INDEPENDENT EXTERNAL WAKE IMPACT ASSESSMENT

GRASSRIDGE AND BAYVIEW WINDFARMS, EASTERN CAPE, SOUTH AFRICA

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GRASSRIDGE AND BAYVIEW WINDFARMS, EASTERN CAPE, SOUTH AFRICA

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Table of contents

DISTRIBUTION LIST 3

TABLE OF CONTENTS 4

DOCUMENT REVIEW HISTORY 7

GLOSSARY 8

EXECUTIVE SUMMARY 12

1. INTRODUCTION 14

2. SITE AND PROJECT DESCRIPTION 15

3. WIND DATA PROCESSING 18

3.1. Short-term wind regime 18

3.2. Long-term extrapolation 22

3.2.1. Reference datasets 22

3.2.2. Best combination of reference data and extrapolation method 26

4. WIND FLOW MODELLING 28

4.1. Terrain model 28

4.1.1. Elevation 28

4.1.2. Roughness length 28

4.2. Wind flow model 29

4.2.1. Vertical extrapolation of the wind regime 29

4.2.2. Horizontal extrapolation of the wind regime 30

5. ENERGY PRODUCTION LOSSES 31

5.1. Gross energy production 31

5.2. Energy production losses 31

5.2.1. Wake losses 31

5.2.2. Remaining losses 32

5.3. Uncertainty analysis 33

5.4. Net energy production 34

6. IMPACT OF THE BAYVIEW PROJECT ON THE GRASSRIDGE WIND FARM 36

7. CONCLUSION AND RECOMMENDATIONS 37

REFERENCES 39

ANNEX A SITE DESCRIPTION ILLUSTRATIONS 41

ANNEX B CONFIGURATION OF MEASUREMENT DEVICE 42

ANNEX C WIND TURBINES COORDINATES 43

ANNEX D MAST EFFECT CORRECTION 46

ANNEX E IN-SITU COMPARISON OF ANEMOMETERS 47

ANNEX F SHORT-TERM WIND REGIME 49

ANNEX G LONG-TERM REFERENCE DATASETS 51

ANNEX H AGREEMENT OF THE SELECTED REFERENCE DATA WITH THE MEASURED DATA 52

ANNEX I LONG-TERM EXTRAPOLATION METHODS 53

ANNEX J LONG-TERM WIND REGIME 54

ANNEX K THE WASP MODEL 55

ANNEX L POWER & THRUST CURVES 56

QUALITY INFORMATION 59

Document Review History

Version n°	Date	Author	Summary of changes
1	12/02/2020	Marie Angot (3E)	Draft version
2	12/03/2020	Marie Angot (3E)	Final version V01
3	05/11/2020	David Schillebeeckx (3E)	Update Bayview wind farm configuration

Glossary

AEP	Annual Energy Production
AGL / ASL	Above Ground Level / Above Sea Level
BOP	BOP (Balance of Plant) corresponds to civil and electrical infrastructures inside the wind farm (inter-array cables, junction boxes, foundations etc.).
CFSR	CFSR (Climate Forecast System Reanalysis) is a reanalysis dataset produced by the National Centers for Environmental Prediction (NCEP). It covers a period from 1979 to the present with a resolution of 0.5°.
Corine Land Cover	The Corine Land Cover database is an inventory of land cover in 44 classes. It was initiated in 1985 by the European Union and has been taken over by the EEA. 3E associates roughness information to each class in order to create roughness maps that are used in the wind flow models.
Displacement height	Large areas of tall obstacles affect the wind shear, lifting the zero velocity theoretical height by a value called the displacement height.
DSM / DEM	As opposed to DTM (Digital Terrain Model), DSM / DEM (Digital Surface Model or Digital Elevation Model) includes objects on the ground surface like forests and buildings.
Era-Interim	ERA-Interim is a reanalysis dataset produced by the European Centre for Medium-Range Weather Forecast (ECMWF). It covers a period from 1979 to the present, with a resolution of 0.75°.
EU-DEM	The Digital Elevation Model over Europe from the GMES RDA project (EU-DEM) is a Digital Surface Model (DSM) representing the first surface as illuminated by the sensors. The EU-DEM dataset is a realisation of the Copernicus programme, managed by the European Commission, DG Enterprise and Industry.
HH	Hub height
Mann-Kendall test	The Mann-Kendall test is a statistical test widely used for the analysis of trends in climatologic time series. The purpose of the test is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time.

MCP	Measure-correlate-predict (MCP) algorithms are used to extrapolate wind measurement time series to the long-term. MCP methods first model the relationship between the site wind measurements (speed and direction) and the long-term reference wind data. It then applies this relationship to the whole reference data in order to construct a long-term time series of wind speed and direction at the site.
MERRA-2	MERRA-2, the Modern Era Retrospective Analysis for Research and Applications is a reanalysis dataset from NASA. It covers the period from 1980 to present with a resolution of 1/2° x 0.625° (latitude x longitude).
MeteoDyn WT	MeteoDyn WT is a CFD (Computed Fluid Dynamics) software package for predicting wind resource and power production from wind farms in complex terrains.
Normal distribution	In probability theory, the normal (or Gaussian) distribution is a bell-shaped continuous probability distribution function with two parameters: the mean and the standard deviation. Normal distributions are extremely important in statistics and are often used in the natural sciences for real-valued random variables whose distributions are not known. One reason for their popularity is the central limit theorem (CLT), which states that, under mild conditions, the mean of a large number of random variables independently drawn from the same distribution is distributed approximately normally, irrespective of the form of the original distribution.
Probability of exceedance	In probability theory and statistics, the probability of exceedance is a number (in the range 0 to 100%) that represents the probability that a random variable falls above (or exceeds) a certain value. It is calculated as one minus the cumulative distribution function (CDF), which describes the probability that a variable will be found at a value less than or equal to X.
RD	Rotor diameter
Reanalysis	Reanalysis data are the results of a meteorological data assimilation process that aims to assimilate historical observational data spanning an extended period, using a single consistent assimilation (or “analysis”) scheme throughout this period.
RIX	The ruggedness index (RIX) at a specific location is the percentage of the ground surface that has a slope above a given threshold (e.g. 40%) within a certain distance.
RP	Rated power

SCADA	SCADA stands for Supervisory Control And Data Acquisition. It refers to the wind turbine monitoring and control systems. It provides the wind turbine operator with data like wind speed and direction measured on the nacelle, power production, rotational speed, pitch and yaw angles (operating point of the wind turbine), etc.
SNHT test	The SNHT test (Standard Normal Homogeneity Test) was initially developed to detect a change in a series of rainfall data. It has been used in a number of studies for climate data homogenization.
SRTM	The Shuttle Radar Topography Mission (SRTM) is an international research effort spearheaded by the U.S. National Geospatial-Intelligence Agency (NGA) and the U.S. National Aeronautics and Space Administration (NASA) that obtained digital surface models on a near-global scale from 56° S to 60° N, to generate the most complete high-resolution digital topographic database of Earth. The resolution of the produced datasets is three arc-second.
Wake losses	The wake losses are production losses due to the mutual interaction of wind turbines, caused by the wind energy deficit downstream of the wind turbine rotors.
WAsP	WAsP (Wind Atlas Analysis and Application Program) is a software package that simulates wind flows for predicting wind climates, wind resources, and power productions from wind turbines and wind farms. WAsP is developed and distributed by DTU Wind Energy, Denmark. It has become the wind power industry-standard PC-software for wind resource assessment.
Weibull distribution	In probability theory and statistics, the Weibull distribution is a continuous probability distribution function with two parameters: k (shape) and A (scale). It is widely used in the wind power community as an approximation of the frequency distribution of wind speeds from a time series.
Wind Index	The wind index of a period quantifies the windiness of this period compared to a long-term reference period. It is usually done in terms of wind turbine power output. The long-term period is given an index of 100. Hence, a period with an index of 105 is 5% windier than the long-term. In this case, the long-term correction factor is 0.95.
Wind regime	In the WAsP methodology, the wind rose is divided into 12 sectors et the wind speed distribution in each sector is approximated by a Weibull distribution defined by 2 parameters A & k. A wind regime is defined by these parameters A & k, as well as the weight of each wind sector.

Wind shear	The wind shear is a measure of how the wind speed decreases in the lower atmosphere close to the ground. This phenomenon is due to the drag forces exerted by the ground and its roughness on the air flow. It shapes the wind speed and turbulence profiles, the former of which is often described with a logarithmic or exponential law.
WindPRO	WindPRO is a software package for designing and planning wind farm projects. It uses WAsP to simulate wind flows. It is developed and distributed by the Danish energy consultant EMD International A/S. It is trusted by many investment banks to create wind energy assessments used to determine financing for proposed wind farms.

Executive Summary

This report, requested by Engie presents the impact of the planned wind farm of Bayview on its direct neighbour, the Grassridge wind farm located about 20km north-west from Colchester, in the Eastern Cape Province of South Africa.

The existing configuration of the Grassridge wind farm comprises 20 Vestas V112 3.075 MW wind turbines with 112 m rotor diameter and 84 m hub height for a total installed capacity of 61.5 MW. Three potential wind farm configurations were considered for the Bayview wind farm, comprising a maximum of 40 wind turbines:

- 40 Vestas V136 3.45 MW wind turbines with 136m rotor diameter and 132 m hub height,
- 40 Vestas V150 4.2 MW wind turbines with 150 m rotor diameter and 123 m hub height,
- 40 Nordex N149 4.5 MW wind turbines with 149 m rotor diameter and 145m hub height.

Short-term measurements of the met mast on Bayview site were correlated to long-term reference data to compensate for seasonal and annual wind variations.

The terrain at site was modelled (elevation, roughness and obstacles to the wind flow) and the wind flow model WAsP was used to extrapolate the wind regime to the location and hub height of each wind turbine.

The wind regime at the location and hub height of each wind turbine was then combined with the air density-adjusted power curves of each considered wind turbine type, in order to assess its gross energy production.

The difference between the production with and without the planned Bayview wind farm has been determined and the impact of the planned Bayview windfarm on Grassridge was assed and its associated uncertainty was calculated. The results are presented in the table below.

