CESEPIANO WIND FARM

Indicative Energy Production Assessment Report

RWE Renewables Italia S.r.l.

Report No.: 01, Rev. A
Document No.: 10452667-ITBO-R-01-A
Date: 04 August 2023

Project name:	Cesepiano Wind Farm	DNV - Energy Systems
Report title:	Indicative Energy Production Assessment Report	DNV Italy S.r.l.
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Date of issue:	2023-08-04	
Project No.:	10452667	
Organisation unit:	Energy Systems	
Report No.:	01, Rev. A	
Document No.:	10452667-ITBO-R-01-A	

Applicable contract(s) governing the provision of this Report: Call Off 37 Global FA - iEPA Cesepiano, PO n. 4300012280

Objective:

Provide an Indicative Energy Production Assessment Report for the Cesepiano Wind Farm

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Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	2023-08-04	First issue	Arian Hoxha	Jacopo Antonelli	Alice Vergnani

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List of abbreviations

Abbreviation	Meaning
AEP	Annual Energy Production
ASL	Above Sea Level
BOP	Balance of plant
DNV	DNV Italy S.r.l.
NASA	National Aeronautics and Space Administration
P50	Exceedance probability: The probability of reaching a higher or lower annual energy production is 50:50
P90	Exceedance probability: The probability of reaching a higher or lower annual energy production is 90%
PC	Power curve
PLF	Plant Load Factor (equivalent to Capacity Factor)
RD	Rotor Diameter
SPV	Special Purpose Vehicle
SRTM	Shuttle Radar Topography Mission
TI	Turbulence intensity
WTG	Wind turbine Generator

1 INTRODUCTION

RWE Renewables Italia S.r.l. (the "Customer") retained DNV Italy S.r.l. (DNV), part of the DNV Group, to complete an independent indicative analysis of the wind regime and energy production of the proposed Cesepiano Wind Farm project. This report is issued to RWE Renewables Italia S.r.l. pursuant to a written agreement arising from the Proposal Call Off 37 Global FA - iEPA Cesepiano, dated 24 July 2023.

The Project is located approximately 22 km southeast of the city of Campobasso, in Molise, and comprises of one wind farm, totalling 08 turbines with associated infrastructure.

As no on-site wind speed measurements were available, the results presented in this report are indicative in nature and subject to relatively high levels of uncertainty. It is recommended that the results of this assessment are considered with caution due to the level of uncertainty.

It is recommended that on-site measurements are undertaken at the project site using an IEC-compliant mast with at least three quarters of the proposed hub height, and that a full energy assessment is undertaken after at least 1 year of on-site data are available.

