External wake impact assessment of the Kraaltjies Wind Farm

South Africa Mainstream Renewable Power Developments (Pty) Ltd

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DNV South Africa (Pty) Ltd.

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Information about this document (the "Report")

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Revision log

Revision	Date	Description
A	2023-08-22	Original version
B	2023-08-24	Updated to include compliance table, specialist declaration and Sivest impact rating
C	2023-08-28	Clarification of the origin of the neighbouring wind farm configuration and recommended mitigation.

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List of abbreviations

Abbreviation	Meaning
CFD	Computational Fluid Dynamics
ECMWF - ERA	European Centre for Medium-Range Weather Forecasts - European Reanalysis
GEOS-5	Goddard Earth Observing System Data Assimilation System Version 5
MARS	Meteorological Archival and Retrieval System
MEASNET	Measuring Network of Wind Energy Institutes
MERRA	Modern-Era Retrospective Analysis for Research and Applications
NASA	National Aeronautics and Space Administration
NCAR	United States National Center for Atmospheric Research
O&M	Operation and maintenance
RANS	Reynolds Averaged Navier-Stokes
SRTM	Shuttle Radar Topography Mission
TSA	Turbine Supply Agreement
WAsP	Wind Atlas Analysis and Application Program
WRF	Weather Research and Forecasting

EXECUTIVE SUMMARY

South Africa Mainstream Renewable Power Developments (Pty) Ltd ("the Customer") retained DNV South Africa (Pty) Ltd. ("DNV") to complete an independent analysis of the wake impact of the planned Kraaltjies Wind Farm ("the Project") on planned neighbouring wind farms. Table 1 summarizes the Project and the results of the wake impact analysis for 14 scenarios.

Table 1 Project summary

Project summary	
Wind farm name	Kraaltjies Wind Farm
Turbine type	Vestas V163-4.5
Turbine hub height	96 m
Turbine rated power	4500 kW
Number of wind turbines	20
Total installed capacity (nameplate)	90
Wind resource summary	
On-site measurement period	9.1 years
Long-term reference period	12.2 years
Average wind farm hub-height wind speed	7.0 m/s
Wake impact summary	
Neighbouring wind farm impacted	**Total turbine interaction loss due to the Project**
Beaufort West	1.2%
Trakas	0.2%
Heuweltjies	0.1%
Kwagga 1	1.5%
Kwagga 2	0.2%
Kwagga 3	0.1%
Koup 1	0.9%
Koup 2	0.3%
Carissa E	0.6%
Carissa SW	0.4%
Carissa NW	0.1%
Jessa M	0.0%
Jessa S	0.0%
Jessa Z	0.0%

Given the early developmental stage of the planned wind farms, the turbine model and layout for each wind farm is yet to be finalised. Therefore, the current assessment is based on information made available by the respective developers of each planned wind farm. DNV recommends that the assessment be updated as final turbine configurations become available.

All known planned neighbouring wind farms were considered in the assessment. However, there exists uncertainty in the development status of each planned wind farm. Therefore, DNV has only considered the total turbine interaction effect of the Project on each planned neighbour in isolation.

Since the Project area including all the proposed neighbouring wind farms is very large, some wind turbines are located more than 50 km from a met mast. These turbine locations are not considered as represented by the locations of the masts. However, for the purpose of this early-stage wake impact assessment, the elevated uncertainty in the individual turbine wind speeds is deemed acceptable.

As shown in the wake impact summary some proposed neighbouring wind farms are subject to significant turbine interaction losses resulting from the Project. However, wake impacts between neighbouring wind farms are well within what is considered to be normal in the industry. Therefore, at this early stage, DNV does not recommend any mitigation measured to reduce the impact of neighbouring wind farm wakes. Once the layouts of the Project and its neighbours are well defined, a CFD assessment of wakes and blockage losses could be performed to more accurately capture turbine interaction losses at the Project area.

Although the wake impacts are within normal levels, the resulting loss in revenue could be accounted for in the financial modelling of the proposed wind farms by either:

1. entering into a wake compensation agreement to mitigate against lost revenue in the case of a neighbouring project reaching financial close before the Project,
2. or including the wakes of the Project as an existing wind farm in the financial modelling of the neighbouring wind farm in the case of the Project reaching financial close first.