Configuration	Bayview as V136 3.45MW @132m	Bayview as V150 4.2MW @123m	Bayview as N149 4.5MW @145m
Impact on the net production [%]	0.34 ± 0.20	0.42 ± 0.26	0.38 ± 0.25

The results show that there is a limited additional wake loss at Grassridge due to the planned Bayview wind farm. This can be explained by the wind rose on site where it can be seen that Bayview is located in the lee of Grassridge.

The wake impact of the Bayview wind farm increases with an increase of rated power of the turbine types due to a higher thrust. 3E is of opinion that this increase can be partially compensated by selecting a higher hub height.

3E would like to remind the reader that the results presented in this report, are only valid if the following aspects considered in the study are consistent with those of the turbine supply agreement:

- Power curves.
- Thrust curves.

1. Introduction

Objectives

Engie has appointed 3E to calculate the wake impact of the planned wind turbines of Bayview wind farm on the existing wind farm of Grassridge.

Methodology

This study is carried out according to the best industry practices [1] [2], and managed according to the ISO 9001:2008 standard, under which 3E has been certified since 2010.

Outline of the report

- Section 2 details the site and project, including the site location and environment, the available wind measurements and the wind farm configurations of both the Grassridge and Bayview wind farms,
- Section 3 details the processing of wind data of Bayview mast into a representative wind regime meant for energy production calculations,
- Section 4 details wind flow modelling,
- Section 5 details energy production calculations,
- Section 6 details the wake impact analysis,
- Section 7 summarizes the findings of the study and provides recommendations.

2. Site and Project Description

Site Description

The site is located about 20km north-west from Colchester, in the Eastern Cape Province of South Africa, as indicated in Figure 1. The region is open with vegetation consisting of grassland thicket as illustrated in ANNEX A. The terrain is rather flat although some elevation features can still be observed, with differences in elevation of about 200 metres between the highest and lowest locations within the project boundaries. The west of the site shows the highest elevations (cf. ANNEX A).

A new wind farm hereunder named as "Bayview wind farm" is planned to be built north-east of the site. Based on information provided by the client, it is expected to comprise 40 wind turbines with a maximum hub height of 150m and a maximum rotor diameter of 150m.

Figure 1: Site location (Source: Google Earth)

Available wind measurements

The client has provided 3E with wind measurements from a 100 m mast (Bayview Mast), located at the site of the planned Bayview wind farm, as indicated in Figure 2.

Wind farm configurations

In this report, a configuration refers to the combination of a wind farm layout and a wind turbine type (turbine model + hub height). The existing configuration of Grassridge wind farm comprises 20 Vestas V112 wind turbines for a total installed capacity of 61.5 MW. Three potential configurations for Bayview wind farm are considered, comprising 40 wind turbines. One of them has been provided by the Client. The other two have been selected by 3E to assess the impact of the Bayview configuration on the wake loss. The Bayview configurations all agree with the following restrictions: a maximum of 40 wind turbines, a maximum hub height of 150 m and a maximum rotor diameter of 150m. The configurations under study are detailed in Table 1. The wind farm layout is illustrated in Figure 2, whereas wind turbines coordinates are listed in ANNEX C.

Table 1: Wind farm configurations

Configuration		Grassridge	Bayview		
		V136 3.075MW @84m	V136 3.45MW @132m	V150 4.2MW @123m	N149 4.2MW @145m
Wind turbine manufacturer	[-]	Vestas	Vestas	Vestas	Nordex
Wind turbine type	[-]	V136	V136	V150	N149
Number of wind turbines	[-]	20	40	40	40
Rated power per turbine	[MW]	3.075	3.45	4.2	4.5
Total rated power	[MW]	61.5	138	168	180
Rotor diameter	[m]	136	136	150	149
Hub height	[m]	84	132	123	145

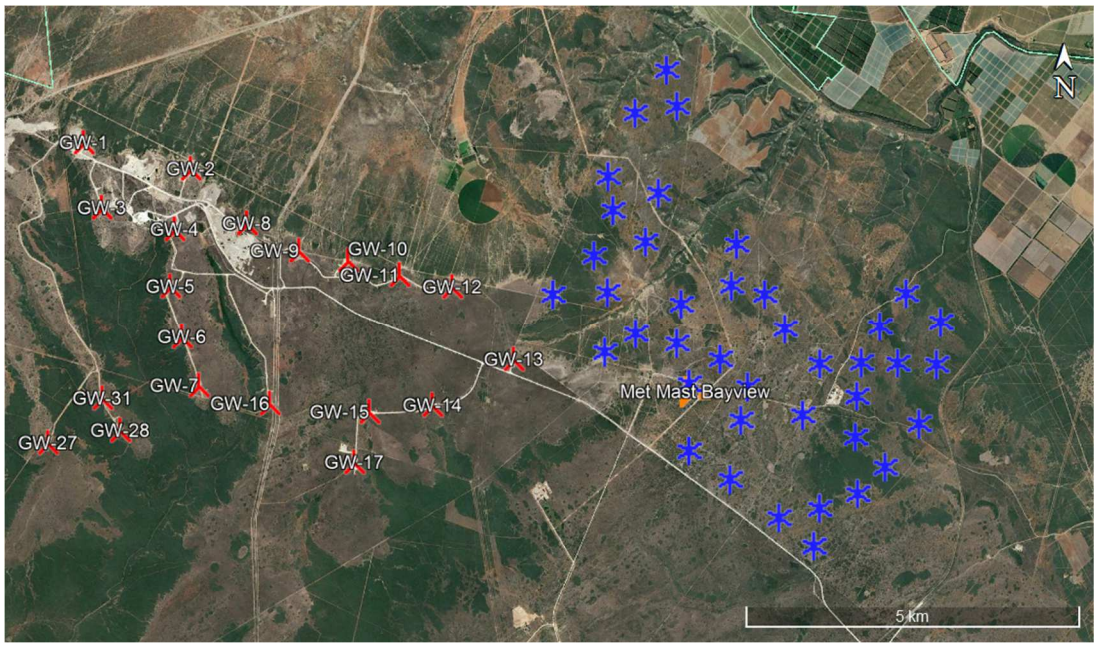

Figure 2: Aerial picture of the site with measurement device, existing wind turbines of Grassridge in red and planned wind turbines of Bayview in blue

3.Wind Data Processing

3.1. Short-term wind regime

The Bayview mast configuration complies with best practices. The period selected for the following steps of the study covers 5 years and 10 months (17/02/2014-11/12/2019). Over this period, the mean wind speed is of 6.91 m/s at 100 m AGL.

Configuration of measurement device

The mast was installed at the Bayview site by the Wind Measurement International on 13/01/2014. It is a lattice mast, equipped with anemometers and wind vanes measuring the wind speed and direction at three levels (from 50 m to 100 m AGL). The client provided 3E with an installation report [4], anemometers calibration certificates, maintenance reports and 10-minutes measurement data covering the period from 17/02/2014 to 11/12/2019 (5 years and 10 months). The mast's coordinates and configuration details are provided in ANNEX B.

It should be noted that 3E assumes that any information provided by Engie is correct. As no site visit is included in the scope of this study, 3E cannot verify this information.

The mast configuration complies with best practices [1] [2].

Issues encountered during the measurement campaign

The following issues were reported to 3E:

- The 68 m wind vane was faulty from 30/05/2014 and has been replaced on 25/06/2017,
- Several issues occurred on the relative humidity and temperature sensors,
- Some communication issues have been reported consequently on 17/04/2014, 12/05/2017 and 29/09/2017.

Data processing

Data are processed according to best practices [1] [2].

Anemometers calibration parameters have already been applied to the data provided to 3E. As a result, 3E assumes, but could not verify, that those parameters have been correctly applied.

The data are then cleaned. Most significant changes applied to the data are the following:

- The mast shading effect is corrected by alternatively using the measurements of both anemometers depending on the wind direction (cf. ANNEX D),

- The wake effect on the measurements due to the existing wind turbines of Grassridge (commissioned in September 2015) comprising 20 Vestas V112 3.075MW with an 84m hub height was corrected. The reduction of mean wind speed per wind sector and wind speed interval at the location of the mast according to NO Jensen wake effect model with a wake decay of 0.056 is added to the measured data. This is accounted for in the uncertainty assessment (cf. section 5.3).

To verify the validity of an anemometer's calibration throughout the measurement period, the IEC 61400-12-1 [3] offers two methods: a post-calibration or an in-situ anemometer comparison. Since no post-calibration has been carried out, the in-situ calibration procedure as described in Annex K of the IEC standard has been carried out to check the anemometer integrity throughout the measurement period. The two anemometers mounted at 100m were considered for the test; the one at 100m and 237° as the primary and the other one at 99.85 and 57° as the control anemometer. The in-situ test identified that side-mounted anemometer at 100 m with a 237° boom direction maintains the validity of its calibration throughout the full measurement period.

More details on the procedure and results of the in-situ test are provided in ANNEX E.

After data processing, a period covering 5 years and 10 months (17/02/2014 to 11/12/2019) is identified as being of sufficient quality for the purpose of this study.

Representativeness of the measurements for the site

The distance between the Bayview mast and the furthest wind turbine of Grassridge is about 10 km. Considering the terrain characteristics, the measurements may not be representative for the full extent of the Grassridge site. This is accounted for in the uncertainty assessment (cf. section 5.3). However, since the mast is located at the Bayview site, the measurements are suitable for the Bayview wake impact analysis, which is the main focus of this study.

Limitation of the short-term period

In order to avoid the introduction of a seasonal bias in the next step of the study, the short-term period is limited to complete years (5 years in this case). For the selection of a single five-year period within the whole short-term period of 5.8 years, the long-term expected production is calculated for each of the 10 rolling 5-year periods (with 1-month shift). As indicated in Table 2, the period between 18/08/2014 and 17/08/2019 is the most representative period for long-term extrapolation and is thus selected for the next steps of the study.

