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# REGIONE CAMPANIA

## PROVINCIA DI SALERNO

## COMUNE DI CAGGIANO

*Titolo del Progetto:*

**REALIZZAZIONE DI UN IMPIANTO EOLICO UBICATO NEL COMUNE DI CAGGIANO (SA) IN LOCALITA' "TEMPA DEL VENTO", CON POTENZA NOMINALE PARI A 46.2 MW**

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PRELIMINARY WIND RESOURCE ASSESSMENT
RELAZIONE ANEMOLOGICA

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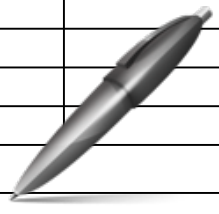

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# PRELIMINARY WIND RESOURCE ASSESSMENT

## Caggiano

June 2023

# Details

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## Contents

# 1. FOREWORD

I-Project S.r.l. (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 of the Caggiano wind site (the "**Project**") in development in Italy.

The activity consisted in the preliminary estimation of the expected wind statistics at the site extrapolated from a Virtual Met Mast downscaled to a location deemed as representative of the wind farm, according to the **Technical Advisor**'s analysis on the long-term wind regime representative of the area.

The whole study was carried out with professional approach and instruments, as prescribed by the international methodologies for a trustworthy assessment of expected wind farm production.

Being the assessment based on re-analysis data characterized by a higher level of uncertainty compared to a measurement on site, the presented wind resource shall be considered as preliminary, and the analysis should be updated when a full year measurement campaign onsite is available.

## 2. WIND RESOURCE ASSESSMENT

The supplied material useful for this preliminary assessment of the wind resource includes:

1. Area of the wind site

As requested by the Client, the wind assessment has been performed by adopting the WAsP 12 model propagation as embedded in WindPRO 3.6. The height contours and roughness maps to be included in the wind flow model were not provided and therefore they were downloaded from online sources covering an area of about 20 km x 20 km. In particular, the elevation map was retrieved from the TINITALY Model with a 10 m vertical spacing for the wind farm area while the roughness map was downloaded from the Corine Land Cover 2018 database and its values adjusted to the site based on satellite images.

The proposed area extends on a mountain, with turbine elevation ranging from 600 m to 1260 m. The orography of the site can be classified as very complex with medium to low terrain roughness.

No information has been provided regarding other 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 it is observed that there aren't operating turbines in the area within a radius of approximately 6 km distance from the **Project**.

The location of the proposed site area is shown in Figure 1.