National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA) and Environmental Impact Assessment (EIA) Regulations, 2014 (as amended) - Requirements for Specialist Reports (Appendix 6)

Regulation GNR 326 of 4 December 2014, as amended 7 April 2017, Appendix 6	Section of Report
(a) details of the specialist who prepared the report; and the expertise of that specialist to compile a specialist report including a *curriculum vitae*;	Appendix B-1
(b) a declaration that the specialist is independent in a form as may be specified by the competent authority;	Appendix B-2
(c) an indication of the scope of, and the purpose for which, the report was prepared;	1
(cA) an indication of the quality and age of base data used for the specialist report;	3
(cB) a description of existing impacts on the site, cumulative impacts of the proposed development and levels of acceptable change;	2
(d) the duration, date and season of the site investigation and the relevance of the season to the outcome of the assessment;	N/A
(e) a description of the methodology adopted in preparing the report or carrying out the specialised process inclusive of equipment and modelling used;	Appendix C
(f) details of an assessment of the specific identified sensitivity of the site related to the proposed activity or activities and its associated structures and infrastructure, inclusive of a site plan identifying site alternatives;	5
(g) an identification of any areas to be avoided, including buffers;	N/A
(h) a map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	2
(i) a description of any assumptions made and any uncertainties or gaps in knowledge;	5
(j) a description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives on the environment or activities;	5
(k) any mitigation measures for inclusion in the EMPr;	5
(l) any conditions for inclusion in the environmental authorisation;	N/A
(m) any monitoring requirements for inclusion in the EMPr or environmental authorisation;	N/A
(n) a reasoned opinion— i. whether the proposed activity, activities or portions thereof should be authorised; iA. Regarding the acceptability of the proposed activity or activities; and ii. if the opinion is that the proposed activity, activities or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr or Environmental Authorization, and where applicable, the closure plan;	5
(o) a summary and copies of any comments received during any consultation process and where applicable all responses thereto; and	N/A -No feedback has yet been received from the public participation process regarding the visual environment
(p) any other information requested by the competent authority	N/A. No information regarding the visual study has been requested from the competent authority to date.
(2) Where a government notice gazetted by the Minister provides for any protocol or minimum information requirement to be applied to a specialist report, the requirements as indicated in such notice will apply.	N/A

1 INTRODUCTION

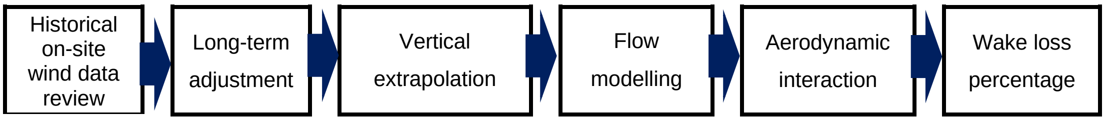
The Customer is developing the Kraaltjies Wind Farm. The Project consists of 20 wind turbines and it is located approximately 60 km south of Beaufort West in the Western Cape Province of South Africa, as shown in Figure 1-1.

Figure 1-1 Project location

The Customer instructed DNV to carry out an independent analysis of the wake impact of the Project on its planned neighbouring wind farms. The results of the work are reported in this document, which has been prepared pursuant to the DNV proposal referenced OPP-00317174-ZACT-P-01 Revision B dated 2023-08-04 and is subject to the terms and conditions contained therein.

DNV has considerable consulting experience in the South African wind energy market since 2010 having assisted its customers with mast commissioning, wind data monitoring, energy production assessments, power curve measurements and technical due diligence for development, financing and for merger and acquisition processes. The South African technical team responsible for this study has been involved in the assessment of over 10 GW of similar wind energy projects, relying additionally on the support and knowledge of the global DNV Project Development department.

This report presents the sequential steps that were followed to derive the total turbine interaction effect, as illustrated in the flow chart below. The main body of the report presents the results for each step, while the detailed methodology is included in Appendix C.



Section 6 presents the DNV observations and recommendations.

To aid the reader of this report, the uncertainty contribution of each individual step in the analysis is colour-coded based on DNV's risk categories for Technical Due Diligence analyses, shown in Table 1-1.

Table 1-1 DNV's risk categories

Uncertainty level identified	**Very low**	**Low**	**Average**	**High**	**Very high**
DNV's suggested course of action	Mitigation is not essential	Mitigation is advantageous	Mitigation is recommended	Mitigation is required	Mitigation is critical

2 PROJECT DESCRIPTION

2.1 Site characteristics

The site is located in the central Karoo, at an elevation of approximately 1020 m above sea level. The terrain at the site is considered to be relatively simple, since there are few areas of steep slopes within the Project area.

Based on public aerial imagery, the ground cover at the site consists predominantly of sparse grasses and low bushes. There is no forestry at the site.