Table 2: Long-term productions vs. mean, depending on the selected rolling period

Period	Difference [%]
18/02/2014-17/02/2019	-0.2 %
18/03/2014-17/03/2019	-0.3 %
18/04/2014-17/04/2019	-0.3 %
18/05/2014-17/05/2019	-0.3 %
18/06/2014-17/06/2019	-0.1 %
18/07/2014-17/07/2019	-0.2 %
18/08/2014-17/08/2019	**0.0 %**
18/09/2014-17/09/2019	0.3 %
18/10/2014-17/10/2019	0.4 %
18/11/2014-17/11/2019	0.7 %

Short-term wind regime

Table 3 presents Weibull parameters of the short-term wind regime over the 5 years from 18/08/2014-17/08/2019. The Weibull mean wind speed at 100 m AGL is 6.92 m/s, and is in agreement with the measured mean wind speed of 6.87 m/s, which validates the approximation of the wind regime by a Weibull distribution. Figure 3 shows the fit between the Weibull curve and the Probability Density Function (PDF) of wind speeds.

ANNEX F presents the Weibull parameters per sector as well as charts of the short-term wind regime at 100 m AGL (wind speed distribution, mean wind speed, frequency and energy roses).

The wind direction measurements could be verified by comparing the mast shading effect with the boom directions. The resulting wind rose is also in line with 3E's experience in the region. Although the wind predominantly blows from west-south-west sector, higher mean wind speeds are measured in sectors west-south-west and west. Consequently, most of the wind energy is available from sectors west-south-west and west.

Table 3: Weibull parameters of the short-term wind regime

Wind measurement device	[-]	Bayview mast
Selected period	[-]	18/08/2014-17/08/2019
Height AGL	[m]	100
Arithmetic mean wind speed	[m/s]	6.87
Weibull mean wind speed	[m/s]	6.92
Weibull A	[m/s]	7.81
Weibull k	[-]	2.020
Prevailing wind directions	[-]	WSW
Wind directions with most energy content	[-]	WSW-W

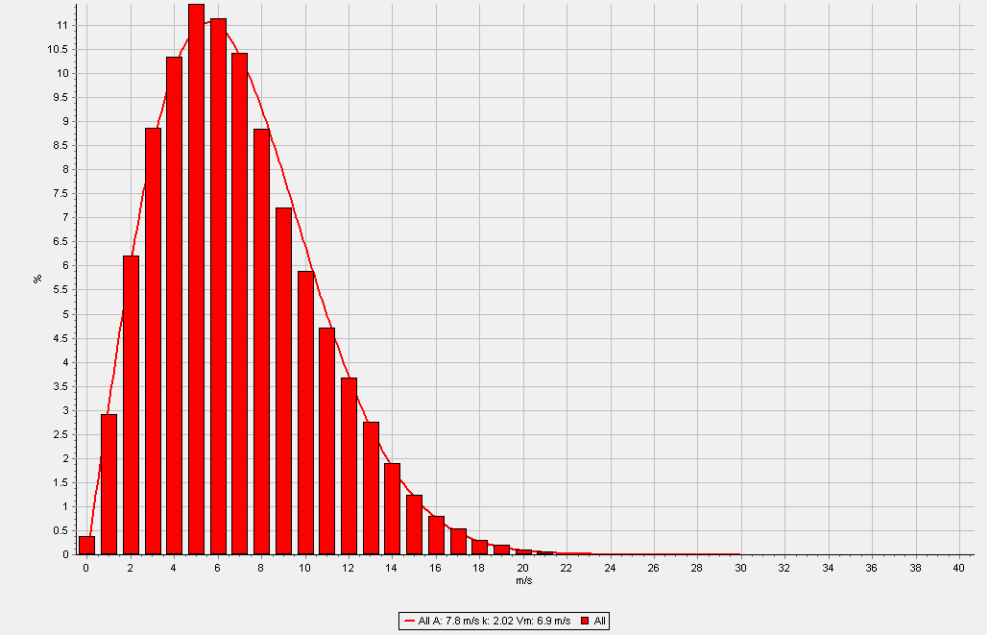

Figure 3: Weibull distribution vs PDF of wind speeds - short-term wind regime (18/08/2014-17/08/2015)

3.2. Long-term extrapolation

The long-term extrapolation is performed in three steps: first, the most reliable reference datasets are identified, then the best combination of reference data and extrapolation method is selected. Eventually, the combination of dataset and method resulting in the lowest uncertainty (cf. section 5.3) is selected.

3.2.1. Reference datasets

3E selects reference dataset from the following sources:

- MERRA-2 reanalysis data from WindPRO (4 closest grid points),
- Post-processed ERA5 reanalysis data from WindPRO (4 closest grid points),
- Any long-term data provided by the client.

In cases these sources are considered insufficient, the following are also considered:

- Post-processed CFSR-E reanalysis data from WindPRO,
- Native ERA-Interim and CFSR data,
- NOAA meteorological station data and publicly available data from meteorological institutes.

The following criteria are used to select reference datasets from these sources:

- **Agreement**: the reference dataset should agree with the measurements in terms of wind speed variations over time. This agreement is quantified by the Pearson correlation coefficient "r". 3E considers a Pearson coefficient of 0.7 (all data or monthly averages) as a minimum prerequisite for a reference dataset to be considered for long-term extrapolation.
- **Time resolution**: the time resolution of the reference dataset should be constant over time. In case time resolution varies, 3E resamples data to a constant time resolution.
- **Data availability**: missing periods should be limited and evenly distributed over time. 3E considers data availability above 80 % as a minimum prerequisite for a reference dataset to be used for long-term extrapolation.
- **Consistency**: the reference dataset should not reveal any abrupt change or unrealistic trend. 3E applies a SNHT test [11] in order to identify discontinuities. If this happens, then the available period is limited to ensure homogeneity. 3E then also applies a Mann-Kendall test [12][13] (90% confidence interval) in order to identify possible trends. Again, the available period is limited to ensure the absence of a trend.

When several reference datasets from the same reanalysis project are considered, 3E only selects the one providing the best r (all data) and the one providing the best r (monthly averages).

The datasets eventually selected as reference are highlighted in bold in Table 4. Their long-term behaviours in terms of windiness are illustrated in Figure 4, whereas their geographical locations are indicated in ANNEX G. Please note that no ground meteorological stations have been considered for the following steps of the process due to their poor correlation with the on-site measurements.

Table 4: Selection of reference datasets

Type	Name	Time shift[1] [h]	r (all data)	r (monthly averages)	Long-term period[2]	Concurrent period [years]	Time resolution [h]	Data availability [%]	Trend test result[3] [%]
MERRA2	**MERRA2 33.5°S 25.0°E**	**+1h**	**0.614**	**0.877**	**01/01/2000-31/12/2019**	**5.82**	**1.00**	**100**	**OK**
MERRA2	MERRA2 33.5°S 25.6°E	+1h	0.623	0.860	01/01/2000-31/12/2019	5.82	1.00	100	OK
MERRA2	MERRA2 33.5°S 26.2°E	+2h	0.619	0.867	01/01/2000-31/12/2019	5.82	1.00	100	OK
MERRA2	MERRA2 34.0°S 25.6°E	+2h	0.586	0.688	01/01/2000-31/12/2019	5.82	1.00	100	OK
ERA5	**ERA5 33.6 °S 25.6°E**	**+2h**	**0.743**	**0.872**	**01/12/1999-30/11/2019**	**5.79**	**1.00**	**100**	**OK**
ERA5	ERA5 33.8°S 25.6°E	+2h	0.685	0.578	01/12/1999-30/11/2019	5.79	1.00	100	OK
ERA5	ERA5 33.8°S 25.9°E	+2h	0.615	0.518	01/12/1999-30/11/2019	5.79	1.00	100	OK

[1] Time shift providing best r (all data). By default, 3E assumes it to be 0h. In cases where there is ambiguity on the time definition of the site wind measurements, or if the agreement of site wind measurements is insufficient, then 3E considers the benefit of applying a time shift comprised between -3 and +3h

[2] After eventual filtering to ensure consistency of time resolution and availability, as well as the absence of any discontinuity (SNHT test)

[3] Result of a Mann-Kendall test

Type	Name	Time shift[1] [h]	r (all data)	r (monthly averages)	Long-term period[2]	Concurrent period [years]	Time resolution [h]	Data availability [%]	Trend test result[3] [%]
ERA5	33.6°S 25.9°E	+2h	0.703	0.861	01/12/1999-30/11/2020	5.79	1	100	OK