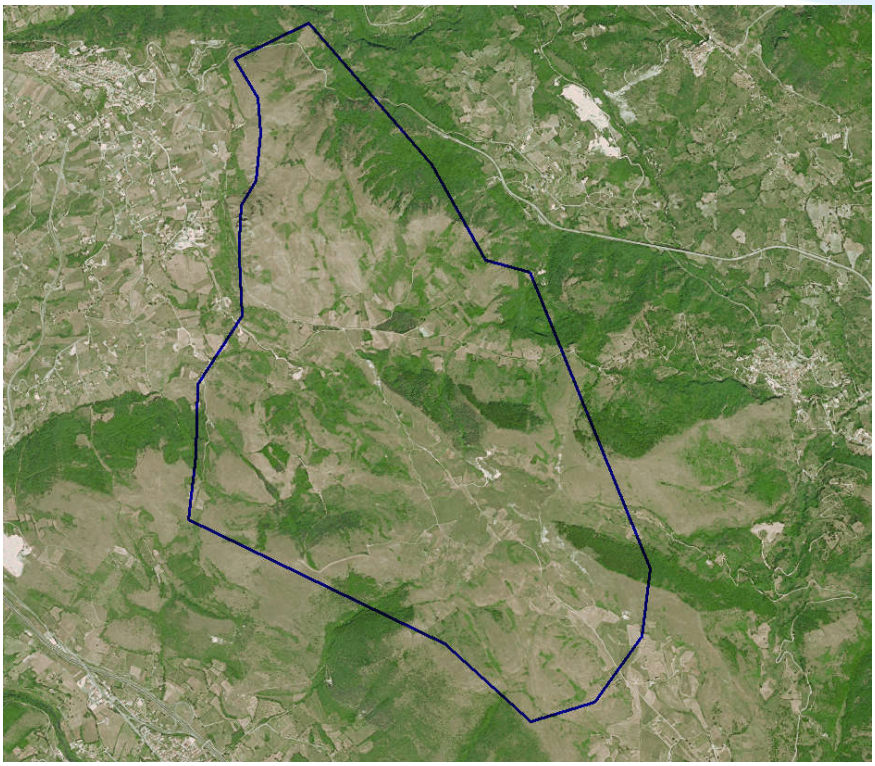


Fig. 1 - Proposed wind site

Considering that a measurement campaign recorded onsite is not yet available, the preliminary estimation of the wind resource of the Project is extrapolated from a Virtual Met Mast downscaled to a representative location of the Caggiano site at 100 m height. The Virtual Met Mast statistics are usually obtained by using the sources available in the area deemed as representative, such as land-based wind data and mesoscale data. For the Project, 10-year Vortex Series ERA-5 hourly time series has been acquired.

It is necessary to emphasize that the Virtual Met Mast does not replace a traditional on-site measurement mast and therefore any assessment of the wind resource will have a high uncertainty. **The results shall be intended as a preliminary estimation only.** It is recommended to install at least one met mast onsite, in a position representative of the planned wind farm and characterized by a good exposure, whose structure should be high at least 2/3 of the proposed hub height, in order to reduce the vertical extrapolation uncertainties, and to update the analysis accordingly.

The long-term wind regime expected onsite has been assessed using the Virtual Met Mast characterized by a long-term wind speed at 100 m of 5.44 m/s, whose Weibull distribution, energy and wind roses split into five wind speed classes and 12 sectors are reported below. It is observed the prevailing winds are from the northern and southern sectors.

