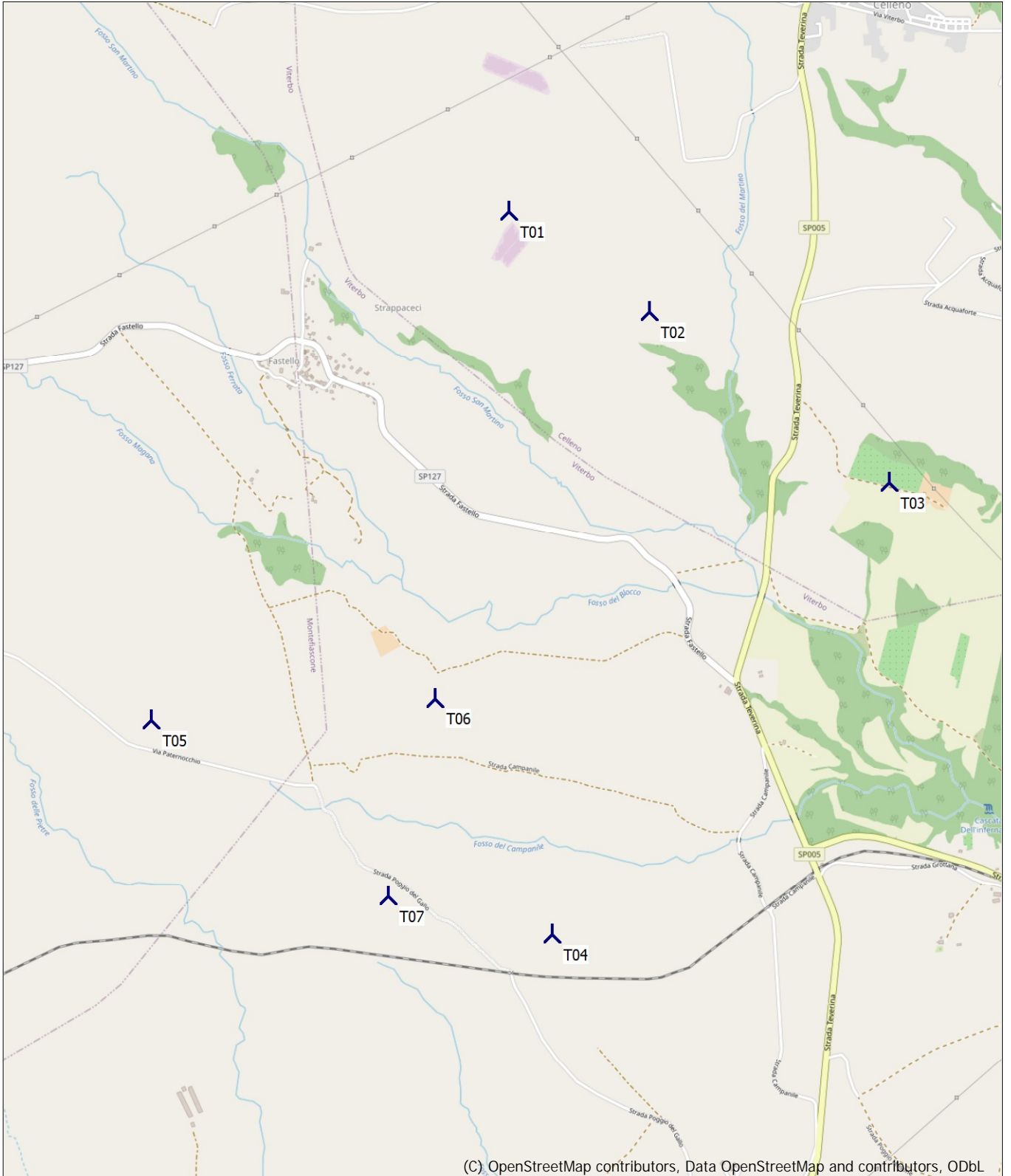
Sector	Free mean wind speed [m/s]	Wake reduced mean wind speed [m/s]	Frequency [%]
0 N	7.2	7.0	5.1
1 NNE	9.0	8.7	30.0
2 ENE	3.3	3.3	7.1
3 E	2.8	2.8	6.6
4 ESE	3.4	3.4	7.8
5 SSE	3.7	3.5	5.9
6 S	5.6	5.2	7.9
7 SSW	6.4	6.1	10.8
8 WSW	5.6	5.6	9.1
9 W	5.0	4.7	5.4
10 WNW	4.8	4.8	2.8
11 NNW	4.0	4.0	1.4
All	6.1	5.9	100.0



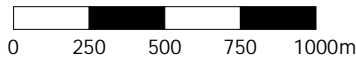
Free mean wind speed Wake reduced mean wind speed

PARK - Map

Calculation: 2024-03-20|Celleno|7 x SG170-6.6MW 115m HH|Layout 2024-03|EYPA



(C) OpenStreetMap contributors, Data OpenStreetMap and contributors, ODbL



Map: EMD OpenStreetMap , Print scale 1:25 000, Map center UTM (north)-WGS84 Zone: 32 East: 755 025 North: 4 714 064

 New WTG