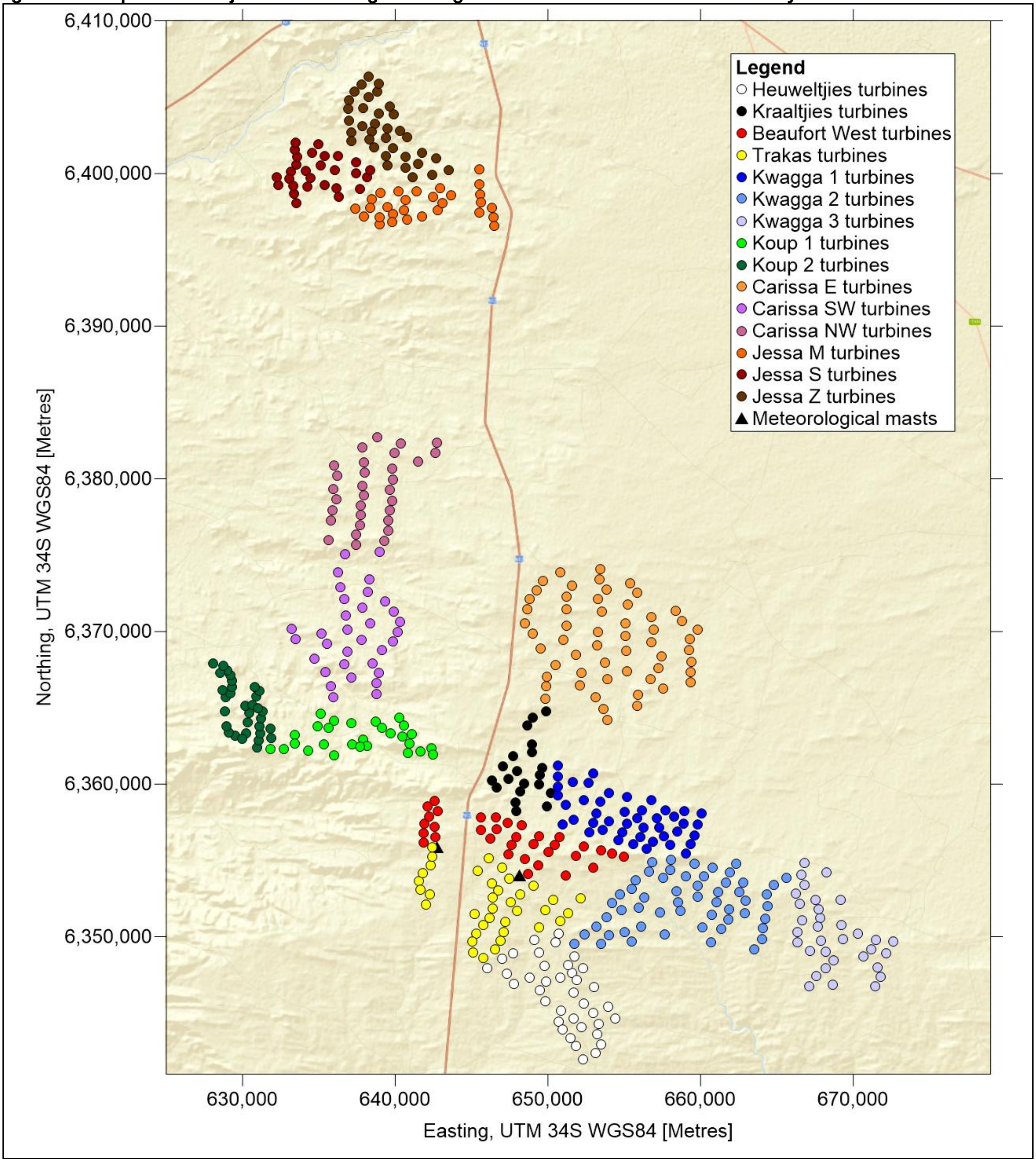
2.2 Neighbouring wind farms

The Project is proposed within a region of high wind farm development activity. The map in Figure 2-1 and the list in Table 2-1 present the information supplied by the Customer regarding proposed neighbouring wind farms. The known characteristics and layout of the planned neighbouring wind turbines are listed in Appendix A.

Table 2-1 Summary of existing and proposed neighbouring wind farms

Wind farm name	Approximate location	Status
Beaufort West	Immediately south of the Project	Proposed
Trakas	3 km south of the Project	Proposed
Heuweltjies	9 km south of the Project	Proposed
Kwagga 1	Immediately east of the Project	Proposed
Kwagga 2	8 km southeast of the Project	Proposed
Kwagga 3	17 km southeast of the Project	Proposed
Koup 1	5 km west of the Project	Proposed
Koup 2	15 km west of the Project	Proposed
Carissa E	Immediately north of the Project	Proposed
Carissa SW	9 km northwest of the Project	Proposed
Carissa NW	16 km northwest of the Project	Proposed
Jessa M	34 km north of the Project	Proposed
Jessa S	37 km north of the Project	Proposed
Jessa Z	37 km north of the Project	Proposed

Figure 2-1 Map of the Project and its neighbouring wind farms considered in the analysis



2.3 Wind turbine technology and layout

The Customer instructed DNV [1] to consider the wind turbine models shown in Table 2-2.