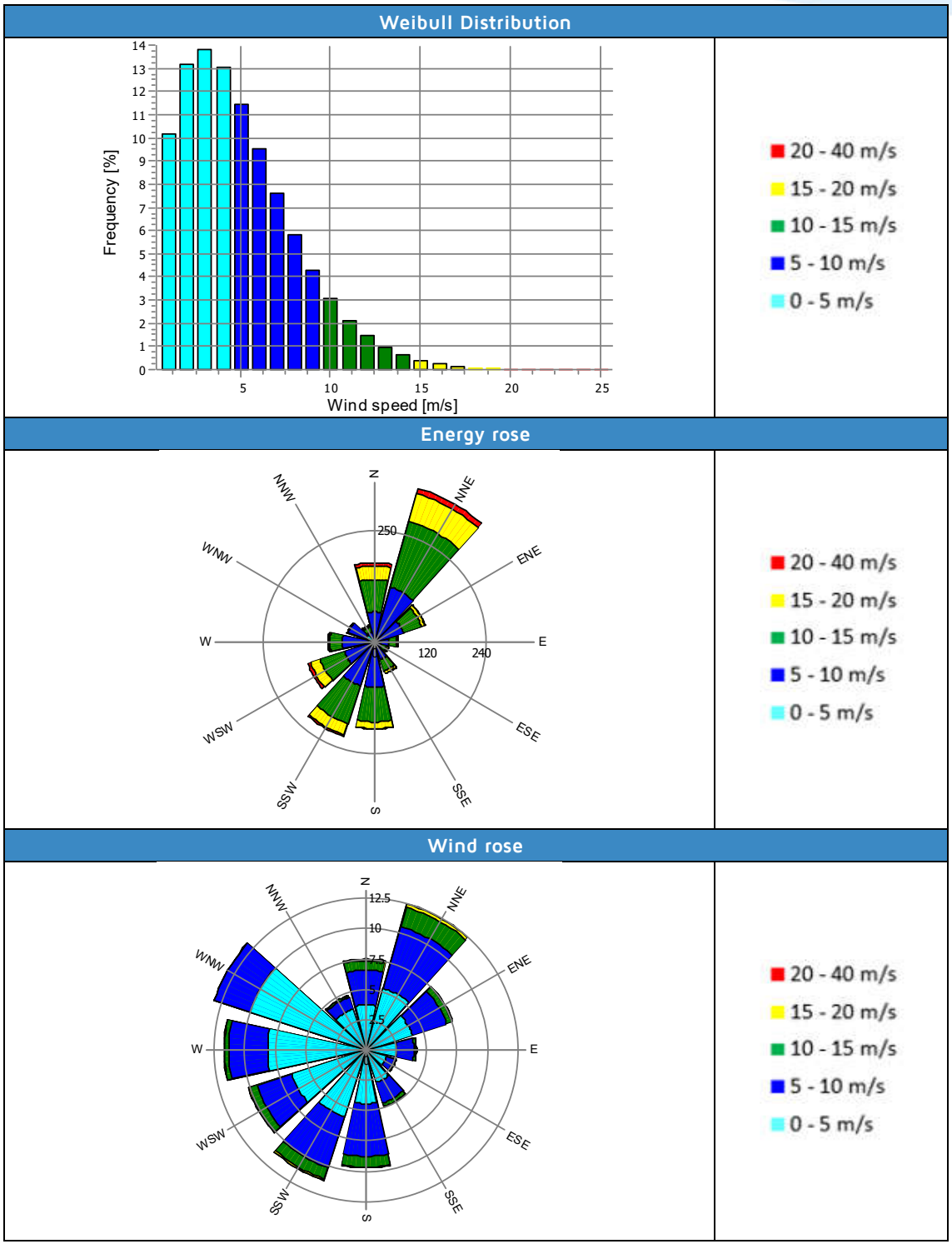



Fig. 2 - Wind conditions at the Virtual Met Mast at 100 m

The following figure shows the estimated wind resource on the site area.