2 PROJECT DESCRIPTION

2.1 General

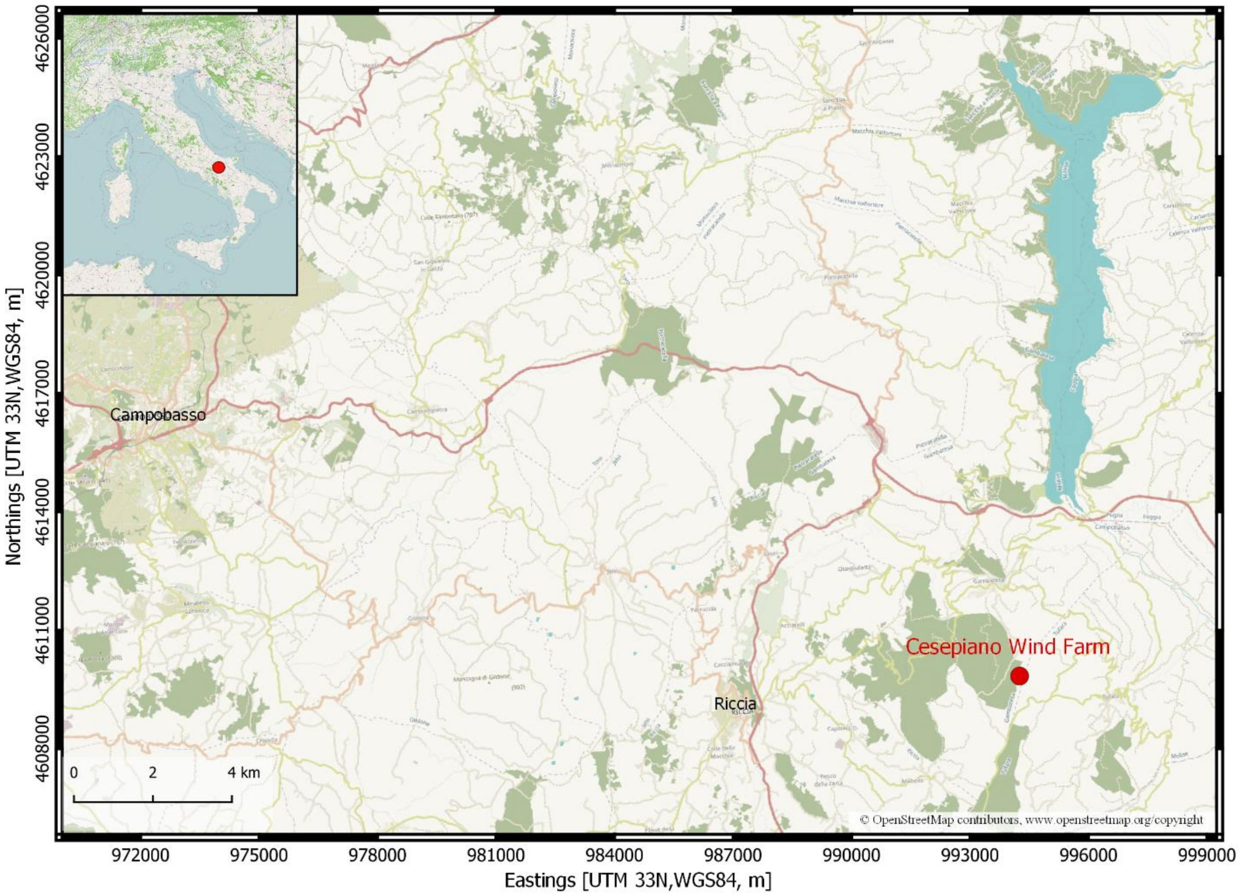
As shown in Figure 2-1 the Project is located in Molise. The Cesepiano Wind Farm is approximately 22 km southeast of Campobasso.

DNV has analysed one layout and one turbine configuration for the wind farm, as provided by the Customer /1/. The proposed configurations are summarised in the table below.

Table 2-1 Proposed configurations

Configuration	Number of turbines	Wind farm rated power [MW]	Turbine manufacturer	Turbine model	Turbine hub height [m]
A	08	52.8	Siemens Gamesa	SG 6.6-170	115

Figure 2-1 Location of the proposed Cesepiano Wind Farm



2.2 Site description

Figure 2-2 is a map of the site, showing the turbine locations and elevation contours.