Table 2-2 Wind turbine model

Wind turbine model	Manufacturer	Rated power [MW]	Rotor diameter [m]
V163-4.5MW	Vestas	4.5	163
N155-5.7MW	Nordex	5.7	155
GW165-6.0MW	Goldwind	6.0	165
GW182-6.2MW	Goldwind	6.2	182

This report presents of the aerodynamic interference impact of the Kraaltjies wind farm in the 14 wind farms mentioned in Table 2-1. The wind turbine layout characteristics are presented in Table 2-3 and the coordinates for each wind turbine location are listed in Appendix A.

Table 2-3 Wind turbine layout

Wind farm	Wind turbine model	Hub height [m]	Number of wind turbines	Total installed capacity [MW]	Source of wind turbine layout	Source of wind turbine model information
Heuweltjies	V163-4.5MW	96	38	171	Customer[1]	Customer[2]
Kraaltjies	V163-4.5MW	96	20	90	Customer	Customer
Beaufort West	V163-4.5MW	96	34	153	Customer[1]	Customer[2]
Trakas	V163-4.5MW	96	34	153	Customer[1]	Customer[2]
Kwagga 1	N155-5.7MW	120	45	256.5	Customer[1]	Customer[2]
Kwagga 2	N155-5.7MW	120	55	313.5	Customer[1]	Customer[2]
Kwagga 3	N155-5.7MW	120	33	188.1	Customer[1]	Customer[2]
Koup 1	GW165-6.0MW	120	28	168	Customer[1]	Customer[3]
Koup 2	GW165-6.0MW	120	32	192	Customer[1]	Customer[3]
Carissa E	GW165-6.0MW	120	56	336	Customer[1]	Customer[2]
Carissa SW	GW165-6.0MW	120	33	198	Customer[1]	Customer[2]
Carissa NW	GW165-6.0MW	120	31	186	Customer[1]	Customer[2]
Jessa M	GW182-6.2MW	130	29	179.8	Customer[1]	Customer[2]
Jessa S	GW182-6.2MW	130	28	173.6	Customer[1]	Customer[2]
Jessa Z	GW182-6.2MW	130	35	217	Customer[1]	Customer[2]

1. Layout was provided to the Customer by the relevant developer.
2. Turbines and hub height was provided to the Customer by the relevant developer.
3. Assumed turbine model information provided by the Customer, since the developer has not settled on a turbine model.

Given the early developmental stage of the planned wind farms, the turbine model and layout for each wind farm is yet to be finalised. Therefore, the current assessment is based on information made available by the respective developers of each planned wind farm . DNV recommends that the assessment be updated as final turbine configurations become available.

3 ON-SITE WIND MONITORING

Existing on-site wind resource	3.1 On-site monitoring equipment 3.2 On-site measurements quality control	Measured on-site wind resource

3.1 On-site monitoring equipment

The Customer supplied wind data recorded by the on-site measurement equipment listed in Table 3-1. Full details of the site mast mounting arrangements and sensor calibrations are presented in DNV Report No. L2C233510-ZACT-R-03, Rev. A, dated 09-05-2023.

Table 3-1 List of on-site monitoring equipment

Monitoring equipment	Measurement period		Sensor type	Measurement heights b [m]
	Start date	End date		
Mast SA008_02	12-12-2012	15-12-2018	Wind speed	70.8, 70.7, 60.1, 60.0, 51.8, 51.7, 30.1, 30.1
			Wind direction	68.6, 55.0, 28.5
Mast SA008_03	14-04-2015	18-05-2022	Wind speed	121.0, 120.9, 100.0, 99.9, 80.0, 79.9, 60.0, 59.9
			Wind direction	118.0, 78.0, 58.0

3.2 On-site measurements quality control

Wind data from the monitoring equipment supplied by the Customer have been processed and validated in accordance with DNV’s standard quality control process in order to identify records which were affected by equipment malfunction and other anomalies. These records were excluded from the analysis. Full details of the on-site measurements consistency, selection of primary data sensors and the measured mean wind speed are presented in DNV Report No. L2C233510-ZACT-R-03, Rev. A, dated 09-05-2023.

4 WIND RESOURCE ANALYSIS

Measured on-site wind resource	→	4.1 Long-term wind resource extrapolation 4.2 Vertical wind resource extrapolation 4.3 Spatial wind resource extrapolation	→	Long-term hub-height wind resource at the turbine positions

The wind resource of a wind farm is described by both the long-term wind speed and by the long-term wind speed and direction frequency distribution, at hub-height, at the location of every wind turbine. This section describes the process that is followed to derive these two components of the wind resource.