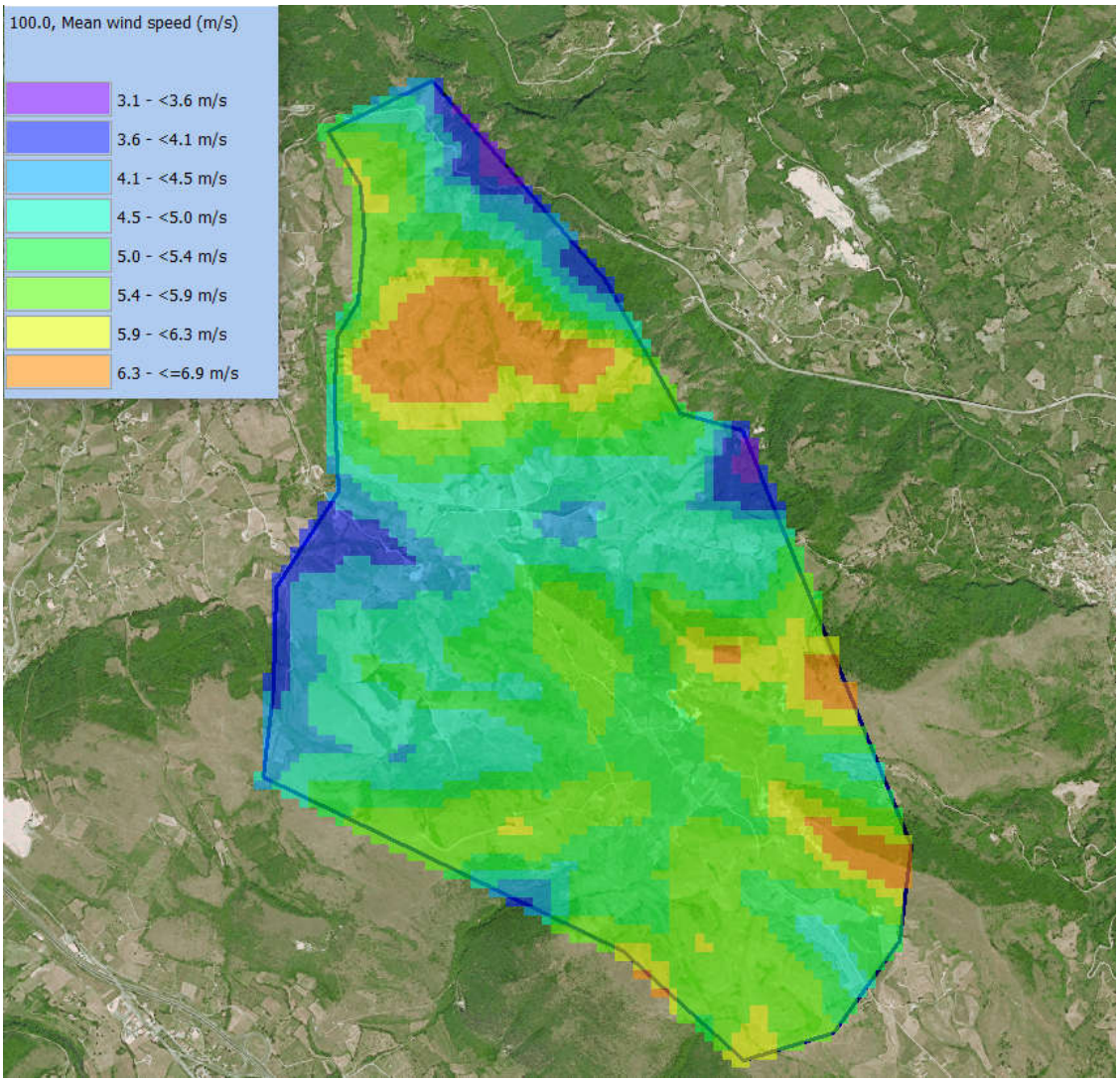



Fig. 3 - Wind resource map

## 3. LAYOUT

Based on the wind map provided in SECTION 2, the Client has designed and supplied a layout for the Project consisting in n. 7 wind turbines. The coordinates of the proposed layout are reported in the table below:

| UTM WGS84 ZONE 33 | | | |
|---|---|---|---|
| Turbine ID | Longitude [m] | Latitude [m] | Elevation [m a.s.l.] |
| T1 | 543476 | 4489729 | 1130 |
| T2 | 544127 | 4489708 | 1108 |
| T3 | 544708 | 4489550 | 976 |
| T4 | 543994 | 4488272 | 1008 |
| T5 | 544490 | 4488031 | 1087 |
| T6 | 545296 | 4487523 | 1170 |
| T7 | 545239 | 4486470 | 1166 |

Tab. 1 – Caggiano wind farm coordinates

The location of the proposed turbines in red is shown in Fig. 4.