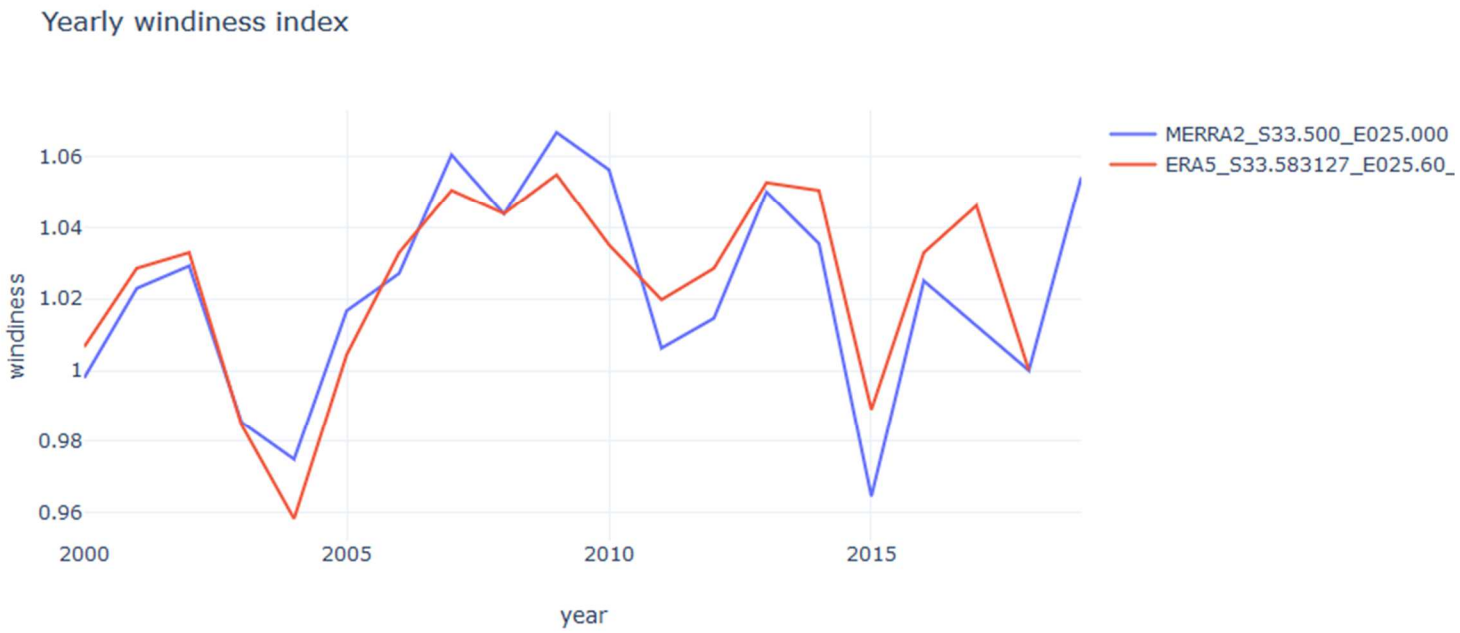

Figure 4: Annual windiness relative to last concurrent year

3.2.2. Best combination of reference data and extrapolation method

3E considers 3 state-of-the-art long-term extrapolation methods: Linear regression MCP, Matrix MCP and Wind Index. A comparative analysis of these methods is provided in ANNEX I.

3E only considers MCP methods if r (all data) exceeds a threshold of 0.7. For the Wind Index method, 3E considers that the same threshold applies, but this time using the monthly averaged r-value.

For each selected reference dataset, 3E applies the applicable extrapolation method(s), depending on r (all data) and r (monthly averages).

The least uncertainty[4] is obtained from ERA5 at grid point 33.6°S 25.6°E using the Matrix MCP method, which is therefore the selected combination of reference data and extrapolation method. ANNEX H illustrates the agreement between the measurements and the reference dataset.

The result of the long-term extrapolation based on the MCP method is a new time series of expected wind speeds and directions, over the 20-year period 01/12/1999-30/11/2019. The Weibull parameters of this new time series are given in Table 5. Weibull parameters per sector at 100 m AGL and charts of the long-term wind regime (wind speed distribution, mean wind speed, frequency and energy roses) are provided in ANNEX J. The mean wind speed expected over the long-term is slightly lower than measured over the short-term (6.85 m/s compared to 6.87 m/s); the prevailing wind direction is west-south-west, west.

Table 5: Long-term extrapolation results

Wind measurement device	[-]	Bayview mast
Long-term period	[-]	01/12/1999-30/11/2019
Height AGL	[m]	100
Arithmetic mean wind speed	[m/s]	6.85
Weibull mean wind speed	[m/s]	6.91
Weibull A	[m/s]	7.79

[4] Uncertainty figure results from a calculation based on many parameters (cf. section 5.3) and is calculated for every potential combination of reliable reference data and long-term extrapolation method.in order to identify the combination with the lowest uncertainty, which should then be used in the study.

Weibull k	[-]	2.01
Prevailing wind directions	[-]	WSW
Wind directions with most energy content	[-]	WSW-W

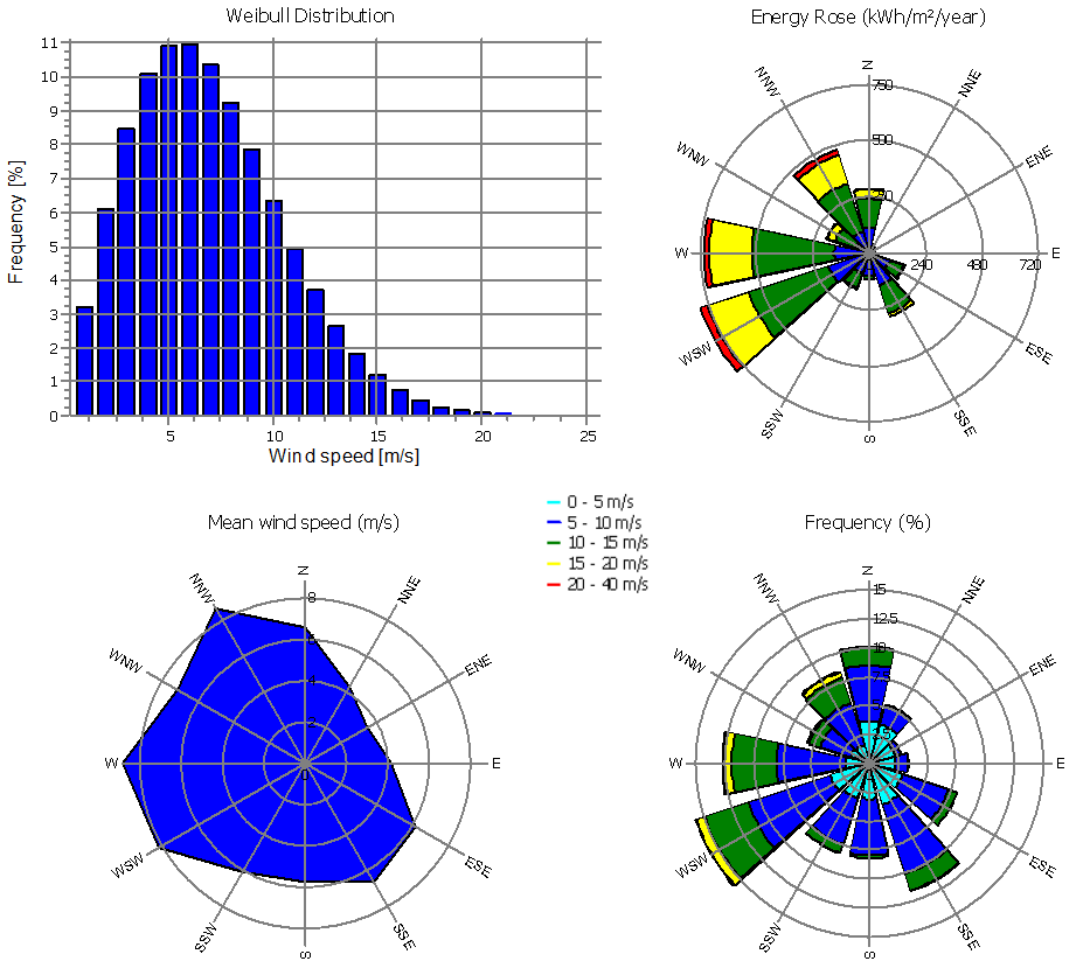

Figure 5: Long-term wind regime at 100m AGL at the Bayview Mast

4.Wind Flow Modelling

4.1. Terrain model

Terrain features influence the wind flow and thus play a significant role in the spatial extrapolation of the wind regime. The software package WindPRO and the WAsP wind flow model are used in the present study. WAsP requires a terrain model describing elevation, roughness and other relevant obstacles to the wind flow that are not modelled as roughness (cf. ANNEX K).

The terrain model used in this study represents the current conditions, which are assumed to remain the same over the wind farm lifetime.

4.1.1. Elevation

The wind regime can be highly influenced by elevation differences across the site. For this study, terrain elevation is modelled within a radius of 15 km (in line with WAsP recommendations [5]) based on SRTM data. Height contour lines are then generated with an elevation difference of 5 m between two successive lines.

It should be noted that SRTM is a digital surface model (DSM), which includes features such as forests and buildings. This is accounted for in the uncertainty assessment (cf. section 5.3).

WAsP is designed for ΔRIX values close to 0, where RIX[5] quantifies the complexity of the elevation model and ΔRIX the difference in complexity between two locations. The validity of the WAsP model is checked according to WAsP recommendations [5], by computing ΔRIX between each wind turbine location and the location of the measurement device used for wind flow simulations.

The ΔRIX value is equal to 0 for this project, which allows WAsP to be used for wind flow simulations.

4.1.2. Roughness length

Roughness length is a key parameter of the equation that governs wind shear. Changes in roughness length cause variations of wind shear, which propagate vertically as the air flows over the site. The impact at measurement or hub height therefore varies with distance to roughness changes but is also related to atmospheric conditions.

Given that roughness length is closely related to land use, terrain roughness is modelled using a land-use database. The Copernicus CGLS-LC100 Africa database is used and roughness length values specific to each land use are applied according to 3E's methodology [6].

[5] Ruggedness index

The validity of the land use areas and of the roughness lengths is checked by comparison to aerial imagery.

The aerial imagery from Google Earth and dated from June 2019 is used for this purpose and is assumed representative of the site conditions at the time of writing this report.

Following WAsP recommendations, the terrain roughness is modelled within a radius of 20 kilometres.

4.2. Wind flow model

WAsP is used to extrapolate the wind regime to the location and hub height of each wind turbine. It involves two steps: a vertical extrapolation of the wind regime to hub height and a horizontal extrapolation of the wind regime to each wind turbine location.

4.2.1. Vertical extrapolation of the wind regime

By default, WAsP is configured for atmospheric conditions typical of North-Western Europe. Therefore, parameters sometimes need to be adapted. In particular, some parameters strongly affect the vertical extrapolation of the wind regime and can be validated and calibrated if necessary, by comparison of the measured and calculated wind shears.

In this study, WAsP parameters are adapted so that the calculated wind shear agrees with the short-term measured wind shear.

Figure 6 presents the mean wind speeds measured at the various heights over the short-term period limited to 4 complete years after Grassridge commissioning (cf. Section 3.1) and the vertical wind speed profile calculated by WAsP from the measurements at 100 m AGL and adapted model parameters.