4.1 Long-term wind resource extrapolation

To reduce the uncertainty of the long-term wind resource estimate at the Project site, it is desirable that firstly a concurrent dataset from all sensors on each mast is established for the longest possible period, in order to maximize the use of on-site wind data, and then that an adjustment is made based on quality long-term reference sources.

Full details of the on-site data reconstruction, measured and reconstructed mean wind speed, long-term reference data, adjusting on-site wind speed to the long-term and the long-term mean wind speed are presented in DNV Report No. L2C233510-ZACT-R-03, Rev. A, dated 09-05-2023.

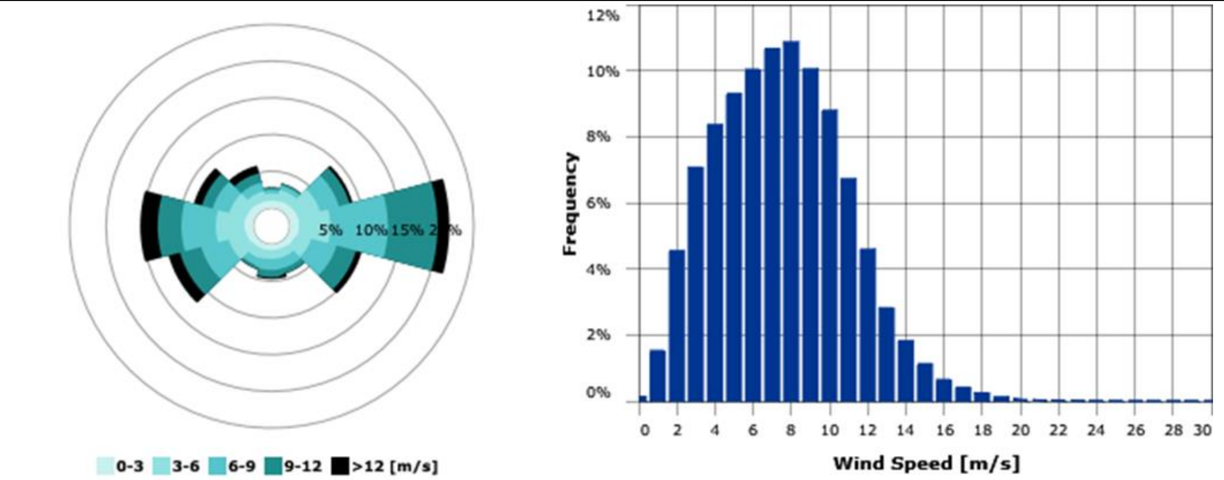
4.2 Vertical wind resource extrapolation

Wind shear determines the variation of wind speed with height above the ground. Accurately establishing this vertical wind speed profile depends on the installation height of the wind sensors, on the period of measured wind data available, and on the complexity of the atmospheric wind flow at the site.

Full details of the effective historical mast measurement heights, wind shear profile, long-term hub-height mean wind speed, hub-height wind speed and direction frequency distribution, hub-height ambient turbulence intensity, and hub-height mean air density are presented in DNV Report No. L2C233510-ZACT-R-03, Rev. A, dated 09-05-2023.

The resulting hub height wind rose and frequency distribution for Mast SA008_02 at 96 m, which is considered representative of the site, is shown in Figure 4-1.

Figure 4-1 Long-term wind speed and direction frequency distribution for Mast SA008_02 at 96 m



4.3 Spatial wind resource extrapolation

To determine the wind resource at the location of each wind turbine, flow modelling is required to spatially extrapolate the wind resource obtained at the location of each mast.

4.3.1 Flow model

The variation in wind speed over the site was predicted using a combination of the Vortex FARM© mesoscale model and the publicly available WASA wind speed map [11] to produce a wind speed map with a horizontal resolution of respectively 100 m for the Project area and 250 m for the wider area.

As observed in Section 4.2, the mean wind speed, wind shear exponent, wind speed frequency distribution and wind rose, are similar for all masts, suggesting that the wind flow at the site is relatively simple.

There is some uncertainty in using a flow model such as a mesoscale mapping to capture the wind speed variation across such a site, considering the strong atmospheric stability diurnal cycles and the very large distances between some wind turbines and the masts.

4.3.2 Flow model setup

The flow model setup includes the topographic map, the ground cover map, and any potential reductions in wind turbine hub-height due to neighbouring forestry. Table 4-1 presents these flow model setup characteristics.