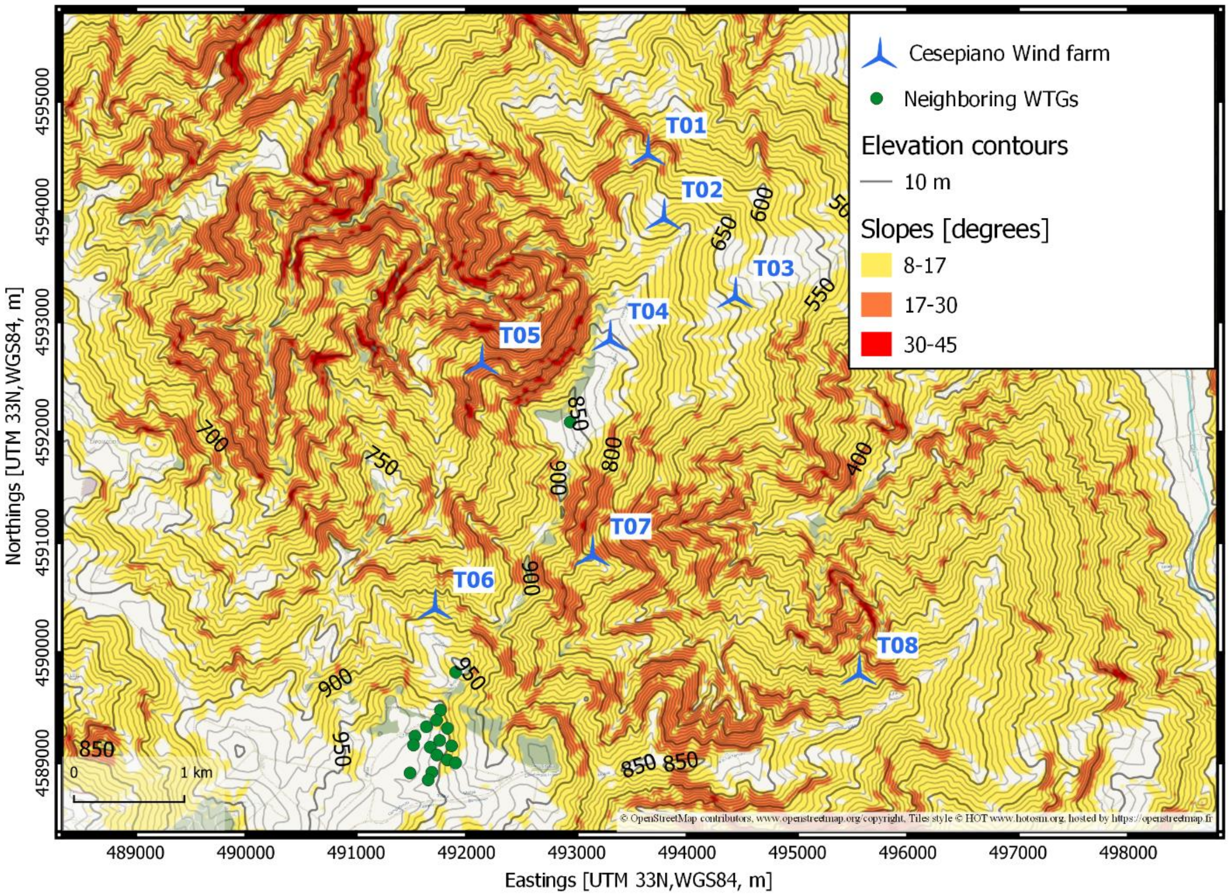
DNV has not visited the site. Publicly available aerial images have been used to assess the ground cover. The Project is located in a hilly area. The terrain at the site is considered to be significantly complex, since there are many areas of steep slopes within the Project area. The elevation of the proposed turbine locations ranges between approximately 611 m and 874 m above sea level.

The ground cover at the site consists predominantly of agricultural land and forestry, with patches of vegetation and a number of small settlements across the site area. 3.5 km from the site area there is the a lake.

Measurements of the wind regime have not been made at the site.

Turbine coordinates are shown in Appendix A.

Figure 2-2 Map of the Cesepiano Wind Farm



2.3 Turbine models

Table 2-2 summarises the turbine model under consideration for the Cesepiano Wind Farm project.

Table 2-2 - Proposed turbine model parameters

Turbine	Rated power [MW]	Hub height [m]	Peak power coefficient [Cp]	PC air density [kg/m3]	PC turbulence intensity range [%]	Operational Temperature
SG 6.6-170	6.6	115	0.48	1.2	$5\% < TI_i < 12\%$	-20°C to +45°C

Using historical pressure and temperature records from nearby meteorological stations and standard lapse rate assumptions, the long-term mean air density at the site is estimated to be 1.119 kg/m^3 at hub elevation of 834 m above sea level.

The power curve used in this analysis, has been retrieved from DNV database. The power curve is based on the manufacturer's calculations and has been adjusted to the site density.

2.4 Turbine layout

Turbine layouts have been supplied by the Customer /1/. The following comments are made:

- A minimum inter-turbine separation of 7.1 rotor diameters is proposed in the prevailing southwest wind direction sector. Turbine spacings generally appear adequate.
- Some turbines are proposed near slopes. The slopes may increase the ambient turbulence and cause significant flow inclination at these turbines.

It is recommended that this is investigated further through a site meteorological conditions analysis, and that the turbine supplier be approached at an early stage to gain approval for the proposed layout and to ensure that sufficient warranty provisions are in place to cover these issues.

It is noted that dwellings were observed within the proposed wind farm area based on satellite imagery. DNV is not aware whether these are used for permanent living or they have cadastral records. The Customer should investigate the state of these buildings with the cadastral local office and in the light of this information update the constraints to the layout design where needed.

2.5 Neighbouring wind farms

The Cesepiano Wind Farm is located in an area of high wind farm development activity. Based on the review of publicly available data sources /2/ and information provided by the Customer /1/, DNV has identified several operational wind turbines near the project.