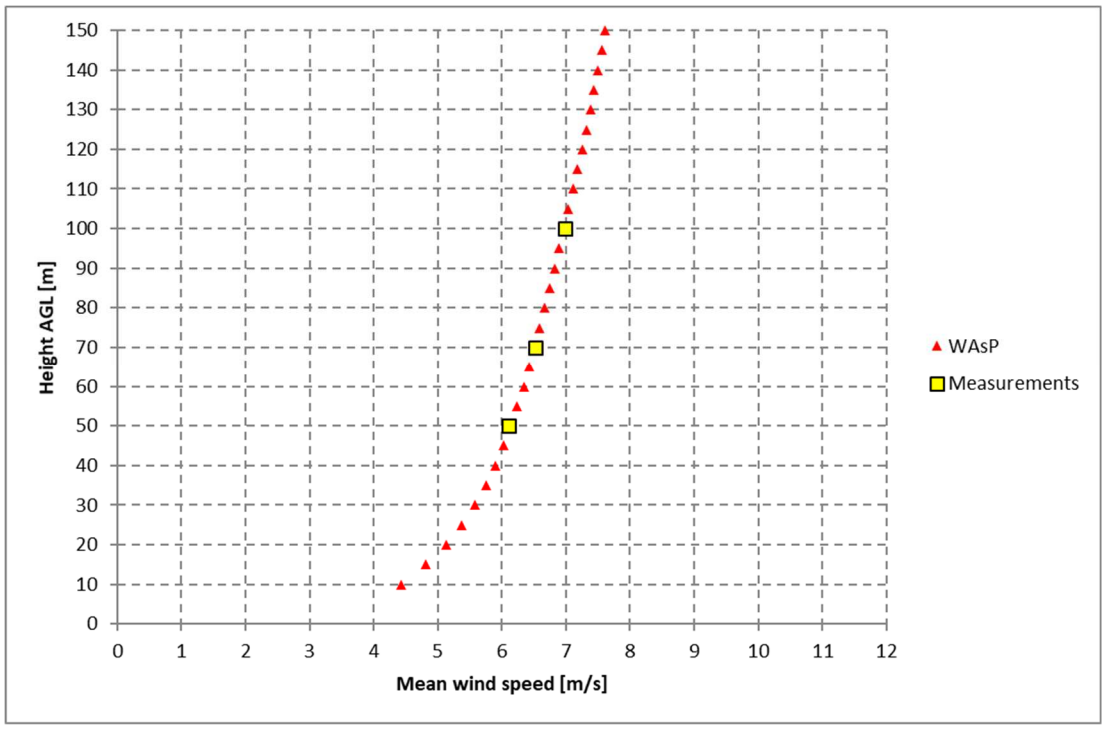

Figure 6: Mean wind speeds measured over the short-term period limited to 4 complete years and vertical wind speed profile calculated by WAsP using measurements at 100m AGL

4.2.2. Horizontal extrapolation of the wind regime

In this study, wind measurements are only made available at a single location which does not allow any validation of the horizontal extrapolation of the wind regime.

5.Energy Production Losses

5.1. Gross energy production

A gross energy production refers to the theoretical energy production that would be achieved if there was no operational loss. It is calculated by combining the wind regime at a wind turbine location and hub height to the power curve specific to the considered wind turbine type and corrected for local hub height air density. This is done using the software WindPRO. For ease of reading, these results are provided in section 5.4. Power curves are provided in ANNEX L.

Since the energy content of the wind varies proportionally to air density, power curves are adapted accordingly before being used in calculations. The adaptation is done using the new recommended WindPRO method (adjusted IEC 61400-12 method, improved to match turbine control) [8].

For this project, air density at hub height ranges between 1.167 and 1.174 kg/m³, depending on the wind turbine location and hub height. Air density is calculated by WindPRO based on the temperature and pressure measurements from the meteorological station of Uitenhage, located 25 km and a relative humidity of 50% according to the recommendations from IEC 61400-12-1. According to 3E's experience, this calculation is accurate enough for the purpose of this study.

Important Note: AEP calculation results are specific to the considered wind turbine power curve. Therefore, when procuring the wind turbines for the project, it should be verified that the power curve guaranteed by the manufacturer in the procurement contract corresponds to the one used in this study. Any change to the power curve may require the recalculation of the AEP.

5.2. Energy production losses

In addition to energy conversion losses taken into account in the power curve, other losses affect the electrical power expected to be delivered to the grid. The following losses are taken into account in this study and are summarised in Table 6 further below. Other losses may apply but are considered negligible in this study.

5.2.1. Wake losses

Wake losses are due to the mutual influence of the wind turbines and are calculated using the N.O. Jensen (EMD) wake model with a wake decay of 0.056 as implemented in WindPRO. The influence of the planned Bayview wind farms is taken into account in the calculations (cf. section 2). This

study provides the energy yield estimates with and without Bayview windfarm. A special attention has been given to the impact of the Bayview wind farm on Grassridge in section 6.

5.2.2. Remaining losses

The following remaining losses taken into account in this study are summarised below:

- **Unavailability losses:** Unavailability losses are due to downtime of the wind turbines or balance of plant (maintenance or technical incidents) as well as downtime of the power grid.
- **Performance losses:** Turbine performance losses are typically due to high wind hysteresis, yaw misalignment, wind flow inclination, turbulence, wind shear and other differences between turbine power curve test conditions.
- **Electrical losses:** Electrical losses occur in cables and transformers ensuring electrical transmission to the wind farm substation.
- **Environmental losses:** Environmental losses account for the performance degradation of the wind turbines due to environmental conditions.

The energy production losses defined in the preceding sections are summarised in Table 6.

Important note: The losses taken into account in this study are industry standard values that 3E estimates relevant for the project. They are not based on contractual documents or specific studies.

Table 6: Expected energy production losses

Configuration		Grassridge			
Scenario		w/o Bayview	Bayview V136	Bayview V150	Bayview N149
Wake losses	[%]	4.2	4.5	4.6	4.5
Unavailability losses	[%]	3.5	3.5	3.5	3.5
Performance losses	[%]	0.3	0.3	0.3	0.3
Electrical losses	[%]	2.5	2.5	2.5	2.5
Environmental losses	[%]	0.5	0.5	0.5	0.5
Total losses	**[%]**	**10.5**	**10.8**	**10.9**	**10.9**

(*) The production losses in % are combined as: $Total = 100 - \frac{\prod_i (100 - Loss_i)}{100^{(N-1)}}$

5.3. Uncertainty analysis

Some uncertainty components are directly quantified in terms of energy production, whereas some other uncertainty components are first quantified in terms of wind speed, then translated into uncertainties in terms of energy production, by applying a sensitivity factor. The sensitivity factor relates energy production change to wind speed change.

The global uncertainty is then calculated from the individual uncertainty components by assuming that they are independent and that the resulting uncertainty follows a normal distribution (central-limit theorem). They can therefore be combined by calculating the square root of the sum of the squares of each uncertainty.

In this study, the following sources of uncertainty are considered.

- Wind measurements (wind speed)
- Long-term extrapolation (wind speed)
- Vertical extrapolation (wind speed)
- Future wind variability (wind speed)
- Spatial variation (wind speed)
- Power curve (production)
- Energy production losses (production)

The table below present the breakdown of uncertainty analysis of annual energy production.

Table 7: Uncertainty associated with AEP results

Configuration		Grassridge			
Scenario		w/o Bayview	Bayview V136	Bayview V150	Bayview N149
Wind measurement	[% AEP]	3.6	3.6	3.6	3.6
Long-term extrapolation	[% AEP]	4.9	4.9	4.9	4.9
Vertical extrapolation	[% AEP]	1.6	1.6	1.6	1.6
Future wind variability	[% AEP]	3.1	3.1	3.1	3.1
Spatial variation	[% AEP]	5.8	5.8	5.8	5.8
Power curve	[%AEP]	5.5	5.5	5.5	5.5

Configuration		Grassridge			
Scenario		w/o Bayview	Bayview V136	Bayview V150	Bayview N149
Energy production losses	[%AEP]	2.0	2.1	2.1	2.1
Total uncertainty	**[% AEP]**	**10.9**	**10.9**	**10.9**	**10.9**

5.4. Net energy production

Energy production losses are applied to the expected annual gross energy production, resulting in the expected net Annual Energy Production (AEP).

The expected AEP and other energy production figures are presented in Table 8. For each configuration, the following results are provided:

- **Mean wind speed**: corresponds to the lowest and highest mean wind speeds expected at the location and hub height of wind turbines.
- **Gross energy production**: corresponds to the theoretically recoverable annual energy production at the outlet side of the generator, without production losses.
- **Energy production losses**: as calculated in Section 5.2.
- **Net energy production (AEP)**: corresponds to the annual energy production expected to be delivered to the grid (taking into account all energy production losses).
- **Net full load equivalent hours**: is the amount of time it would take for the wind farm to yield its annual production if it was able to constantly produce at full load.
- **Net capacity factor**: is the net full load equivalent hours divided by the total number of hours in a year. It represents the usage of the installed capacity.
- **Uncertainty**: is the standard uncertainty percentage of the net energy production.

Table 8: Expected Grassridge wind farm energy production figures

Configuration		Grassridge			
Scenario		w/o Bayview	Bayview V136	Bayview V150	Bayview N149
Mean wind speed	[m/s]	6.4 - 7.3	6.4 - 7.3	6.4 - 7.3	6.4 - 7.3
Gross energy production	[MWh/y]	184,062	184,062	184,062	184,062
Total energy production losses	[%]	10.5	10.8	10.9	10.9
Net energy production (AEP)	**[MWh/y]**	**164,710**	**164,156**	**164,026**	**164,081**
Net full load equivalent hours	[h/y]	2,678	2,669	2,667	2,668
Net capacity factor	[%]	30.6	30.4	30.4	30.4
Uncertainty	[%]	10.9	10.9	10.9	10.9

6. Impact of the Bayview project on the Grassridge wind farm

Using the previous results, 3E could estimate the impact of Bayview on Grassridge existing wind farm. For the wake loss estimation, the difference between the production with and without the planned Bayview wind farm has been determined. To assess the uncertainty of the wake loss, a sensitivity analysis has been carried out by verifying the impact of:

- the wind direction and wind speed (the mean wind speed uncertainty was used to define the range in order to translate the wind speed uncertainty to a wake loss uncertainty),
- the wake model itself (NO Jensen, NO Jensen 2005, NO Jensen 2018, EWTSII),
- the wake decay coefficient (ranging from 0.056 to 0.067).