Table 4-1 Wind flow modelling setup characteristics

Site characteristic	Resulting setup in the analysis		Source
Topography	Digital terrain map with 1 m horizontal resolution and 10 m contours within the site boundaries, extended with SRTM elevation data with horizontal resolution of 38 m to output 39 km x 34 km.		Publicly available SRTM data [7]
Ground cover	Site and surrounding areas	0.03 m	Publicly available satellite images, based on the Davenport classification [8]
	Water	0.0001 m	
	Shrubs	0.075 m	
	Built up area	0.5 m	

Up-to-date detailed ground cover maps were supplied and the ground cover at parts of the site was corroborated independently by DNV as part of a site visit.

As described in Section 2.1, the site is not considered to be forested.

A high-resolution digital terrain map was not provided by the Customer, and the publicly available SRTM digital topographic map obtained by DNV does not have the necessary resolution. However, since the flow modelling is based on independent mesoscale wind speed maps, the low-resolution terrain data does not adversely affect the uncertainty in the wind flow modelling results.

4.3.3 Flow modelling adjustments

Flow modelling accuracy must be analysed in order to assign the mast that will provide the input data to model the flow at the location of each wind turbine, to determine the need for flow modelling adjustments and also to quantify the uncertainty associated with the underlying process. The accuracy of flow modelling was analysed by cross predicting the wind speeds at the monitoring equipment locations at hub height, as shown in Table 4-2.

Table 4-2 Flow model precision check

Prediction error [%]		Reference monitoring equipment	
		Mast SA008_02	Mast SA008_03
Target monitoring equipment	Mast SA008_02	-	-1.0
	Mast SA008_03	+1.0	-

These results show good agreement at most mast locations. For each wind turbine of the Project, the flow model was initiated by the wind data from the most representative met mast and pragmatic wind speed adjustments to the flow modelling results were not required.

Since the Project area including all the proposed neighbouring wind farms is very large, some wind turbines are located more than 50 km from a met mast. These turbine locations are not considered as represented by the locations of the masts as the wind turbines closer to the met masts. However, for the purpose of this early-stage wake impact assessment, the elevated uncertainty in the individual turbine wind speeds is deemed acceptable.

4.3.4 Long-term hub-height wind speed at the wind turbine positions

The average long-term mean wind speed for each wind farm is presented in Table 4-3.

Table 4-3 Average wind farm wind speeds

Wind farm	Hub-height [m]	Number of wind turbines	Average wind speed [m/s]
Beaufort West	96	34	7.5
Trakas	96	34	7.3
Heuweltjies	96	38	7.2
Kraaltjies	96	20	7.0
Kwagga 1	120	45	7.2
Kwagga 2	120	55	7.2
Kwagga 3	120	33	7.3
Koup 1	120	28	7.6
Koup 2	120	32	7.4
Carissa E	120	56	7.0
Carissa SW	120	33	7.5
Carissa NW	120	31	7.2
Jessa M	130	29	7.1
Jessa S	130	28	6.7
Jessa Z	130	35	7.0

5 WAKE IMPACT ANALYSIS

The wind flow modelling results derived in the previous section were combined with the wind turbine performance parameters, as inputs to the Wind Farmer: Analyst software, in order to calculate the gross energy production at individual turbine locations. The expected gross energy production is a theoretical value to which efficiency factors should be applied to estimate the net energy production. These efficiency factors are determined below, according to the methods detailed in Appendix C-4.

5.1 Turbine aerodynamic interaction effect

Wake effects are specific to the project and result from the interaction between wind turbines belonging to the Project itself, wind turbines belonging to nearby projects that are already operational, or wind turbines belonging to nearby projects that may be built in the future.

The turbine interaction effects were calculated using the Ainslie wake model [13], with modifications that account for Large Wind Farm interactions with the atmospheric boundary layer and the Blockage Effect caused by the geometry of the wind turbine layout. All of these are described in Appendix C-4.1.

5.1.1 External turbine aerodynamic interaction effect

These are the wake and blockage effects that the Project wind turbines will have on the planned neighbouring wind farm being considered.

All known planned neighbouring wind farms were considered in the assessment. However, there exists uncertainty in the development status of each planned wind farm. Therefore, DNV has only considered the total turbine interaction effect of the Project on each planned neighbour in isolation.

The total turbine interaction loss due to the Project for each proposed neighbouring wind farm are presented in Table 5-1.