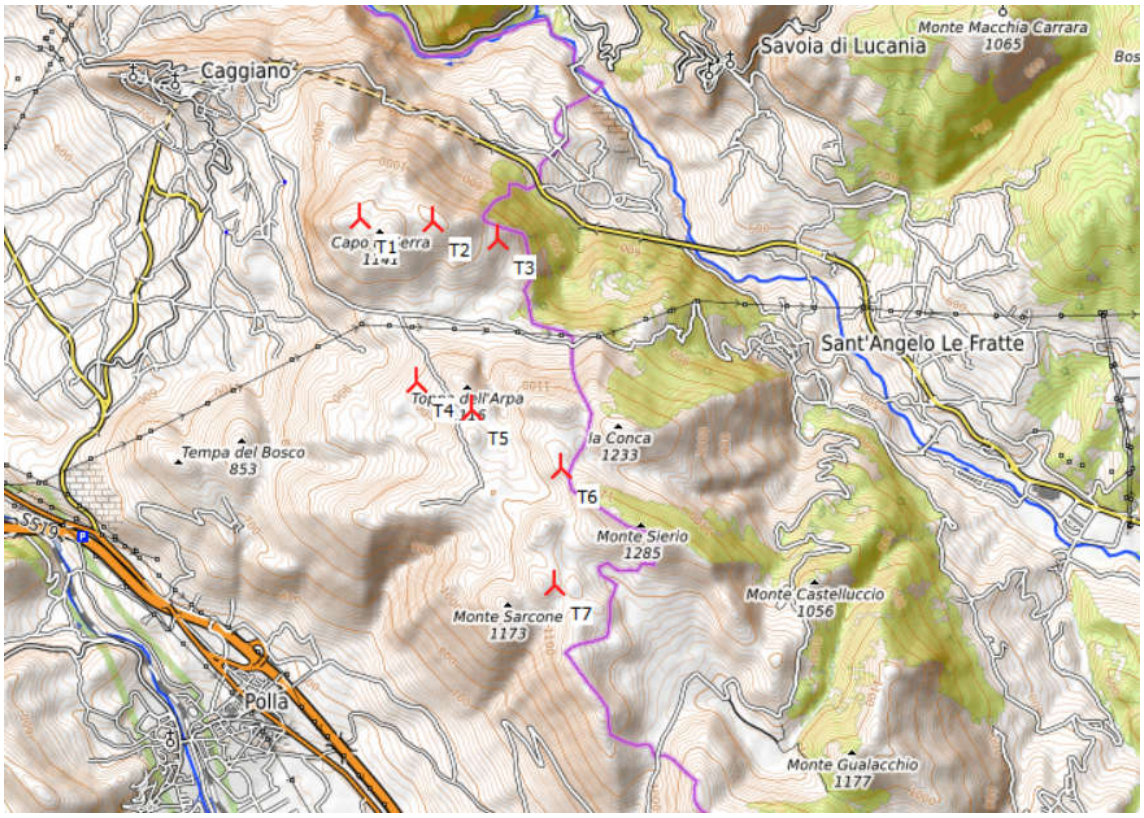



Fig. 4 - Proposed wind turbines

**Technical Advisor**'s standard requirements for distances between turbines are five rotor diameters in the prevailing wind direction, and three rotor diameters in directions perpendicular to the prevailing. The next table shows the distances separating the wind turbines in diameters of 170 m rotor.

| RD=170m\Meter | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|---|---|---|---|---|---|---|---|
| T1 | - | 651 | 1245 | 1546 | 1978 | 2860 | 3705 |
| T2 | 3.8 | - | 602 | 1442 | 1716 | 2478 | 3424 |
| T3 | 7.3 | 3.5 | - | 1464 | 1535 | 2111 | 3125 |
| T4 | 9.1 | 8.5 | 8.6 | - | 551 | 1502 | 2190 |
| T5 | 11.6 | 10.1 | 9.0 | 3.2 | - | 953 | 1731 |
| T6 | 16.8 | 14.6 | 12.4 | 8.8 | 5.6 | - | 1055 |
| T7 | 21.8 | 20.1 | 18.4 | 12.9 | 10.2 | 6.2 | - |

