REGIONE BASILICATA
PROVINCIA DI MATERA
COMUNE DI GROTTOLE

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LUCANIA WIND Energy S.r.l
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Parco Eolico "Grottole"

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PRELIMINARY WIND RESOURCE & ENERGY YIELD ASSESSMENT

SUMMARY REPORT

GROTTOLE

June 2023

Details

Prepared for:

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Reference: VRIT23143

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V00	Initial version	28/04/2023	NF	GP	CP
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Contents

1. FOREWORD

Vestas Wind System A/S (the "**Client**") engaged Vector Renewables Italia S.r.l. as "**Technical Advisor**" (or "**TA**") to perform a preliminary analysis for the definition of the wind resource and energy assessment of the Grottole wind farm (the "**Project**") in development in Italy.

The **Project** includes n. 6 turbines with the following configuration:

Turbine model	Rotor Diameter [m]	Hub height [m]	Tip height [m]	Number of turbines	Wind farm capacity [MW]
Vestas V162-6.0MW	162.0	125.0	206.0	6	36.0

Tab. 1 - Configuration of Grottole wind farm

The activity consisted in the examination of the provided documentation, in order to acknowledge all the information useful for the assessment. The wind data collected at site have been validated and processed and the long-term wind conditions have been established, by comparisons and correlations with historical sources.

Based on the resulting long-term wind distributions, the expected production of the wind farm has been assessed using the WindSim CFD wind flow model as embedded in WindPRO 3.6.

As requested by the Client, the current document will present only the key figures of the wind regime and energy yield assessment undertaken, in the form of summary tables. It is stressed that this summary report is not intended to be a thorough report; therefore, the details of the analysis undertaken, and any related assumptions, are not provided herein, as this is beyond the agreed scope of work.

On the 8th of June, 2023 a site inspection has been carried out to evaluate the IEC compliance of the mast along with the terrain conditions, in terms of obstacles, orography and roughness, of the location of the turbines. The results of the assessment are provided in the in the report RVRIT23207. Even if not all the locations were fully reachable, the site visit has broadly confirmed the assumption made for the implementation of the CFD model.

2. SUPPLIED MATERIAL

The supplied material useful for the Preliminary Wind Resource and Energy Yield Assessment consists of these items:

1. Wind data collected by one met mast located at site;
2. Mast Installation report including calibration certificates and drawings;
3. Logger configuration files;
4. Proposed layout for the Project.
5. Proposed wind turbine model for the Project.

2.1. Mast data

Data recorded by the mast located on site have been provided. The following characteristics – mast name, height, position in the UTM WGS84 Zone 33 coordinate system, elevation and measurement periods of the provided data – are reported in the table below:

Mast name	Mast height AGL [m]	Coordinates		Elevation [m]	Recording period		N° of months
		Easting [m]	Northing [m]		Starting date	Ending date	
MM1	99	618279	4505734	295	17/03/2022	01/05/2023	13.5

Tab. 2 - Mast overview

The met mast has a lattice tower equipped with seven THIES 4.3351.00.000 cup anemometers, individually calibrated at a Measnet facility, side-by-side mounted at 99 m, 80 and 60 m on booms oriented at 60° and 240°, and a single mounted anemometer at 40 m on a boom oriented at 60°; three THIES 4.3351.00.173 wind vanes at 98, 78 and 58 m.

Logger configuration files for the beginning and the end of the measurement period have been provided allowing the verification of the correct setting of the logger and fully ensuring the integrity of the wind data.

A detailed assessment of the compliance of the mast with the IEC 61400-12-1 ed.2 standard has been undertaken in the report RVRIT23207, following a site survey and mast audit perform on the 8th of June 2023. For more information, please refer to such report. The results of such assessment have been taken into account in the current revision of the study.

Overall, the mast is deemed as broadly compliant and fulfilling the rule of 2/3 of the proposed hub height.

2.2. Site and wind farm layout

The metric coordinates of the Grottole layout are shown in the following table:

UTM WGS84 – Zone 33			
WTG	Easting [m]	Northing [m]	Elevation [m]
T1	615489	4504798	215
T2	616042	4504739	230
T3	617868	4505492	265
T4	618438	4505823	274
T5	618833	4506449	314
T6	617624	4500670	225

Tab. 3 – Grottole layout coordinates

The proposed layout extends approximately 4 km by 7 km: the northern cluster consists of five turbines with turbine T6 located at more than 4 km distance from the other turbines towards the South. The layout lays on a hilly complex with turbine elevation ranging from 215 m to 315 m above sea level. The terrain at the site is considered to be moderately complex, since the turbines are located close to areas of steep slopes. Based on public aerial imagery, the ground cover at the site consists predominantly of farmlands.

Height contours with 10 m vertical spacing were provided covering an area of about 30 km x 30 km. The roughness map to be included in the wind flow model was not provided and therefore was downloaded from the Corine Land Cover 2018 database and its values adjusted to the site based on satellite images.

The location of the proposed turbines in red and of the measurement mast in orange are shown in the next figure. The mast is located at the northern cluster of the site. VR considers that the measurement at site is sufficiently representative of the turbine locations at the northern cluster. The installation of an additional measurement is deemed as beneficial to improve the accuracy of the assessment and reduce the uncertainty but not required as mandatory.