In the absence of a site visit, DNV estimated the external wake losses based on generic assumptions for these turbines. The operation of these wind farms and the resulting wake effect was included in the analysis.

It is possible that additional wind energy projects will be built in the vicinity of the Project. However, there is insufficient information available to reasonably estimate the impact of future developments on the Project within the scope of work, and these have not been considered here. It is recommended that information regarding the neighbouring wind farms and future developments is collected and wake analysis reviewed accordingly.

3 INDICATIVE WIND ANALYSIS

3.1 Methodology

The indicative analysis of the site wind regime involved several steps, which are summarised below:

- The long-term frequency distribution at the site was derived based on Vortex FARM© data /3/. A tabular distribution (.tab file) based on a 100 meters horizontal resolution wind resource grid at 115 m height was extracted at the position of T04.
- In parallel, the long-term wind speed has been predicted for the site at the proposed hub height at the position of T04, using the DNV Windicative platform, which is based on aggregated anonymised data from DNV experience. The search radius considered for the Windicative estimate is 30 km.
- The Windicative tool is intended to be used in those areas with significant wind farm development where DNV experience is sufficiently high. In that case, DNV considers that the uncertainty associated to Windicative predicted wind speeds is lower than corresponding Vortex data, as the platform is based on measured data. Therefore, the Vortex frequency distribution for the site was scaled to the predicted Windicative long-term wind speed to derive the hub height wind speed and direction frequency distribution at each turbine location.

Vortex FARM© data and DNV Windicative platform are described in more details in Sections 3.1.1 and 3.1.2 below.

Despite the use of Vortex and Windicative platform based on measured data, it must be acknowledged that, due to the absence of on-site measurements, the prediction of the long-term wind speed presented here is subject to a relative high level of uncertainty.

3.1.1 Vortex virtual data

In the absence of suitable on-site wind data, the wind frequency distribution at the site has been estimated via the use of Vortex FARM© data /3/.

Vortex FARM© data is developed from a mesoscale-model-based dynamical downscaling system that provides high-resolution modelled wind data for any location in the world, both on and offshore. At the heart of Vortex data is the Weather Research and Forecasting (WRF) Model, a mesoscale model developed and maintained by a consortium of more than 150 international agencies, laboratories, and universities, which employs a sophisticated land surface model, and high-resolution land- and sea-surface state data. Vortex data is driven by a number of high-resolution inputs, such as Modern Era Retrospective-analysis for Research and Applications (MERRA 2) data or European Centre for Medium-Range Weather Forecasts data (ERA 5) and downscaled to account for the effects of the local terrain and vegetation in and around the potential wind farm site.

A virtual tabular distribution (.tab file), centred at the site and based on a 100 meters horizontal resolution grid, was obtained for the analysis. The .tab file was obtained at 115 m height, and then scaled to the long-term wind speed predicted by Windicative.

3.1.2 DNV Windicative

DNV has used outputs from its Windicative service to assist with calibration of wind speeds and reduce uncertainty.

By leveraging the industry’s largest commercial database of wind energy assessment experience, Windicative is able to provide data-driven estimates of hub height wind resource at locations without measurements. The distributions of wind speed at both the site and within the region provide a more informed view when compared to virtual series on their own.

The Windicative process begins by radially querying DNV's energy assessment database for previous observations of the wind regime around the Customer’s site. The search radius has been defined to include a minimum number of observations around each site in order to anonymise data from the DNV database and include a sufficient number of points in the analysis. The regional wind speed data, representative of the long-term, are adjusted to hub height, using a localised shear exponent and the Power Law, and then transformed, using a windiness ratio calculated from a mesoscale model, into a series of predictions of mean wind speed at the Customer's location of interest. A cross prediction analysis is conducted to quantify confidence in the model and filter for outliers. The final predictions are then aggregated into a distribution to inform the mean wind speed and standard deviation.

Both the use of the Global Wind Atlas 3.0 /4/ and European Wind Atlas /5/ have been considered and tested. Based on this analysis, DNV has selected the Global Wind Atlas to be used as mesoscale model within the Windicative tool.

Global Wind Atlas 3.0 /4/ is a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info.