Tab. 2 - Spacings in rotor diameter and meters of Caggiano wind farm

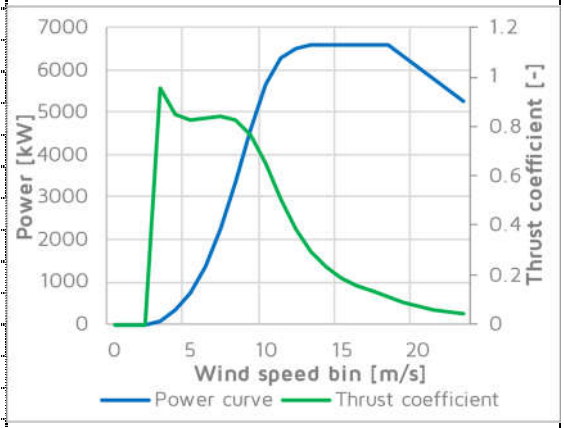
All turbines are spaced by at least three rotor diameters. Considering the most energetic sector from NNE, all turbines fully meet the above requirements.

Anyway, 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.

# 4. WIND TURBINE MODELS

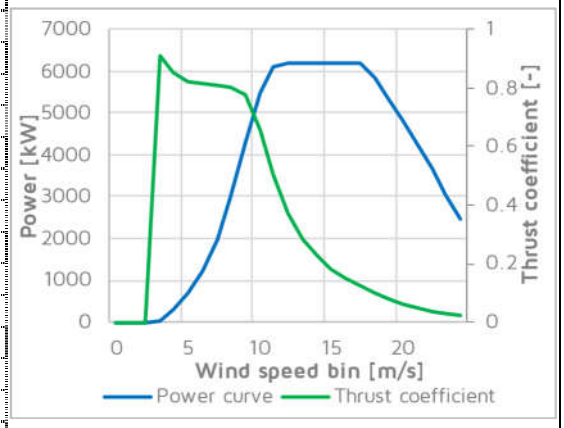
The expected energy production of the wind farm is estimated considering the following two wind turbine models requested by the Client, whose power and thrust curves have been derived from the WindPRO database and adjusted at the site air density of 1.09 kg/m$^3$ according to the IEC 61400-12 method correction.

| Turbine type | | SG 6.6-170 | Diameter [m] | 170.0 |
|---|---|---|---|---|
| Rated power [MW] | | 6.6 | Hub height [m] | 115.0 |
| Rated wind speed [m/s] | | 15.5 | IEC class | S |
| Cut-in/Cut-out wind speed [m/s] | | 3.0/23.0 | Air density [kg/m$^3$] | 1.225 |
| Bin wind speed [m/s] | Power [kW] | Thrust coefficient [-] | | |
| 0 | 0 | 0 | | |
| 1 | 0 | 0 | | |
| 2 | 0 | 0 | | |
| 3 | 89 | 0.953 | | |
| 4 | 328 | 0.847 | | |
| 5 | 758 | 0.824 | | |
| 6 | 1376 | 0.833 | | |
| 7 | 2230 | 0.837 | | |
| 8 | 3346 | 0.825 | | |
| 9 | 4600 | 0.766 | | |
| 10 | 5660 | 0.648 | | |
| 11 | 6272 | 0.506 | | |
| 12 | 6510 | 0.383 | | |
| 13 | 6579 | 0.294 | | |
| 14 | 6596 | 0.231 | | |
| 15 | 6599 | 0.186 | | |
| 16 | 6600 | 0.155 | | |
| 17 | 6600 | 0.132 | | |
| 18 | 6600 | 0.115 | | |
| 19 | 6336 | 0.087 | | |
| 20 | 6072 | 0.072 | | |
| 21 | 5808 | 0.060 | | |
| 22 | 5544 | 0.050 | | |
| 23 | 5280 | 0.042 | | |