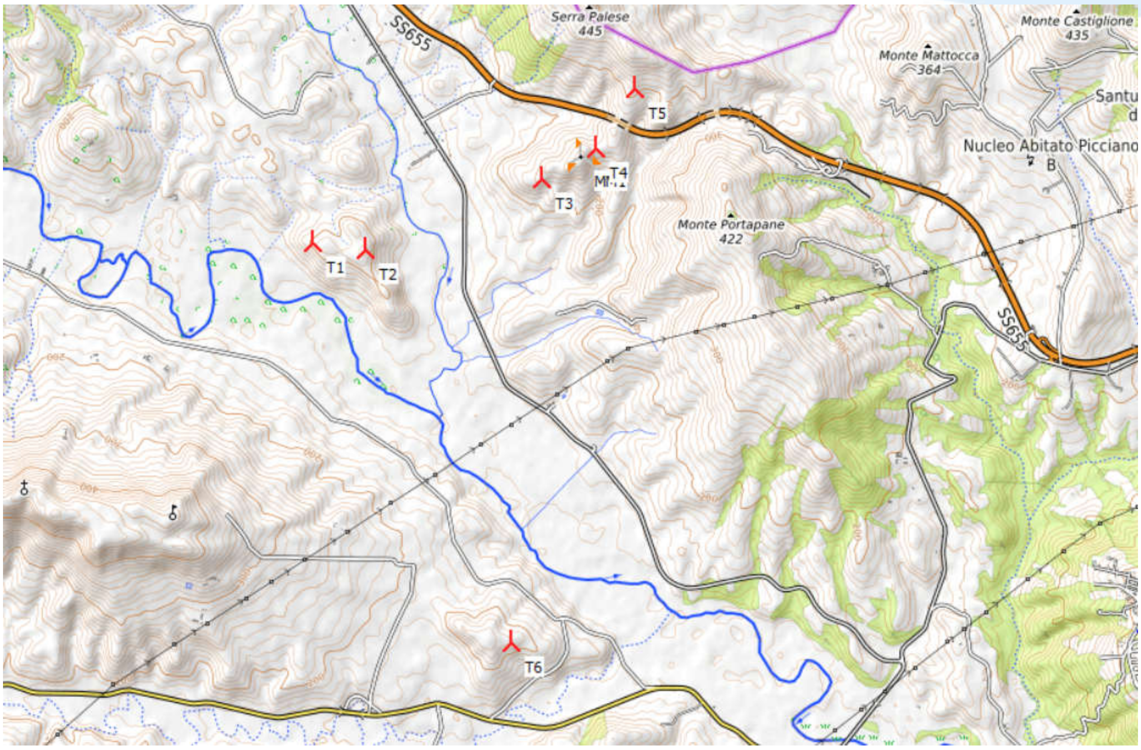


Fig. 1 - Map of the site with proposed wind turbines and mast

Technical Advisor's standard requirements for distances between turbines are five rotor diameters in the prevailing wind direction, and three rotor diameters in direction perpendicular to the prevailing. The next table shows the distances separating the wind turbines in diameters of 162 m rotor.

RD=162m\Meter	T1	T2	T3	T4	T5	T6
T1	-	556	2478	3122	3729	4647
T2	3.4	-	1975	2630	3273	4366
T3	15.3	12.2	-	659	1359	4828
T4	19.3	16.2	4.1	-	740	5217
T5	23.0	20.2	8.4	4.6	-	5904
T6	28.7	26.9	29.8	32.2	36.4	-

Tab. 4 - Spacings in rotor diameter and meters of Grottole wind farm

It is observed that the requirements are fully met both in prevailing and non-prevailing wind direction, with a minimum distance of 3.4 rotor diameters.

It is recommended to obtain the turbine manufacturer's Mechanical Load assessment and site suitability Analysis (MLA), in order to ensure that the desired wind turbine model and the proposed layout will be suitable for the site according to IEC 61400-1 Standard Ed.3 and that the fatigue loads, resulting from the wind conditions onsite and acting on the turbine main components, are within the design load envelope.

2.3. Neighbouring wind farms

No information has been provided regarding neighbouring turbines in operation or even in development phase and no site inspection has been carried out at this stage in order to verify this or presence of any other obstacle that might affect the Project.

From public database and aerial pictures publicly available online, no operating turbines are detected in the surroundings of the Project within a radius of approximately 20 time the proposed rotor diameter, and therefore no external wake effect has been included within the calculation.

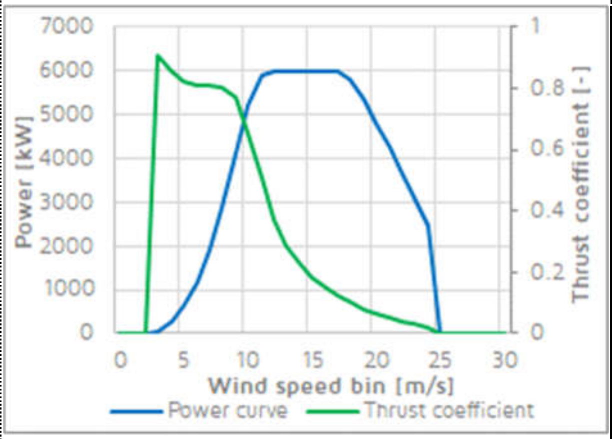
In case additional information is available on existing or under development wind farms, it is recommended to provide the relevant layouts and turbine models involved (rated power, rotor size and hub height) to properly account for their effect in terms of additional wakes induced on the Project.

2.4. Wind turbine

The expected energy production of the wind farm is estimated considering the following wind turbine model, whose power and thrust curves have been adjusted at the site air density of 1.18 kg/m^3 according to the IEC 61400-12 method correction. The temperature recorded by the nearest climate station available in the WindPro database has been considered in order to evaluate site proper air density; the average temperature recorded by the station (1950-1980) at 350 m. a.s.l. is 13.8 °C and the respective one on the VMM position at the hub height is 13.3°C.