Furthermore, the uncertainty on the potential blockage effect is accounted for. The results of this analysis are presented in the table below which shows the impact of the Bayview wind farm on the Grassridge wind farm and its associated standard uncertainty. The resulting wake losses are presented both in terms of a loss percentage and as an energetic loss value.

Table 9: Impact of Bayview planned wind farm on Grassridge per Bayview configuration

Configuration	Bayview as V136 3.45MW @132m	Bayview as V150 4.2MW @123m	Bayview as N149 4.5MW @145m
Impact on the net production [%]	0.34 ± 0.20	0.42 ± 0.26	0.38 ± 0.25
Net losses [MWh/y]	554	685	629

The results show that the wake impact of the Bayview wind farm increases with an increase of rated power of the turbine types due to a higher thrust. However, this increase can be partially compensated by selecting a higher hub height, as can be seen from the results of the N149 Bayview configuration.

The wake analysis and the wind rose on site show that the Grassridge wind turbines named GW- 11, GW- 12, GW-13 and GW-14 (cf. Figure 2) are impacted the most by the Bayview planned wind farm. The largest wake contribution is coming from the line of Bayview wind turbines located south-east (125°) of Grassridge.

7.Conclusion and Recommendations

3E has calculated the wake impact of the Bayview project on the Grassridge wind farm. Three potential wind farm configurations (V136, V150, N149) were considered. The results are shown in Table 10.

For the Bayview wind farm, 3E recommends selecting a wind turbine type with a higher rated power coupled with a higher hub height.

Table 10: Expected yield assessments results for Grassridge wind farm

Configuration		Grassridge			
Scenario		w/o Bayview	Bayview V136	Bayview V150	Bayview N149
Mean wind speed	[m/s]	6.4 - 7.3	6.4 - 7.3	6.4 - 7.3	6.4 - 7.3
Gross energy production	[MWh/y]	184,062	184,062	184,062	184,062
Additional wake loss on the net production	[%]	0	0.34 ± 0.20	0.42 ± 0.26	0.38 ± 0.25
Total energy production losses	[%]	10.5	10.8	10.9	10.9
Net energy production (AEP)	**[MWh/y]**	**164,710**	**164,156**	**164,026**	**164,081**
Net full load equivalent hours	[h/y]	2,678	2,669	2,667	2,668
Net capacity factor	[%]	30.6	30.4	30.4	30.4
Uncertainty	[%]	10.9	10.9	10.9	10.9

Important notes:

- It should be noted that 3E assumes that any information communicated by the client is correct.
- Results of AEP calculations are specific to a wind turbine power curve. Therefore, when procuring the wind turbines for the project, it should be verified that the power curve guaranteed by the manufacturer and as provided in the procurement contract corresponds to the one used in this study. Any change to the power curve will require the recalculation of AEP.

- Several energy production losses taken into account in this study are industry standard values that 3E estimates relevant for the project. They are not all based on contractual documents or specific studies and they should be reviewed for the financial closing of the project.

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ANNEX A Site Description Illustrations

Figure 7: Typical site environment (Google Earth – 2019)

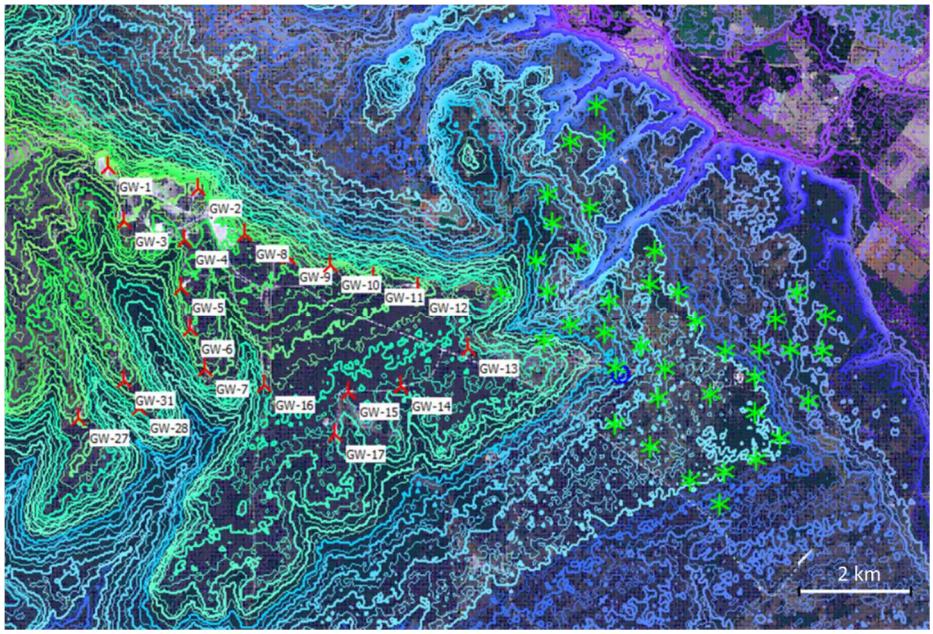

Figure 8: Site elevation (contour lines every 10 metres, and warmer colours denote higher elevations)

ANNEX B Configuration of Measurement Device

Table 11: Characteristics of measurement device(s) (coordinate system: WGS1984 - UTM Zone 35S)

Measurement device	Device name
Longitude (X)	375,723 m
Latitude (Y)	6 273 741 m
Altitude	138 m
Measurement heights AGL	100 m, 70 m, 50 m
Date begin	17/02/2014
Date end	11/12/2019
Period length	69.8 months
Availability	99.5 %

Table 12: Instruments for the Bayview mast and calibration factors

Channel	Sensor	Slope	Offset	Height AGL	Orientation
C1	Vector Anemometer	0.05020	0.1859	100 m	237 °
C2	Vector Anemometer	0.05024	0.1695	99.85 m	57 °
C3	Vector Anemometer	0.05061	0.1510	70 m	237°
C4	Vector Anemometer	0.05058	0.2153	69.85 m	57°
C5	Vector Anemometer	0.05029	0.1762	50 m	237°
C6	Vector Anemometer	0.05057	0.1884	49.85 m	57°
SE1	Wind vane W200p	N/A	N/A	98 m	237°
SE2	Wind vane W200p	N/A	N/A	68 m	237°

ANNEX C Wind Turbines Coordinates

Table 13: Wind turbines coordinates and altitudes of Grassridge wind farm (coordinate system: WGS1984 - UTM Zone 35S)

Turbine	Longitude (X)	Latitude (Y)	Altitude
	[m]	[m]	[m]
GW-1	366,513	6,277,336	250
GW-2	368,122	6,276,967	240
GW-3	366,796	6,276,372	240
GW-4	367,891	6,276,065	230
GW-5	367,839	6,275,216	222
GW-6	368,023	6,274,458	215
GW-7	368,286	6,273,734	200
GW-8	368,972	6,276,169	221
GW-9	369,761	6,275,771	221
GW-10	370,496	6,275,639	205
GW-11	371,269	6,275,429	211
GW-12	372,061	6,275,264	200
GW-13	372,996	6,274,185	186
GW-14	371,788	6,273,487	185
GW-15	370,845	6,273,374	185
GW-16	369,351	6,273,480	190
GW-17	370,628	6,272,623	185
GW-27	366,037	6,272,851	200

GW-28	367,116	6,273,051	195

Table 14: Wind turbines coordinates and altitudes of Bayview wind farm (coordinate system: WGS1984 - UTM Zone 35S)

Turbine	Longitude (X)	Latitude (Y)	Altitude
WTG01	373,573	6,275,189	190
WTG03	374,376	6,276,957	139
WTG05	374,456	6,276,456	139
WTG06	374,361	6,274,338	163
WTG07	374,768	6,277,903	115
WTG08	374,949	6,275,991	139
WTG10	375,133	6,276,719	115
WTG11	375,231	6,278,549	100
WTG12	375,394	6,278,012	103
WTG13	375,437	6,274,482	143
WTG14	375,495	6,275,070	130
WTG15	375,629	6,273,876	148
WTG16	375,641	6,272,879	120
WTG17	376,244	6,275,361	114
WTG18	376,313	6,275,976	112
WTG19	376,261	6,272,463	115
WTG20	376,507	6,273,844	116
WTG21	377,000	6,271,901	113
WTG22	377,054	6,274,721	110

Turbine	Longitude (X)	Latitude (Y)	Altitude
WTG23	377,336	6,273,435	115
WTG24	377,529	6,271,485	99
WTG25	377,607	6,272,048	110
WTG26	378,130	6,273,114	110
WTG27	378,144	6,273,723	110
WTG28	378,174	6,272,273	110
WTG29	378,474	6,274,773	79
WTG30	378,581	6,272,675	110
WTG31	378,862	6,275,272	70
WTG32	379,081	6,273,328	80
WTG33	379,331	6,274,215	70
WTG34	379,386	6,274,851	70
WTG36	374,389	6,275,233	129
WTG37	374,181	6,275,777	143
WTG38	374,820	6,274,619	140
WTG40	376,744	6,275,230	107
WTG41	376,090	6,274,254	130
WTG42	377,584	6,274,202	104
WTG43	376,412	6,273,348	117
WTG44	378,750	6,274,223	77
WTG45	378,204	6,274,228	84

ANNEX D Mast Effect Correction

Table 15: Mast effect correction

Height	Primary anemometer	Secondary anemometer	Wind directions where secondary anemometer is used
100 m	C1 (237°)	C2 (57°)	33 ° - 54 °
70 m	C3 (237°)	C4 (57°)	33 ° - 78 °
50 m	C5 (237°)	C6 (57°)	33 ° - 80 °

ANNEX E In-situ comparison of anemometers

It is mandatory to check and document that the anemometer maintains the validity of its calibration throughout the measurement period. This can be achieved by either comparing the initial calibration results with the outcome of the post-calibration or as an alternative, the in-situ anemometer comparison following Annex K of the IEC 61400-12-1 standard [3] is permissible.