Tab. 3 – SGRE SG 6.6-170, power and $C_t$ curves

| Turbine type | | V162-6.2 | Diameter [m] | 162.0 |
|---|---|---|---|---|
| Rated power [MW] | | 6.2 | Hub height [m] | 119.0 |
| Rated wind speed [m/s] | | 12.5 | IEC class | S |
| Cut-in/Cut-out wind speed [m/s] | | 3.0/24.0 | Air density [kg/m³] | 1.225 |
| Bin wind speed [m/s] | Power [kW] | Thrust coefficient [-] | | |
| 0 | 0 | 0 | | |
| 1 | 0 | 0 | | |
| 2 | 0 | 0 | | |
| 3 | 34 | 0.908 | | |
| 4 | 292 | 0.853 | | |
| 5 | 676 | 0.819 | | |
| 6 | 1229 | 0.812 | | |
| 7 | 2000 | 0.807 | | |
| 8 | 3017 | 0.799 | | |
| 9 | 4284 | 0.775 | | |
| 10 | 5483 | 0.657 | | |
| 11 | 6114 | 0.504 | | |
| 12 | 6197 | 0.370 | | |
| 13 | 6200 | 0.283 | | |
| 14 | 6200 | 0.223 | | |
| 15 | 6200 | 0.180 | | |
| 16 | 6200 | 0.148 | | |
| 17 | 6186 | 0.124 | | |
| 18 | 5853 | 0.100 | | |
| 19 | 5348 | 0.078 | | |
| 20 | 4825 | 0.062 | | |
| 21 | 4251 | 0.048 | | |
| 22 | 3664 | 0.037 | | |
| 23 | 3064 | 0.029 | | |
| 24 | 2451 | 0.022 | | |




Tab. 4 – Vestas V162-6.2, power and $C_t$ curves

# 5. PRELIMINARY EXPECTED ENERGY YIELD ASSESSMENT

The expected energy production of the Caggiano wind farm has been estimated with the wind turbine configuration requested, using the long-term wind statistics of the Virtual Met Mast and adopting the WAsP 12 model propagation as embedded in WindPRO 3.6. The wake model implemented in the analysis is the N.O. Jensen (RISO/EMD) Park2 2018 wake model with DTU default onshore wake decay constant of 0.090.

The energy production 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 table

**X [m]**: longitude in **UTM WGS84 ZONE 33** coordinates

**Y [m]**: 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 | 543476 | 4489729 | 1130 | 115.0 | 6.79 | 19.60 | 19.35 | 1.27 | 2932 |
| T2 | 544127 | 4489708 | 1108 | 115.0 | 6.72 | 19.17 | 18.34 | 4.32 | 2779 |
| T3 | 544708 | 4489550 | 976 | 115.0 | 6.00 | 16.00 | 14.97 | 6.47 | 2268 |
| T4 | 543994 | 4488272 | 1008 | 115.0 | 5.38 | 12.79 | 12.30 | 3.81 | 1864 |
| T5 | 544490 | 4488031 | 1087 | 115.0 | 5.75 | 14.65 | 13.92 | 4.99 | 2109 |
| T6 | 545296 | 4487523 | 1170 | 115.0 | 5.90 | 15.27 | 14.53 | 4.88 | 2201 |
| T7 | 545239 | 4486470 | 1166 | 115.0 | 5.93 | 15.42 | 15.19 | 1.45 | 2302 |
| | | | | Average | 6.07 | 16.13 | 15.51 | 3.88 | 2351 |
| | | | | | Total | 112.90 | 108.60 | | |

Tab. 5 – Caggiano energy production – SGRE SG 6.6-170

| 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 | 543476 | 4489729 | 1130 | 115.0 | 6.80 | 18.25 | 18.03 | 1.18 | 2909 |
| T2 | 544127 | 4489708 | 1108 | 115.0 | 6.73 | 17.84 | 17.13 | 4.01 | 2762 |
| T3 | 544708 | 4489550 | 976 | 115.0 | 6.02 | 14.91 | 14.02 | 5.97 | 2261 |
| T4 | 543994 | 4488272 | 1008 | 115.0 | 5.41 | 11.92 | 11.50 | 3.50 | 1855 |
| T5 | 544490 | 4488031 | 1087 | 115.0 | 5.78 | 13.66 | 13.04 | 4.53 | 2103 |
| T6 | 545296 | 4487523 | 1170 | 115.0 | 5.92 | 14.23 | 13.59 | 4.47 | 2192 |
| T7 | 545239 | 4486470 | 1166 | 115.0 | 5.96 | 14.39 | 14.20 | 1.33 | 2290 |
| | | | | Average | 6.09 | 15.03 | 14.50 | 3.57 | 2339 |
| | | | | | Total | 105.19 | 101.51 | | |