Table 5-1 Total turbine interaction loss due to the Project

Wind farm	Total turbine interaction loss due to the Project
Beaufort West	1.2%
Trakas	0.2%
Heuweltjies	0.1%
Kwagga 1	1.5%
Kwagga 2	0.2%
Kwagga 3	0.1%
Koup 1	0.9%
Koup 2	0.3%
Carissa E	0.6%
Carissa SW	0.4%
Carissa NW	0.1%
Jessa M	0.0%
Jessa S	0.0%
Jessa Z	0.0%

As shown in Table 5-1 some proposed neighbouring wind farms are subject to significant turbine interaction losses resulting from the Project. However, wake impacts between neighbouring wind farms of the order shown in Table 5-1 are well within what is considered to be normal in the industry. Therefore, at this early stage, DNV does not recommend any mitigation measured to reduce the impact of neighbouring wind farm wakes. Once the layouts of the Project and its neighbours are well defined, a CFD assessment of wakes and blockage losses could be performed to more accurately capture turbine interaction losses at the Project area.

Although the wake impacts are within normal levels, the resulting loss in revenue could be accounted for in the financial modelling of the proposed wind farms by either:

- entering into a wake compensation agreement to mitigate against lost revenue in the case of a neighbouring project reaching financial close before the Project,
- or including the wakes of the Project as an existing wind farm in the financial modelling of the neighbouring wind farm in the case of the Project reaching financial close first.

5.2 External turbine aerodynamic interaction impact rating

At the request of the customer, the wake impact of the Project on its planned neighbours is rated according to the Sivest impact rating table. This table and a description of the methodology is included in Appendix D.

6 OBSERVATIONS AND RECOMMENDATIONS

DNV makes the following observations and recommendations regarding this analysis:

3. The turbine interaction effects were calculated using the Ainslie wake model [13], with modifications that account for Large Wind Farm interactions with the atmospheric boundary layer and the Blockage Effect caused by the geometry of the wind turbine layout.

Wind farm	Total turbine interaction loss due to the Project
Beaufort West	1.2%
Trakas	0.2%
Heuweltjies	0.1%
Kwagga 1	1.5%
Kwagga 2	0.2%
Kwagga 3	0.1%
Koup 1	0.9%
Koup 2	0.3%
Carissa E	0.6%
Carissa SW	0.4%
Carissa NW	0.1%
Jessa M	0.0%
Jessa S	0.0%
Jessa Z	0.0%

4. As shown in Table 5-1 some proposed neighbouring wind farms are subject to significant turbine interaction losses resulting from the Project. However, wake impacts between neighbouring wind farms of the order shown in Table 5-1 are well within what is considered to be normal in the industry. Therefore, at this early stage, DNV does not recommend any mitigation measured to reduce the impact of neighbouring wind farm wakes. Once the layouts of the Project and its neighbours are well defined, a CFD assessment of wakes and blockage losses could be performed to more accurately capture turbine interaction losses at the Project area.

5. Although the wake impacts are within normal levels, the resulting loss in revenue could be accounted for in the financial modelling of the proposed wind farms by either:

   a. entering into a wake compensation agreement to mitigate against lost revenue in the case of a neighbouring project reaching financial close before the Project,

   b. or including the wakes of the Project as an existing wind farm in the financial modelling of the neighbouring wind farm in the case of the Project reaching financial close first.

6. The key contributions to the uncertainty level of the estimate are:

   a. Given the early developmental stage of the planned wind farms, the turbine model and layout for each wind farm is yet to be finalised. Therefore, the current assessment is based on information made available by the respective developers of each planned wind farm. DNV recommends that the assessment be updated as final turbine configurations become available.

   b. There is some uncertainty in using a flow model such as a mesoscale mapping to capture the wind speed variation across such a site, especially because of strong atmospheric stability cycles and the very large distances between some wind turbines and the masts.

c. Since the Project area including all the proposed neighbouring wind farms is very large, some wind turbines are located more than 50 km from a met mast. These turbine locations are not considered as represented by the locations of the masts. However, for the purpose of this early-stage wake impact assessment, the elevated uncertainty in the individual turbine wind speeds is deemed acceptable.

d. All known planned neighbouring wind farms were considered in the assessment. However, there exists uncertainty in the development status of each planned wind farm. Therefore, DNV has only considered the total turbine interaction effect of the Project on each planned neighbour in isolation.

7 REFERENCES

1. Data supplied by the Customer via data room between 2023-08-01 and 2023-08-14

2. IEC 61400-1 Ed3.1: “Wind turbines – Part 1: Design requirements”, 2014.

3. IEC 61400-12-1 Ed2.0, “Wind turbines - Part 12-1: Power performance Measurements of electricity producing wind turbines, Annex G”, 2017.

4. Global Modelling and Assimilation Office (GMAO); MERRA-2; data available from Goddard Earth Sciences Data and Information Services Center (GES DISC); website at https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/data_access/

5. The European Centre for Medium-Range Weather Forecasts (ECMWF); ERA-5; website at https://www.ecmwf.int/en/forecasts/datasets/archive-datasets/reanalysis-datasets/era5.