Turbine model	V162-6.0	Diameter [m]	162.0
Rated power [MW]	6.0	Hub height [m]	125.0
Rated wind speed [m/s]	12.5	IEC class	S
Cut-in/Cut-out [m/s]	3.0/24.0	Air density [kg/m³]	1.175

Bin wind speed [m/s]	Power, Pc [kW]	Thrust coefficient, Ct [-]
0	0	0.00
1	0	0.00
2	0	0.00
3	28	0.910
4	277	0.854
5	645	0.820
6	1175	0.812
7	1916	0.808
8	2893	0.801
9	4102	0.772
10	5233	0.650
11	5889	0.507
12	5994	0.374
13	6000	0.285
14	6000	0.225
15	6000	0.182
16	6000	0.150
17	6000	0.125
18	5822	0.104
19	5341	0.081
20	4822	0.064
21	4250	0.050
22	3672	0.039
23	3088	0.030
24	2463	0.022
25	0	0



Tab. 5 –V162-6.0, power and C_t curves

3. WIND FLOW MODEL

The evaluation of the expected energy production and site suitability has been performed using the WindSim 11 software, developed by WindSim AS and based on CFD analysis of the wind flow, that represents the solving of Navier-Stokes equations using an iterative process.

3.1. Digital terrain model

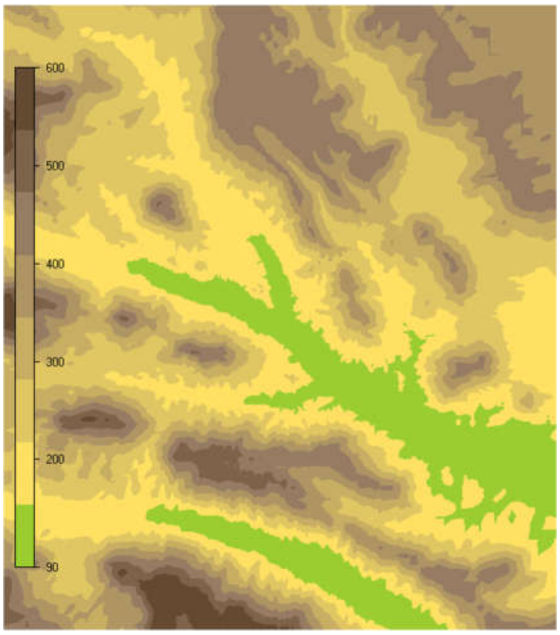
In order to properly implement the CFD analysis, a 3-dimensional model with the following dimensional parameters has been used:

	Minimum [m]	Maximum [m]	Extension [m]	Resolution terrain data [m]
Easting [m]	604000.0	629993.0	25993.0	11.0
Northing [m]	4489000.0	4517996.0	28996.0	11.0

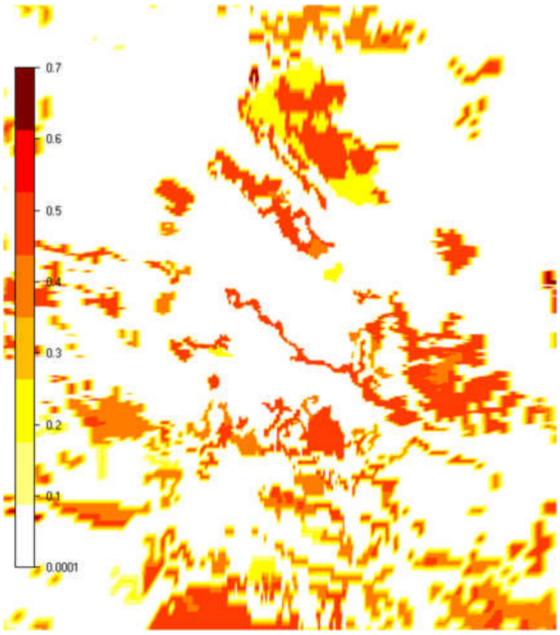
Tab. 6 - Extension and resolution of the digital terrain, coordinates in UTM WGS84 Zone 33

The terrain model used in the assessment represents as far as possible the current conditions at site, assuming that they will remain the same during the lifetime of the wind farm.

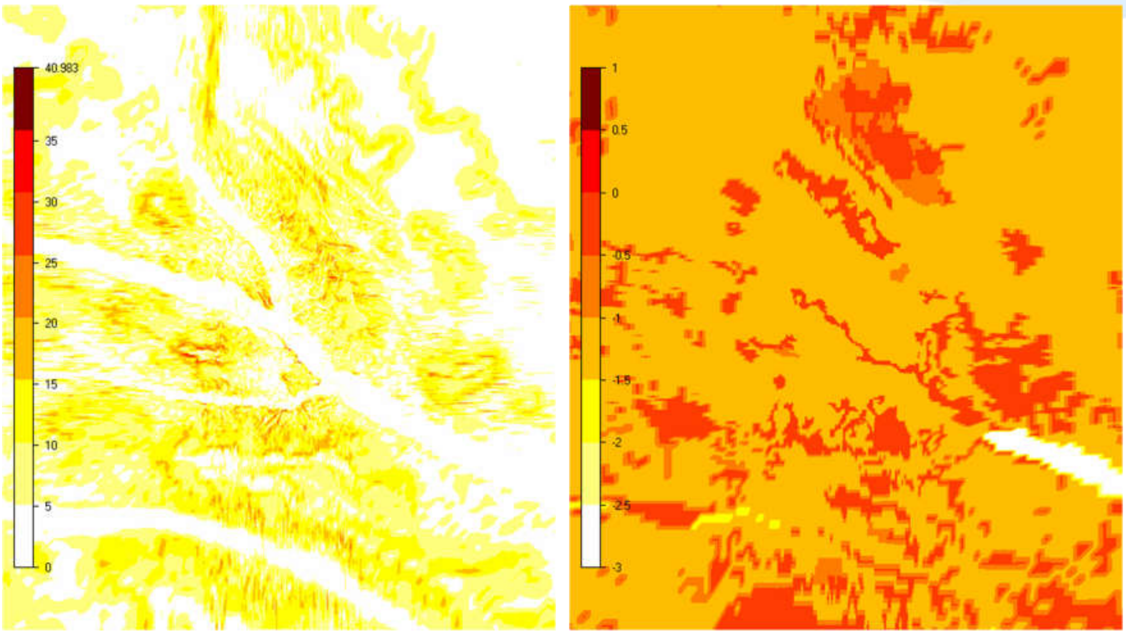
In the following figure, the digital terrain and roughness model are shown. The complexity at the site depends on the changes in elevation and roughness. The complexity in elevation is visualized by the inclination angles which is a derived quantity expressing the first order derivatives of the elevation.