Tab. 6 – Caggiano energy production – Vestas V162-6.2

It should be noted that the energy production presented above accounts only for the losses due to wake effects and air density and no other losses are included.

Overall the wake losses are deemed as acceptable with a maximum wake loss of 6.5% with the SG 6.6-170 and of 6.0% with 162-6.2 found at turbine T3.

The next step in the analysis is to assess the energy losses to determine the energy that will be available for input into the power grid. At this preliminary phase a reasonable assumption of additional loss of the plant for a period of 10 years is equal to **10%**, including losses relating to the availability of the plant (wind turbines, B.O.P. and grid), the performance of wind turbines, electrical and environmental losses and excluding potential limitations. A more detailed assessment can be made at a more advanced design stage and once all supply and O&M contracts for the project have been signed or under discussion.

The following table summarizes the results obtained for the Project:

| Configuration | Wind farm capacity [MW] | Gross production (net of wakes) | | Net production (deliverable to grid) | |
|---|---|---|---|---|---|
| | | [GWh/year] | [h/year] | [GWh/year] | [h/year] |
| SGRE SG 6.6-170 | 46.20 | 108.60 | 2351 | **97.74** | **2116** |
| Vestas V162-6.2MW | 43.40 | 101.51 | 2339 | **91.36** | **2105** |

Tab. 7 – 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.

Without measurements on site, it is not possible to provide an accurate evaluation of the uncertainty of the wind and energy assessment.

In any case, an exercise has been undertaken evaluating the main uncertainty sources according as far as possible to IEC WG15 outcoming standards in order to provide an indicative average uncertainty value for a 10-year period.

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 1.9 has been estimated to convert the uncertainty related to the wind speed into energy uncertainty.

Under these assumptions, and considering such sensitivity factor, the assessment of an indicative uncertainty for the 10-year period provides a value of about **25.5%**.

# 6. CONCLUSIONS

The activity of the current assessment consisted in the preliminary wind resource assessment of the Caggiano wind site. The study was based on the analysis of the long-term wind regime representative of the area at the desired hub height, according to the expected wind statistics at the site extrapolated from a Virtual Met Mast downscaled to a location deemed as representative of the wind farm. The following conclusions are made concerning the preliminary wind regime and energy production assessment:

1. It is necessary to emphasize that the Virtual Met Mast does not replace a traditional on-site measurement mast and therefore any assessment of the wind resource will have a high uncertainty. Therefore, the results shall be intended as a **preliminary estimation only.**
2. **In order to reduce the uncertainties and to achieve a bankable project, at least one met mast shall be installed onsite and update the analysis accordingly.** The location of the mast should be selected to be well exposed with respect to the prevailing wind direction and well representative of the turbine locations. The structure of such mast should be sufficiently high to reduce uncertainty related to the vertical extrapolation: a height of at least 2/3 of the proposed hub height is recommended. After the measurement period, a detailed wind and energy assessment, comprehensive of a site suitability analysis of the planned wind turbine model and layout, should be undertaken.
3. No site visit has been undertaken at this stage to verify information regarding the territory (orography, roughness, obstacles etc.) assumed in the assessment or other issues.
4. At this preliminary stage, a reasonable assumption of the additional losses related to turbine, B.O.P. and grid availability, electrical plant, environment, turbine performance and excluding any potential curtailment consists of about **10%**. A more detailed evaluation could be performed when supply or O&M agreement are in place or even at a discussion phase.
5. 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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