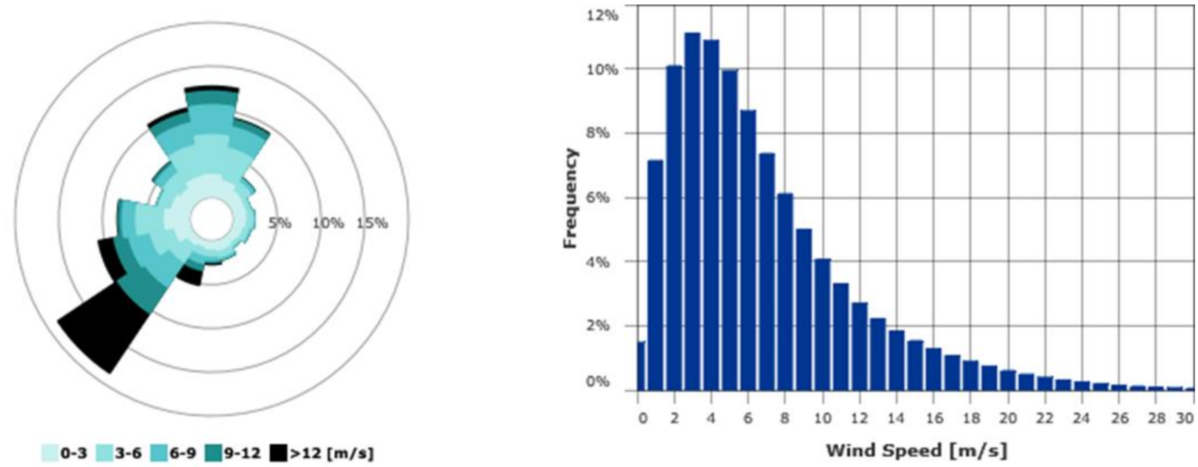
3.2 Results

The resulting estimated wind speed at the proposed hub height is presented in Table 3-1. The corresponding hub height wind rose and wind speed distribution are shown in Figure 3-1.

Table 3-1 Estimated site wind speeds

Configuration	Hub height [m]	Indicative mean wind speed at the position of T04 [m/s]	Average Wind Farm wind speed [m/s]
A	115	6.7	6.1

Figure 3-1 Wind Farm site long-term hub-height wind rose and frequency distribution at 115 m



4 INDICATIVE ENERGY ESTIMATE

4.1 Methodology

The gross energy production at the individual turbine locations has been calculated using the WindFarmer:Analyst software /6/ using the association method and the results of the wind analysis, together with the turbine power curve.

The projected net energy production of the wind farm has been calculated by applying a number of energy loss factors to the calculated gross energy production. The predictions represent the estimate of the annual production expected over the first 10 years of operation although wind farms typically experience some time dependency in availability and other loss factors before mature operation is reached.

It is stressed that the estimate of energy production is subject to several assumptions and is therefore subject to substantial uncertainty.

4.2 Results

The resulting energy production estimate is presented in Table 4-1, including calculation of the array and air density effects as well as assumptions or estimates due to the electrical transmission losses, availability, power curve adjustments, substation maintenance and environmental effects.

The net energy prediction presented below represents the long-term mean, 50% exceedance level, for the annual energy production of the wind turbine. This value is the best estimate of the long-term mean value to be expected from the project. There is therefore a 50% chance that, even when taken over very long periods, the mean energy production will be less than the value given. A more detailed description of potential sources of energy loss that have been estimated, assumed or not considered is given in Table 4-2 below.

Table 4-1 Indicative Energy production summary of the Cesepiano Wind Farm

Layout	A	
Turbine	**SG 6.6-170**	
Wind Farm Rated Power	**52.8**	**MW**
Gross Energy Output	**133.1**	**GWh/annum**
Wake effect	97.0	% Project Specific
Availability	96.3	% DNV Standard
Electrical efficiency	97.0	% DNV Standard
Turbine performance	98.1	% Project Specific
Environmental	100.0	% Not considered
Curtailment	100.0	% Not considered
Net Energy Output	**118.4**	**GWh/annum**
Net Capacity Factor	**25.6**	**%**