Terrain elevation [m]



Roughness length [m]



Terrain inclination [deg] logarithmic roughness [m]

Fig. 2 - Digital terrain model

3.2. Wind flow modelling

In order to properly model the wind flow, the "Refinement Area" technique has been adopted.

The elevation and roughness data defined above is used to define the ground level of a three-dimensional domain divided in cells with a variable horizontal and vertical resolution. The grid is generated and optimized from the digital terrain model.

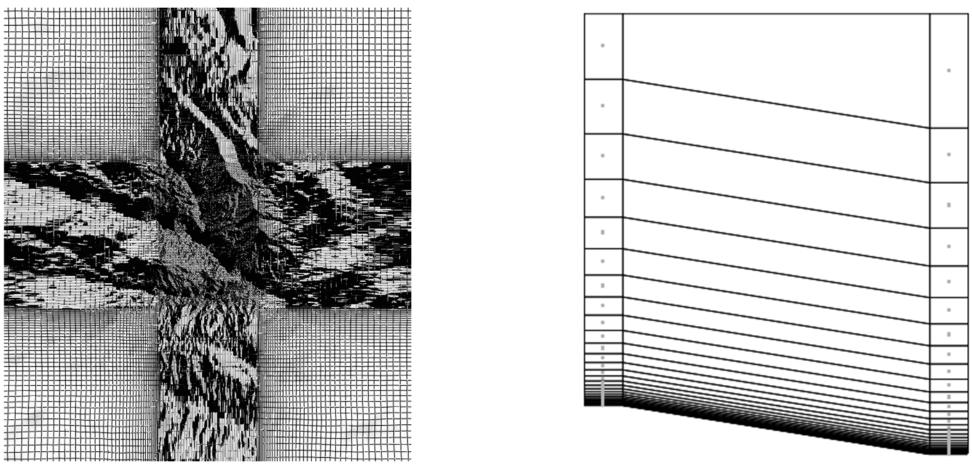


Fig. 3 - Horizontal (left) and vertical (right) grid resolution

	Easting [m]	Northing [m]	Z [m]	Total [-]
Grid spacing [m]	20.0-445.1	20.0-445.1	Variable	-
Number of cells [-]	386	536	33	6827568

Tab. 7 - Grid spacings and number of cells

The grid extends m above the point in the terrain with the highest elevation. The grid is refined towards the ground. The left and right columns display a schematic view of the distribution at the position with maximum and minimum elevation respectively. The nodes, where results from the simulations are available, are situated in the cell centers indicated by dots.

Node	1	2	3	4	5	6	7	8	9	10
z-dist. max [m]	1.0	3.2	5.8	9.0	12.8	17.4	22.8	29.4	37.3	46.8
z-dist. min [m]	1.0	3.2	5.9	9.0	12.8	17.4	22.9	29.4	37.3	46.8

Tab. 8 - Distribution of the first 10 nodes in z-direction, relative to the ground, at the position with maximum and minimum elevation

Once the digital map has been defined and the terrain grid has been created, the settings for the wind flow modelling in the 12 sectors are listed in the table.

Height of boundary layer [m]	500.0
Speed above boundary layer [m/s]	10.0
Boundary condition at the top	fix pres.
Potential temperature	No
Turbulence model	RNG k-e
Solver	GCV
Maximum iterations	1000
Convergence Criteria	0.0001