Since no post-calibration has been performed, the in-situ calibration procedure has been used to check the anemometer integrity throughout the measurement period. In this procedure, a control anemometer is selected to monitor the behaviour of the primary anemometer used for the wind regime estimation. The control anemometer should be in close proximity to the primary one. It should be noted that this method does not identify a gradual degradation of the calibration of the anemometer if the control anemometer degrades at a similar rate.

The procedure performs a linear regression between the two anemometers at the beginning of the measurement period (maximum duration of 8 weeks). This regression is then applied to the control anemometer measurements at the end of the measurement period resulting in an estimated primary anemometer wind speed. The difference in the measured and the estimated primary anemometer wind speed is calculated for 1 m/s wide wind speed bins. Finally, the root-sum-square of the systematic (average of differences) and statistical (standard uncertainty of differences) deviation is calculated for each wind speed bin.

If the value root-sum-square

- is ≤ 0.1 m/s for each bin, the in-situ test has passed; or
- is above 0.1 m/s in at least one bin and does not exceed 0.2 m/s in all bins, the uncertainty of the anemometer calibration shall be increased; or
- exceeds 0.2 m/s in any bin, the in-situ test failed and the test period should be shifted to an earlier period.

The properties and results of the in-situ anemometer comparison for the present study are given in Table 16 and Table 17, respectively.

Table 16: Properties of in-situ anemometer comparison

Tested anemometer	100 m at 237°
Control anemometer	99.85 m at 57°
Wind speed range	4 m/s to 12 m/s
Wind direction range (undisturbed)	[132°, 162°]
Test period at the beginning	01/10/2015 - 05/11/2015
Test period at the end	16/10/219 - 11/12/2019

Table 17: Results of in-situ anemometer comparison test

Wind Speed Bin	Bin count	Root Sum Square
[m/s]	[-]	[m/s]
4	98	0.0209
5	106	0.0196
6	132	0.0179
7	163	0.0218
8	196	0.0284
9	175	0.0027
10	153	0.0306
11	122	0.0232
12	106	0.0423

ANNEX F Short-term Wind Regime

Table 18: Short-term wind regime at 100 m AGL at Bayview mast

Sector	A- parameter	k-parameter	Frequency	Wind speed
[-]	[m/s]	[-]	[%]	[m/s]
Global	**7.81**	**2.020**	**100.0**	**6.92**
N	7.55	2.153	10.9	6.69
NNE	4.70	2.263	5.1	4.16
ENE	3.75	1.911	2.7	3.33
E	4.58	1.987	3.1	4.06
ESE	6.53	2.496	7.5	5.79
SSE	7.76	2.357	12.7	6.88
S	6.38	3.163	7.8	5.71
SSW	6.44	2.326	7.3	5.71
WSW	9.27	2.187	17.4	8.21
W	10.26	2.621	13.3	9.11
WNW	7.42	2.115	5.0	6.57
NNW	9.81	2.271	7.2	8.69

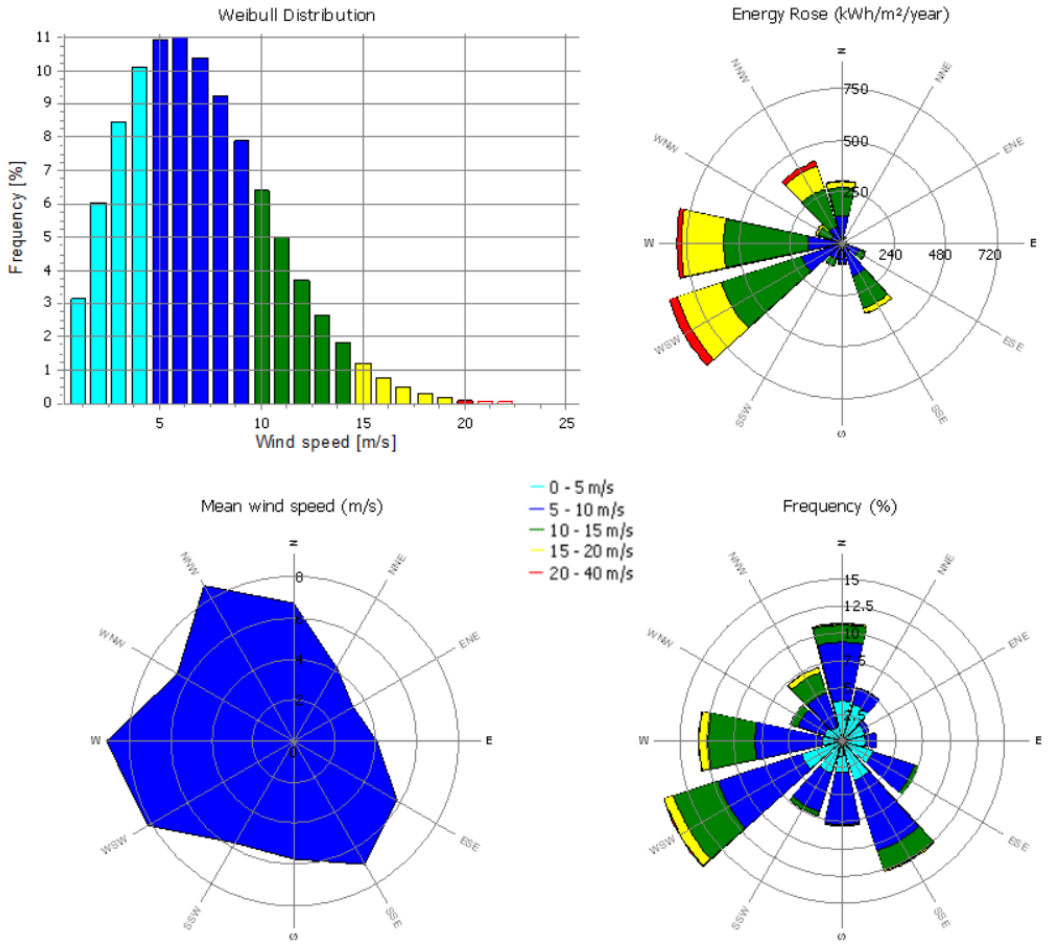

Figure 9 : Short-term wind regime at 100m AGL at Bayview mast

ANNEX G Long-term Reference Datasets

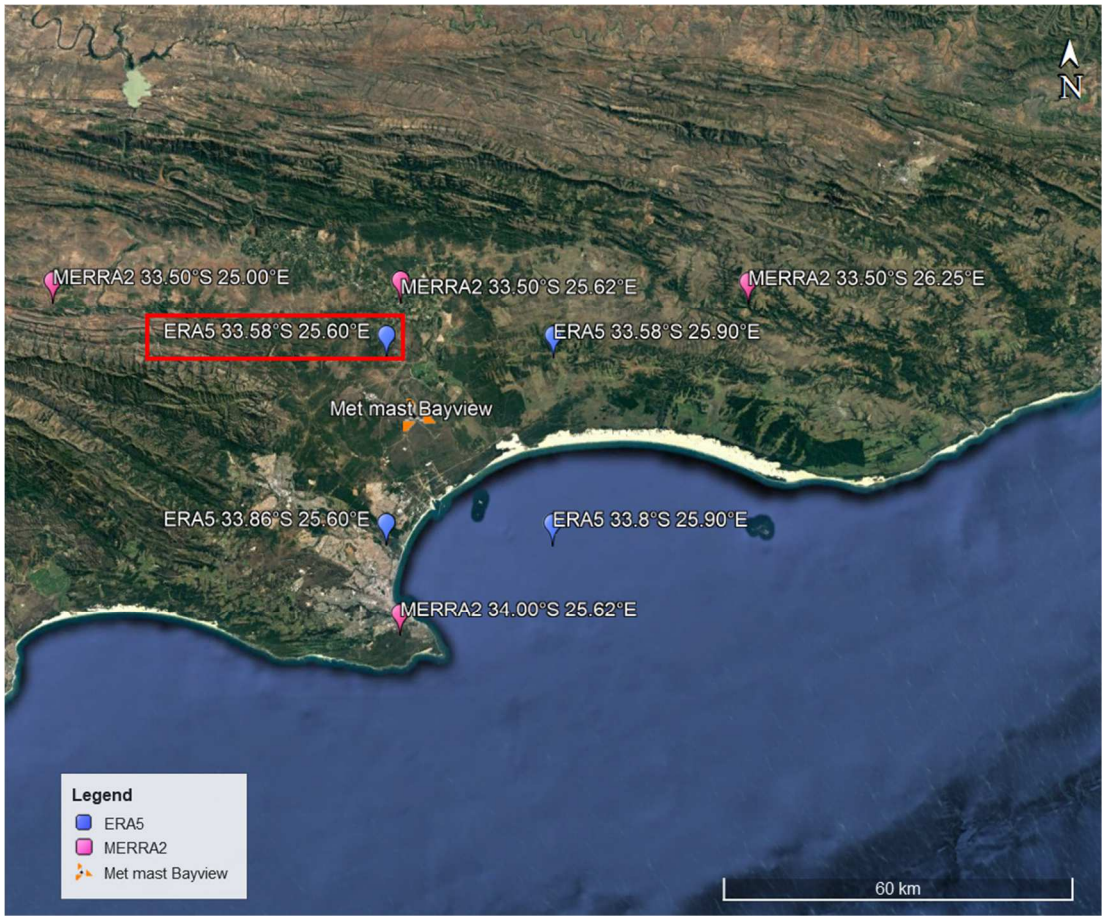

Figure 10: Location of the considered long-term reference datasets with respect to the site