Table 4-2 Energy loss parameters

Loss	Assumption for this analysis and rationale
	Wake effect
Internal wake and blockage effects	*The wake effects have been calculated using the DNV WindFarmer: Analyst Eddy Viscosity large wind farm wake model. The turbine interaction blockage effect has been estimated using an empirical model based on more than 50 CFD simulations /7/.*
External wake	*Wake effects of surrounding operational wind farms have been calculated using the WindFarmer wake model. It is noted that any turbine interaction blockage effects caused by neighboring turbines are included in Internal wake and blockage effects.*
Future wake	*It has been assumed that no future wind farms will be built in the vicinity of the wind farm.*
	Availability The availability loss factors presented here include turbine, balance of plant (BoP) and grid losses, and they have been applied on a project specific basis, taking into account the track record of the turbines under consideration. The details of the track record of the local grid system, and Operation and Maintenance arrangements have not been assessed. No detailed project specific engineering review has been undertaken, and these assumptions may change as part of such a review. This work is normally undertaken as part of a full due diligence exercise, although DNV can complete these reviews at an earlier stage of the project, if required. Project specifics for the availability values are detailed below. Terms are defined in the DNV *white paper /8/.*
Turbine availability	*A turbine availability of* 97.0 *% has been assumed for the first 10 years of operation.*
BOP availability	*A BOP availability of 99.5 % has been assumed.*
Grid availability	*A grid availability of 99.8 % has been assumed.*
	Electrical efficiency The details of the specific balance of plant infrastructure and grid connection point have not been considered. The assumptions below would be subject to change, were a detailed assessment of the electrical infrastructure to be undertaken.
Electrical efficiency	*An electrical efficiency of* 97.0 *% has been assumed.*
Wind farm consumption	*It is assumed that non-operational plant electrical consumption is an operational cost and not a loss factor.*
	Turbine performance The power curve assumptions made here would be subject to change, where a thorough review of the Turbine Supply Agreement and supporting contract documentation is undertaken.
Generic power curve adjustment	*No generic adjustment to the power curve has been made.*
High wind speed hysteresis	*It has been assumed that the High Wind Speed Hysteresis effectively reduces the cut-out wind speed for the turbines:* *SG 6.6-170 from 25 m/s to 23.5 m/s* *between the actual turbine cut-out and re cut-in wind speed for the purpose of the energy calculation.*
Site-specific power curve adjustment	*Site-specific wind flow issues (atmospheric stability, turbulence, wind shear, and upflow angle) will adversely affect the performance of the turbines /9/. In the absence of on-site measurements, DNV has assumed an average value of 99.8% based on typical losses applicable in Italy. This loss factor also accounts for the average blockage effect inherent on power performance test measurements.*
Sub-optimal performance	*A factor of 99.5 % has been assumed to account for sub-optimal performance.*
Performance degradation	*The performance of wind turbines can be affected by degradation of blades and other components. This includes the accretion of dirt, which may be washed off by rain from time to time, as well as physical degradation of the blade surface, such as leading edge erosion, and other components, over prolonged operation. This is a time dependent phenomenon which DNV models as increasing linearly at a rate of 0.1% per year for 20 years, resulting in an average of 1% loss over 20 years. In harsh climates these values are increased by 0.3%.*
	Environmental
Performance degradation – icing	*The effect of performance degradation due to ice accretion on the blades when the turbine is operational has not been considered.*
Icing shutdown	*The energy effect of downtime due to ice accretion on the turbine causing the turbine to shut down or not to start has not been considered.*
Temperature shutdown	*This factor accounts for loss from high temperature or low temperature shutdown of the turbine.* *It is recommended to approach the manufacturer to confirm if no de-rating strategy is to be considered for the turbine under analysis. DNV may need to review this loss if additional information is made available.*
Site access	*Adverse impacts on site access due to extreme remoteness or weather conditions have not been considered.*
Tree growth	*The influence of tree growth in the vicinity of the wind farm has not been considered.*
	Curtailments
Wind sector management	*The possibility of wind sector management has not been considered.*
Grid curtailment	*The possibility of grid curtailment has not been considered.*
Noise, visual and environmental curtailment	*The possibility of noise, visual or environmental curtailment has not been considered.*
	Asymmetric production effect The effect of changes in wind speed has an asymmetric impact on project production, considering the non-linear relationship of wind speed to energy. Therefore, when wind speed variability risk is converted into production risk the resulting distribution is asymmetric, with a P50 (median) value that is less than the average.