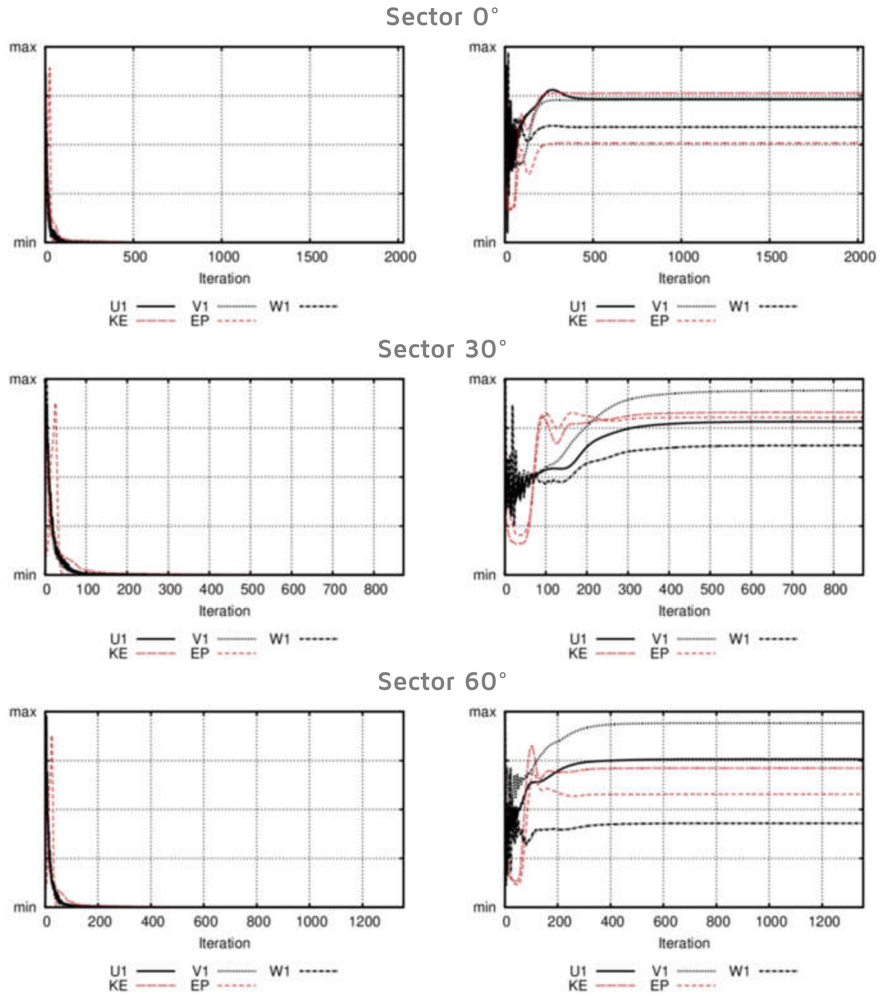
Tab. 9 - Wind flow modelling settings

The simulation time and the number of iterations to reach a converged solution for each sector is given in next table. The column "Status" should display a "C" indicating that the numerical procedure has converged, which means that the found solution actually is a solution of the specified problem. If the solution procedure doesn't find a solution the "Status" will display a "D" for divergence, or a "-" indicating that the solution procedure reached the maximum set number of iterations before a converged solution was found. The convergence of the wind field simulations is evaluated by inspection of the spot and residual values for the velocity components (U1, V1, W1), the turbulent kinetic energy (KE) and its dissipation rate (EP). In case convergence has not been reached yet, the residuals and spot values for each sector should be inspected to verify whether the solution is stable enough and characterized by low residuals so that the wind flow model can still be accepted.

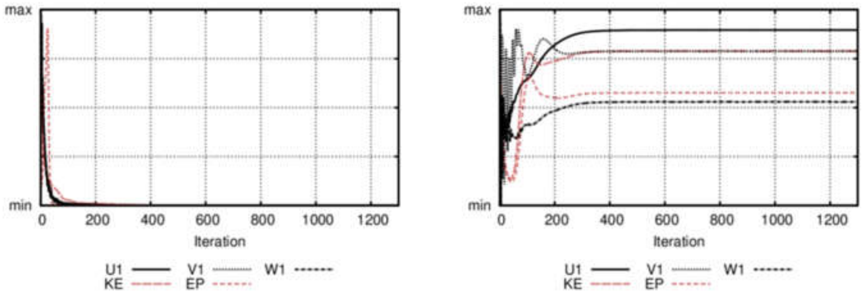
Sector [°]	Simulation time [hh:mm:ss]	Iterations [-]	Status	Sector [°]	Simulation time [hh:mm:ss]	Iterations [-]	Status
0	34:21:11	2030	C	180	27:58:58	1630	C
30	16:01:57	872	C	210	30:45:49	1890	C
60	23:59:57	1355	C	240	19:27:01	1107	C
90	22:39:39	1300	C	270	23:10:28	1355	C
120	18:27:37	1023	C	300	19:01:45	1079	C
150	27:15:51	1536	C	330	15:52:14	862	C

Tab. 10 - Simulation time and convergence status

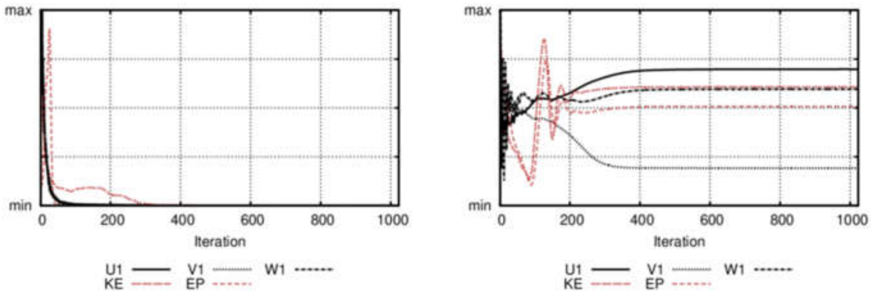
In the following figure, the sector-wise residuals (left) and spot values (right) are shown.