ANNEX H Agreement of the Selected Reference Data with the Measured Data

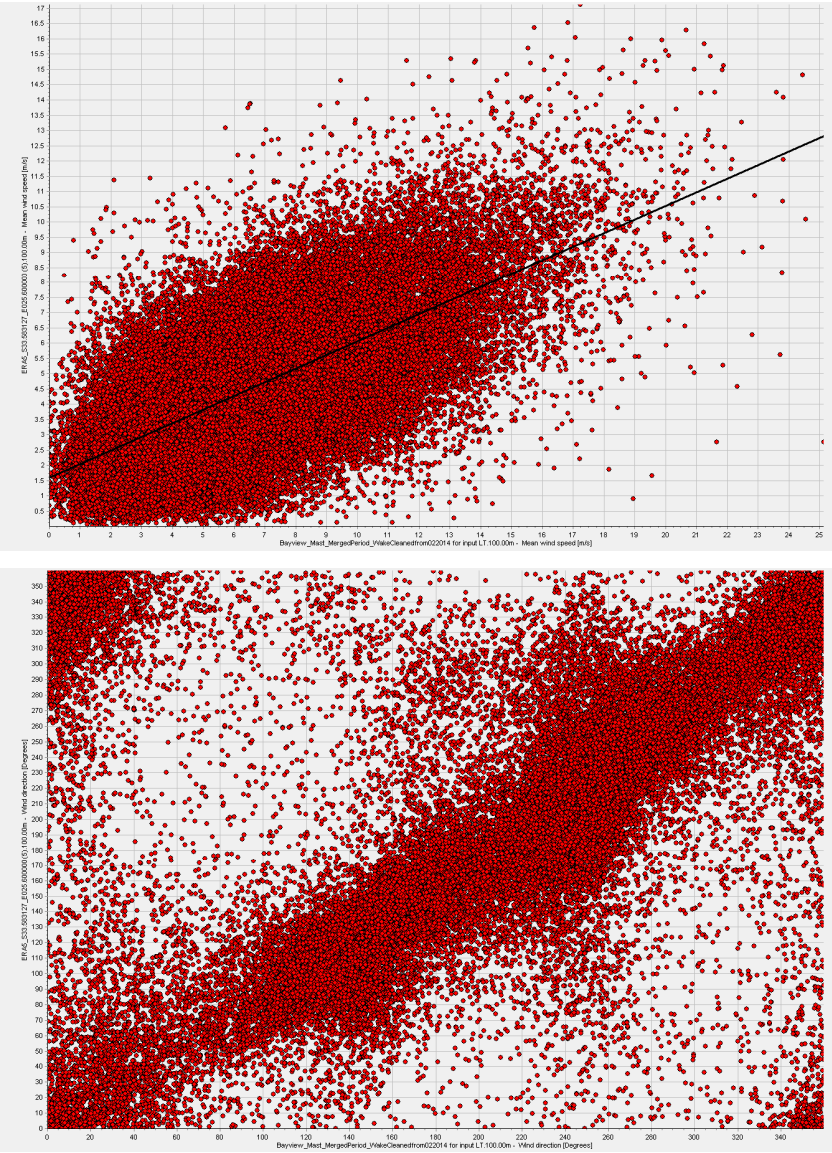

Figure 11: Comparison of the measured (X) and reference (Y) wind directions (top) and speeds (bottom)

ANNEX I Long-term Extrapolation Methods

3E considers three state-of-the-art long-term extrapolation methods: Linear regression MCP, Matrix MCP and Wind Index.

Both MCP methods establish relationships between the wind speeds and directions measured at the site and available in the long-term reference dataset. Then, the long-term reference time series is adjusted accordingly, so as to be representative of the long-term wind regime at the site. The MCP methods are the preferred long-term extrapolation methods because they reconstruct the long-term wind regime, including its wind rose. It is however not necessarily the best suited method to minimise the uncertainty because it is very sensitive to the quality of the agreement between on-site measurements and reference data.

The Wind Index method is more robust but is not meant to estimate the long-term wind regime, and assumes that the wind rose over the short-term is representative of the long-term. It only evaluates the windiness of the short-term period against the long-term in terms of energy production.

ANNEX J Long-term Wind Regime

Table 19: Long-term wind regime at 100m AGL at the Bayview mast

Sector	A- parameter	k-parameter	Frequency	Wind speed
[-]	[m/s]	[-]	[%]	[m/s]
Global	**7.79**	**2.011**	**100.0**	**6.91**
N	7.46	2.046	10.1	6.61
NNE	4.84	2.182	5.3	4.28
ENE	3.86	2.045	2.9	3.42
E	4.71	1.973	3.4	4.17
ESE	6.95	2.265	8.0	6.16
SSE	7.50	2.356	11.6	6.64
S	6.48	2.913	8.2	5.78
SSW	6.88	2.210	8.2	6.09
WSW	9.24	2.223	15.8	8.19
W	9.97	2.469	12.7	8.84
WNW	8.10	2.092	5.6	7.17
NNW	9.78	2.305	8.4	8.67

ANNEX K The WAsP Model

The central point in the wind transformation model of WAsP – the so-called Wind Atlas Methodology – is the concept of a Regional or Generalized Wind Climate, or Wind Atlas. This Generalized Wind Climate is the hypothetical wind climate for an ideal, featureless and completely flat terrain with a uniform surface roughness, assuming the same overall atmospheric conditions as those of the measuring position. The basic "machine" of WAsP is a flow model, representing the effect of different terrain features:

- Terrain height variations,
- Terrain roughness,
- Sheltering obstacles.

To deduce the Generalized Wind Climate from measured wind in actual terrain, the WAsP flow model is used to remove the local terrain effects.

To deduce the wind climate at a location of interest from the Generalized Wind Climate, the WAsP flow model is used to introduce the effect of terrain features.

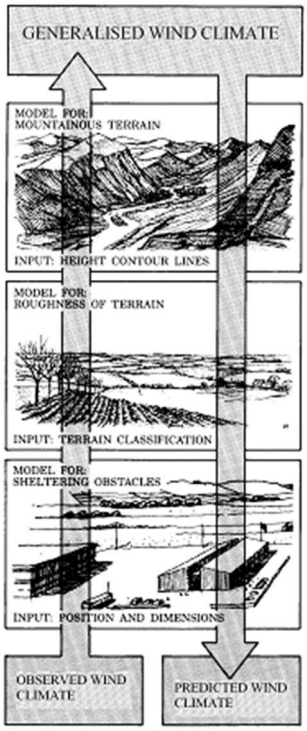

Figure 12: Wind Atlas methodology (Source: wasp.dk)

ANNEX L Power & Thrust Curves

Table 20: Power & thrust curves (PC & TC), air density = 1.225 kg/m³

Wind speed	V136 3.075MW		V136 3.45MW		V150 4.2MW		N149 4.5MW	
	PC	TC	PC	TC	PC	TC	PC	TC
[m/s]	[kW]	[-]	[kW]	[-]	[kW]	[-]	[kW]	[-]
3	26	0.901	49	0.868	78	0.998	31	0.831
3.5	73	0.847	127	0.842	172	0.919	122	0.825
4	133	0.821	224	0.832	287	0.86	247	0.817
4.5	207	0.815	339	0.843	426	0.847	400	0.808
5	302	0.812	480	0.837	601	0.838	584	0.8
5.5	416	0.808	651	0.832	814	0.832	800	0.794
6	554	0.805	857	0.826	1,069	0.823	1,054	0.791
6.5	717	0.801	1,099	0.819	1,367	0.817	1,349	0.789
7	907	0.798	1,382	0.811	1,717	0.806	1,691	0.788
7.5	1,126	0.80	1,705	0.803	2,110	0.793	2,083	0.786
8	1,375	0.79	2,067	0.794	2,546	0.778	2,527	0.774
8.5	1,652	0.80	2,460	0.775	3,002	0.742	3,016	0.741
9	1,958	0.79	2,849	0.727	3,428	0.679	3,506	0.696
9.5	2,282	0.76	3,174	0.653	3,773	0.606	3,894	0.646
10	2,585	0.71	3,369	0.565	4,012	0.53	4,177	0.594
10.5	2,821	0.64	3,434	0.476	4,131	0.455	4,367	0.542
11	2,997	0.56	3,449	0.402	4,186	0.389	4,470	0.49
11.5	3,050	0.48	3,450	0.343	4,198	0.334	4,500	0.44

Wind speed	V136 3.075MW		V136 3.45MW		V150 4.2MW		N149 4.5MW	
	PC	TC	PC	TC	PC	TC	PC	TC
12	3,067	0.41	3,450	0.297	4,200	0.289	4,500	0.392
12.5	3,074	0.35	3,450	0.26	4,200	0.253	4,500	0.346
13	3,075	0.31	3,450	0.229	4,200	0.223	4,500	0.303
13.5	3,075	0.27	3,450	0.205	4,200	0.198	4,500	0.266
14	3,075	0.24	3,450	0.183	4,200	0.177	4,500	0.234
14.5	3,075	0.22	3,450	0.164	4,200	0.159	4,500	0.209
15	3,075	0.19	3,450	0.148	4,200	0.143	4,500	0.188
15.5	3,075	0.17	3,450	0.134	4,200	0.13	4,500	0.17
16	3,075	0.16	3,450	0.122	4,200	0.118	4,500	0.154
16.5	3,075	0.14	3,450	0.112	4,200	0.108	4,500	0.141
17	3,075	0.13	3,450	0.102	4,200	0.099	4,500	0.129
17.5	3,075	0.12	3,450	0.094	4,200	0.091	4,500	0.12
18	3,075	0.11	3,450	0.087	4,200	0.084	4,500	0.112
18.5	3,075	0.10	3,450	0.081	4,200	0.078	4,500	0.105
19	3,075	0.10	3,450	0.075	4,200	0.072	4,500	0.099
19.5	3,075	0.09	3,450	0.069	4,200	0.067	4,500	0.094
20	3,075	0.08	3,450	0.065	4,200	0.062	4,500	0.09
20.5	3,075	0.08	3,450	0.061	4,200	0.058		
21	3,075	0.07	3,450	0.057	4,200	0.055		
21.5	3,075	0.07	3,450	0.054	4,200	0.051		
22	3,075	0.06	3,450	0.051	4,200	0.048		

Wind speed	V136 3.075MW		V136 3.45MW		V150 4.2MW		N149 4.5MW	
	PC	TC	PC	TC	PC	TC	PC	TC
22.5	3,075	0.06	3,450	0.048	4,200	0.045		
23	3,075	0.06						
23.5	3,075	0.05						
24	3,075	0.05						
24.5	3,075	0.05						
25	3,075	0.04						

Quality information

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05/11/2020

Template V.2

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