5 UNCERTAINTIES

The results presented in this report are indicative in nature and subject to relatively high levels of uncertainty, due to the inherent uncertainties related to the prediction of the wind regime in the absence of on-site measurements, the assumptions used in the estimation of losses, and the characteristics of the site terrain and surrounding area.

Indicative probability of exceedance values for the 10-year production estimates are shown in Table 5-1 below for the layout scenarios considered.

Table 5-1 Summary of project indicative net average energy production

Layout	10-year [GWh/annum] Probability of exceedance		
	90 %	**75 %**	**50 %**
A	88.8	102.8	118.4

6 OBSERVATIONS AND RECOMMENDATIONS

No on-site wind data has been recorded at the project site. The wind regime at the site has been estimated via the use of Vortex data and DNV Windicative platform. The following observations and recommendations are made regarding this analysis:

1. The results presented in this report are indicative in nature due to the lack of on-site measurements and subject to relatively high levels of uncertainty. It is recommended that the results of this assessment are considered with caution due to the level of uncertainty.

2. It is recommended that on-site measurements are undertaken at the project site using an IEC-compliant mast with at least three quarters of the proposed hub height, and that a full energy assessment is undertaken after at least 1 year of on-site data are available.

3. The site is proposed within a region of high wind farm development activity. It is likely that additional wind energy projects exist or will be built in the vicinity of the Project. However, there is insufficient information available to reasonably estimate the impact of future developments on the Project within the scope of work, and it is recommended that the Customer procures this information and supplies it in future updates of this work.

4. It is noted that, based on satellite imagery, dwellings were observed within the proposed wind farm area. DNV is not aware whether these are used for permanent living or they have cadastral records. DNV recommends that the noise levels at these locations are carefully considered and assessed. Shadow flicker may also be an issue. The Customer should investigate the state of these buildings with the cadastral local office and in the light of this information update the constraints to the layout design where needed.

5. Some wind turbines are proposed to be located close to slopes or a short distance downhill from ridge tops. These slopes may cause significant upflow and turbulence at these turbine locations. It is recommended that the levels of up flow and turbulence are measured at these locations. These slopes will also make the construction of the wind farm difficult and may also require costly foundations. It is recommended that the turbine manufacturer be approached at an early stage to gain approval for the location of the turbines in relation to the steep slopes and the turbine manufacturer confirms that all proposed turbine positions are acceptable and that sufficient warranty provisions are in place to cover these issues.

6. There are a number of losses for which DNV’s standard assumptions have been made at this stage. It is recommended that the Customer considers each of these points carefully. They may vary materially from standard assumptions and can often be mitigated to some extent. No detailed project specific engineering review has been undertaken, and these assumptions may change as part of such a review.

7 REFERENCES

/1/ Email from Domenico Alberti, RWE, to Arian Hoxha, DNV, on 2023-07-21

/2/ Google Earth^{TM} mapping service.

/3/ https://vortexfdc.com/

/4/ Global Wind Atlas 3.0, https://globalwindatlas.info

/5/ New European Wind Atlas: https://map.neweuropeanwindatlas.eu/

/6/ Garrad Hassan and Partners Ltd, “WindFarmer Theory Manual”, January 2011.

/7/ Bleeg. J et al, “Wind Farm Blockage and the Consequences of Neglecting Its Impact on Energy Production”, June 2018.

/8/ DNV White Paper, “Definitions of Availability Terms for the Wind Industry”, Document No. EAA-WP-15, issue A, dated 9 August 2017.

/9/ Geer, T. “How well are we predicting turbine performance”, DNV, EWEA, November 2015.

APPENDIX A – MEAN WIND SPEED AT TURBINE LOCATIONS

Table C-1 Mean wind speed at turbine locations – Configuration A

Turbine	Easting [1] [m]	Northing [1] [m]	Hub height [m]	Height of base [m]	Mean wind speed [2] [m/s]
T01	493641	4594563	115	611	5.6
T02	493785	4593982	115	667	6.1
T03	494433	4593269	115	639	6.1
T04	493296	4592879	115	802	6.7
T05	492133	4592662	115	693	5.2
T06	491710	4590443	115	874	6.5
T07	493137	4590927	115	786	6.8
T08	495555	4589849	115	678	6.1

1 – Coordinate system is UTM, Zone 33, WGS84 datum
2 – Wind speed at the location of the turbine, not including wake effects.

About DNV

DNV is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.