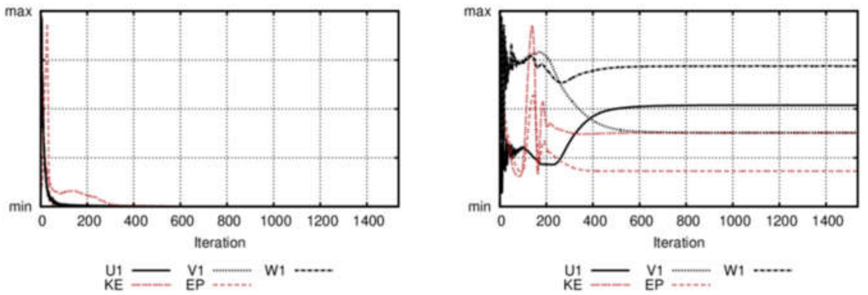
Sector 90°



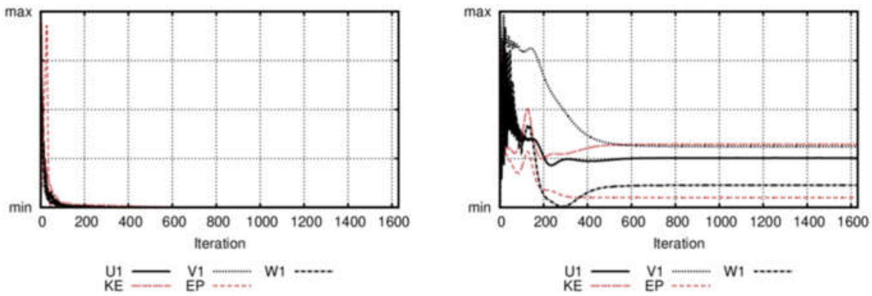
Sector 120°



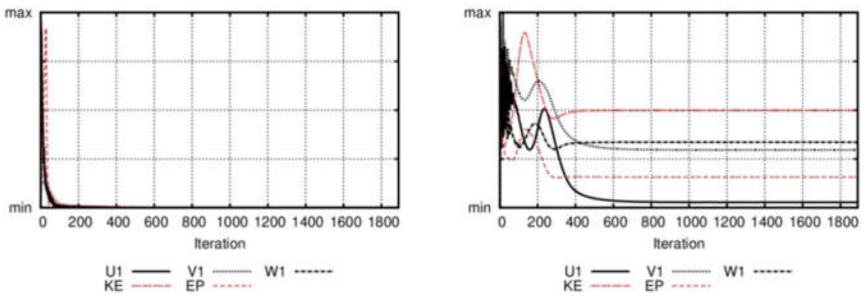
Sector 150°



Sector 180°



Sector 210°



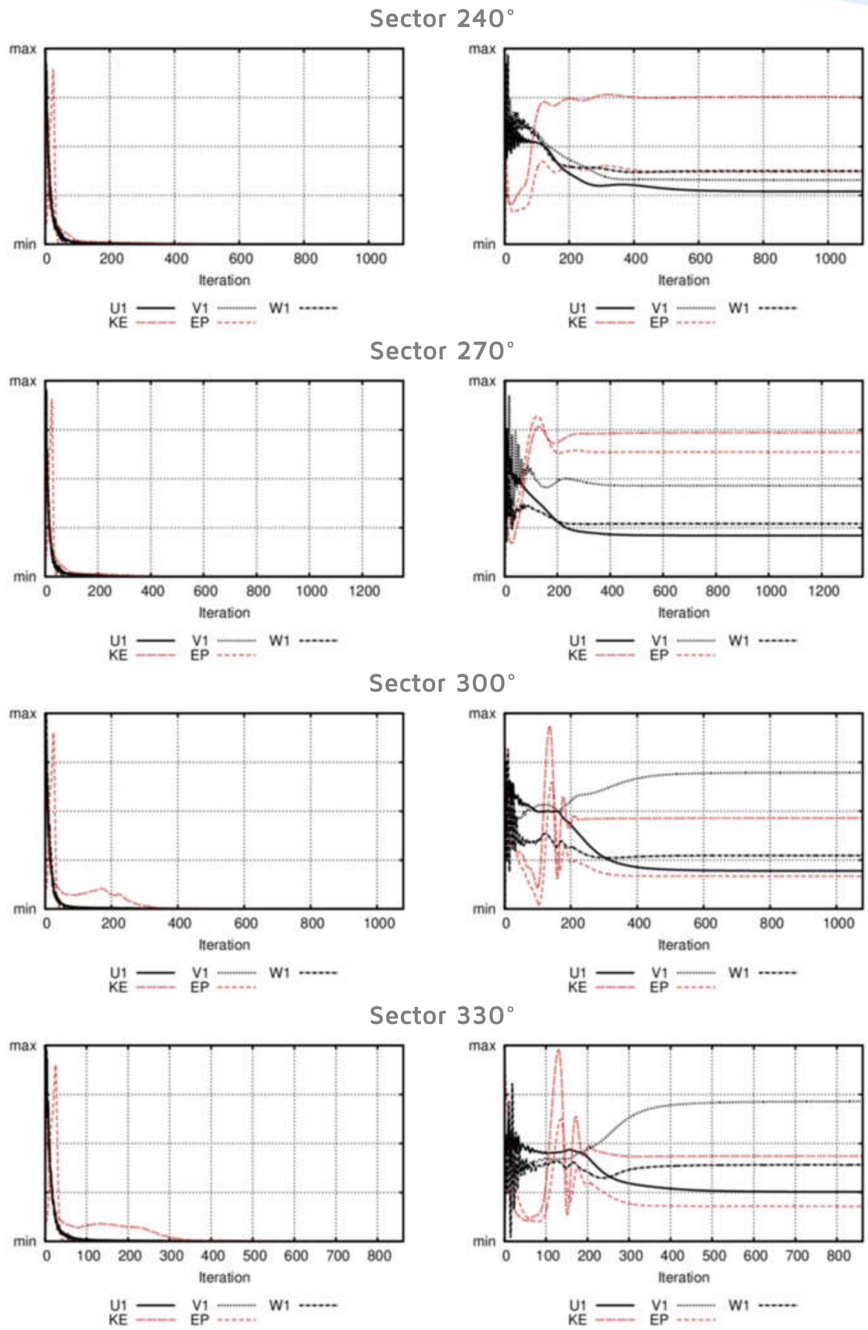


Fig. 4 - Sectorwise residuals (left) and spot values (right) results

4. WIND RESOURCE ASSESSMENT

The main steps of the wind data analysis are summarized below:

1. Data Validation and On site data synthesis: no significant validation undertaken, the data availability at all sensors of about 100% for both wind speed and direction. The co-located anemometers have been combined, assuming the anemometer oriented at 60° as primary and merging data from the anemometer oriented at 240° to remove the influence of tower shading. In order to avoid seasonality bias, a period of a full year from April 2022 to March 2023 has been selected and adopted in the energy yield assessment. The resulting wind speed at 99 m is equal to 5.33 m/s.
2. Long-term assessment: VR has reviewed a number of long-term sources, including two ERA5(T) Rectangular Grid grid cells and two ERA5 (Gaussian Grid) grid cell closest to the Project site. Based on Mann-Kendall test, a 23-year period of the long-term sources was assumed as consistent. The long-term wind speed was assessed adopting one of the ERA5(T) nodes with a representative correlation coefficient R^2 above 0.93. The resulting long-term wind speed is equal to 5.39 m/s with a long-term adjustment factor of +1.1%.
3. Wind shear analysis and hub height long-term wind speed: the measured shear was assumed for the vertical extrapolation of the wind speed to the hub height, adopting a shear matrix binned by direction, season and hour between the data measured at 99 m, 80 m and 60 m and resulting in an average wind shear value of 0.08. The resulting long-term wind speed at 125 m is equal to 5.50 m/s. The measured wind shear as compared to the wind shear modelled with WindSim (0.08) confirming the adoption of the measured wind shear:

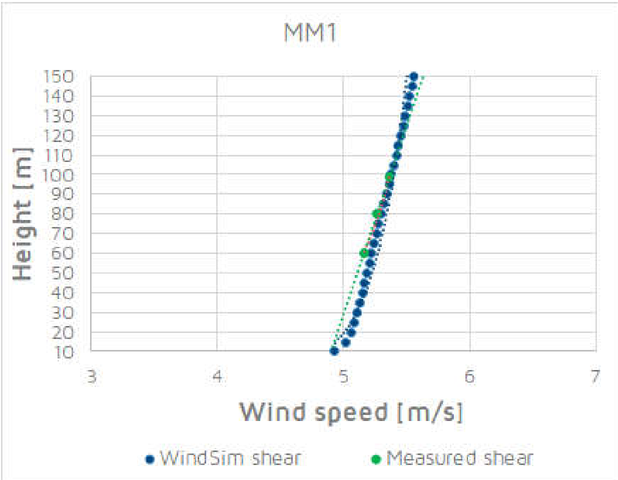


Fig. 5 – Measured and modelled wind shear

The following table show a summary of the main results of the analysis:

Mast	Measurement height	Measured wind speed after on-site data synthesis	Long term wind speed	125 m Hub Height Long Term Wind Speed
	[m]	[m/s]	[m/s]	[m/s]
MM!	99	5.33	5.39	5.50

Tab. 11 – Wind data analysis

Site representative long-term energy and wind roses are shown in Fig. 6.

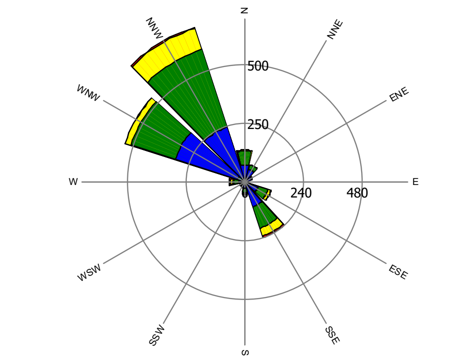
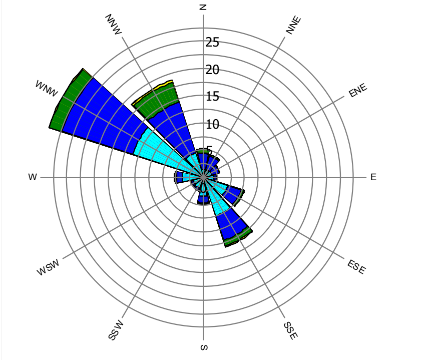
Energy rose [%]	Wind rose [%]	Legend
		20 - 40 m/s 15 - 20 m/s 10 - 15 m/s 5 - 10 m/s 0 - 5 m/s

Fig. 6 – Energy and Wind roses at Mast MM1 at 125 m

5. EXPECTED ENERGY YIELD ASSESSMENT

The expected energy production of the Project has been estimated with the wind turbine configuration requested, using the using the measured timeseries representative of the long-term wind regime of the site and extrapolated to the desired hub height, as described in Section 4. The so-called "time-varying calculation concept" has been selected in order to avoid the influence of the Weibull fit. The energy production accounts for the losses due to wake effects and to the site air density. The wake model implemented in the analysis is the N. O. Jensen (RISO/EMD) Park 2 2018 based on DTU onshore standard wake decay of 0.090, constant for all the sectors.

The energy production shown in the tables below accounts for the losses due to wake effects and to the site air density.

The tables hereunder contain the following information for each wind turbine:

Site ID: ID number of the wind turbine in the tables

Site X [m]: E longitude in **UTM-WGS84 Zone 33** coordinates

Site Y [m]: N latitude in **UTM-WGS84 Zone 33** coordinates

Elev. [m]: elevation above sea level (ASL)

HH [m]: hub height

V [m/s]: average wind speed estimated by the model at hub height

Gross Production [GWh]: expected gross output, gross and net of wake losses

Loss [%]: percent of production lost due to wake losses

Equivalent Hours [h]: equivalent annual hours of gross production, net of wake losses

ID	X [m]	Y [m]	Elev. [m]	HH [m]	V [m/s]	Gross Production [GWh]		Loss [%]	Net Hours [h]
						Gross of wakes	Net of wakes		
T1	615489	450479	215	125.0	5.29	12.79	12.72	0.52	2120
T2	616042	450473	230	125.0	5.44	13.52	13.27	1.83	2211
T3	617868	450549	265	125.0	5.46	13.61	13.46	1.11	2243
T4	618438	450582	274	125.0	5.27	12.61	12.41	1.63	2068
T5	618833	450644	314	125.0	5.18	12.12	12.06	0.49	1982
T6	617624	450067	225	125.0	5.29	12.74	12.68	0.41	2114
				Average	5.32	12.90	12.77	1.00	2128
					Total	77.38	76.60		

Tab. 12 –Vestas V162-6.0 MW - Gross energy production

The next step in the analysis is to assess the energy losses (electrical, production and power losses) to determine the energy that will be available for input into the power grid. The following is a list of the loss factors considered for a **10-year period**: to be noted that the values related to turbine availability and electrical losses have been provided by the Client, while the other values are based on standard assumptions. A more detailed evaluation could be performed when the electrical project design, supply or O&M agreement are in place or even at a discussion phase.

Each loss factor shall be reviewed as soon as the corresponding calculated or contractually agreed values are available.

Loss Factor	Losses [%]
Turbine Availability	-3.0%
Non-contractual turbine availability	-0.5%
B.O.P. availability	-1.0%
Electrical grid availability	-0.3%
Electrical losses	-1.7%
Environment	-0.4%
Turbine Performance	-2.2%
Curtailment	-
Total losses	**-8.7%**

Tab. 13 – Wind farm energy losses

The following table summarizes the results obtained for the Project:

Configuration	Wind Farm Power [MW]	Gross production (net of wakes) [GWh/year]	Net production (deliverable to grid) [GWh/year]
V162-6.0	36.0	69.91	1942

Tab. 14 - Gross and net energy production

The expected net production estimates (deliverable to grid) shown in the table above, represent the so-called $P_{50\%}$, i.e. the production calculated with the average wind conditions, also called central estimate.

The main sources of deviation from the central estimate have therefore been quantified. In this context, the uncertainty of a parameter is defined as the estimate of the standard deviation of the corresponding statistical distribution.

A sensitivity factor of 2.1 has been estimated in order to convert the uncertainty related to the wind speed into energy uncertainty. Based on the detailed uncertainty evaluation, it is possible to compute the values of $P_{75\%}$(1), $P_{90\%}$(1) and $P_{75\%}$(10), $P_{90\%}$(10). Specifically, the $P_{75\%}$ and $P_{90\%}$ values represent, respectively, the average energy production that has a 75% and 90% probability of being exceeded in a given period. In this case, the average value of a 10-year period or of 1 year within 10 years.

Wind farm	Expected annual production in any period of 1 year (GWh/year)			Expected annual production in any period of 10 year (GWh/year)		
	P50%	P75%	P90%	P50%	P75%	P90%
6 x V162-6.0	69.91	62.83	56.45	69.91	63.85	58.40

Tab. 15 - Confidence interval for net energy production

The main uncertainty sources and values considered in this assessment are collected according to the IEC WG15 outcoming standards, leading to an overall level of uncertainty of the expected production for the 10-years period of about 12.8%.

6. SITE CONDITIONS

The parameters calculated in the following sections have been compared against the limits specified in the IEC standard 61400-1 Edition 3. The standard defines a turbine classification based on the environmental conditions summarised in the table below.

Wind Turbine class	I	II	III	S
Vref [m/s]	50	42.5	37.5	Values specified by the designer
A Iref [-]	0.16			
B Iref [-]	0.14			
C Iref [-]	0.12			

Tab. 16 – Basic parameters for wind turbine classes

The following table summarizes the main site conditions at site:

Site conditions										
ID	Mean Wind Speed	Weibull A and k parameters		Ic	Vref	Tieff at 15 m /s	Shear	Max inflow angle	Mean air density	Mean temperature at hub height
	[m/s]	[m/s]	[m/s]	[-]	[m/s]	[%]	[-]	[Deg]	[kg/m³]	[°C]
T1	5.3	5.94	1.64	1	30.7	15.9	0.12	3.4	1.181	13.9
T2	5.5	6.10	1.64	1	31.3	15.9	0.11	2.7	1.180	13.8
T3	5.5	6.14	1.64	1	31.5	15.5	0.11	3.8	1.176	13.5
T4	5.3	5.92	1.65	1	30.0	16.6	0.12	1.8	1.175	13.5
T5	5.2	5.76	1.66	1	29.1	16.9	0.13	5.9	1.170	13.2
T6	5.3	5.93	1.65	1	29.8	16.1	0.13	2.8	1.180	13.8

Tab. 17 – Site conditions at the wind turbines

7. CONCLUSIONS

Valid wind data have been recorded at the Grottole site from the measurement mast on site. Based on the results from the analysis of these data, the following conclusions are made concerning the site wind regime end energy production assessment:

1. The mast is located at the northern cluster of the site. VR considers that the measurement at site is sufficiently representative of the turbine locations at the northern cluster. The installation of an additional measurement is deemed as beneficial to improve the accuracy of the assessment and reduce the uncertainty but not required as mandatory.
2. A detailed assessment of the compliance of the mast with the IEC 61400-12-1 ed.2 standard has been undertaken in the report RVRIT23207, following a site survey and mast audit perform on the 8th of June 2023. For more information, please refer to such report. The results of such assessment has been taken into account in the current revision of the study. Overall, the mast is deemed as broadly compliant and fulfilling the rule of 2/3 of the proposed hub height.
3. The wind data provided cover a period of 13.5 months with high data availability, of about 100%.
4. For the horizontal extrapolation of the wind speed at each turbine location, the WindSim CFD model has been applied. For the vertical extrapolation of the wind speed at the hub height of the turbines, the modelled and the measured vertical profiles were compared finding a good agreement. Therefore, to initialize the wind flow model the time series was extrapolated to the hub height using the measured wind shear.
5. From public database and aerial pictures publicly available online, no operating turbines are detected in the surroundings of the Project within a radius of approximately 20 time the proposed rotor diameter, and therefore no external wake effect has been included within the calculation. In case additional information is available on existing or under development wind farms, it is recommended to provide the relevant layouts and turbine models involved (rated power, rotor size and hub height) to properly account for their effect in terms of additional wakes induced on the Project.
6. At this preliminary stage, an assessment of the additional losses related to turbine, B.O.P. and grid availability, electrical plant, environment, turbine performance and potential curtailment was undertaken. To be noted that the values related to turbine availability and electrical losses have been provided by the Client, while the other values are based on standard assumptions. A more detailed evaluation could be performed when the electrical project design, supply or O&M agreement are in place or even at a discussion phase.

7. It is recommended to obtain the turbine manufacturer's Mechanical Load assessment and site suitability Analysis (MLA), in order to ensure that the desired wind turbine model and the proposed layout will be suitable for the site according to IEC 61400-1 Standard Ed.3 and that the fatigue loads, resulting from the wind conditions onsite and acting on the turbine main components, are within the design load envelope.

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