6. Vortex FARM wind map dataset; Vortex; Data supplied by the Customer.

7. Shuttle Radar Topography Mission (SRTM); “The Mission to Map the World”; NASA; website at https://www2.jpl.nasa.gov/srtm/

8. “Wind speed profiles over terrain with roughness changes”, Engineering Sciences Data, Item No. 84011, April 1993.

9. Mortensen, N.G., Heathfield D.N., Myllerup L., Landberg L. and Rathmann O., “Wind Atlas Analysis and Application Program: WAsP 10 Help Facility”. Risø National Laboratory, Roskilde, Denmark, 2010.

10. Bleeg, James, et al. “Modeling Stable Thermal Stratification and Its Impact on Wind Flow over Topography.” Wind Energy, vol. 18, no. 2, 2014, pp. 369–383., doi:10.1002/we.1692.

11. Vortex FARM validation and description, available at: https://vortexfdc.com/knowledge/vortex-farmremodeled-validation/

12. Bleeg, James, et al. “Wind Farm Blockage and the Consequences of Neglecting Its Impact on Energy Production.” Energies, vol. 11, no. 6, 2018, p. 1609., doi:10.3390/en11061609.

13. WindFarmer white paper, April 2016; website at: https://www.dnvgl.com/publications/windfarmer-white-paper-april-2016-65253.

14. Rubel, F., and M. Kottek, 2010: Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification. Meteorol. Z., 19, 135-141.

APPENDIX A - WIND FARM SITE INFORMATION

Table A-1 Wind farm information

Wind farm	Coordinates [m] WGS84, UTM zone 34S		Wind turbine model	Hub height [m]
Heuweltjies	650,712	6,350,212	V163-4.5 MW	96
Heuweltjies	650,515	6,349,614	V163-4.5 MW	96
Heuweltjies	651,724	6,348,719	V163-4.5 MW	96
Heuweltjies	651,688	6,344,645	V163-4.5 MW	96
Heuweltjies	653,006	6,346,730	V163-4.5 MW	96
Heuweltjies	647,725	6,348,925	V163-4.5 MW	96
Heuweltjies	651,560	6,347,629	V163-4.5 MW	96
Heuweltjies	649,110	6,349,793	V163-4.5 MW	96
Heuweltjies	649,839	6,345,761	V163-4.5 MW	96
Heuweltjies	651,330	6,348,166	V163-4.5 MW	96
Heuweltjies	649,407	6,348,985	V163-4.5 MW	96
Heuweltjies	650,687	6,344,441	V163-4.5 MW	96
Heuweltjies	647,749	6,346,891	V163-4.5 MW	96
Heuweltjies	653,220	6,343,602	V163-4.5 MW	96
Heuweltjies	652,192	6,344,072	V163-4.5 MW	96
Heuweltjies	651,465	6,343,386	V163-4.5 MW	96
Heuweltjies	651,675	6,346,325	V163-4.5 MW	96
Heuweltjies	646,009	6,347,964	V163-4.5 MW	96
Heuweltjies	654,418	6,344,673	V163-4.5 MW	96
Heuweltjies	649,765	6,348,114	V163-4.5 MW	96
Heuweltjies	651,901	6,347,154	V163-4.5 MW	96
Heuweltjies	650,786	6,347,313	V163-4.5 MW	96
Heuweltjies	650,970	6,343,932	V163-4.5 MW	96
Heuweltjies	653,948	6,345,440	V163-4.5 MW	96
Heuweltjies	652,326	6,345,639	V163-4.5 MW	96
Heuweltjies	652,274	6,347,958	V163-4.5 MW	96
Heuweltjies	648,798	6,347,308	V163-4.5 MW	96
Heuweltjies	650,858	6,345,153	V163-4.5 MW	96
Heuweltjies	652,980	6,344,988	V163-4.5 MW	96
Heuweltjies	653,494	6,342,925	V163-4.5 MW	96
Heuweltjies	651,812	6,342,831	V163-4.5 MW	96
Heuweltjies	649,887	6,347,060	V163-4.5 MW	96
Heuweltjies	647,025	6,348,575	V163-4.5 MW	96
Heuweltjies	647,305	6,347,574	V163-4.5 MW	96
Heuweltjies	649,481	6,346,501	V163-4.5 MW	96
Heuweltjies	652,322	6,341,993	V163-4.5 MW	96
Heuweltjies	653,325	6,344,263	V163-4.5 MW	96
Heuweltjies	653,112	6,342,363	V163-4.5 MW	96
Kraaltjies	647,927	6,358,213	V163-4.5 MW	96
Kraaltjies	647,883	6,358,818	V163-4.5 MW	96
Kraaltjies	646,653	6,359,765	V163-4.5 MW	96
Kraaltjies	646,331	6,360,256	V163-4.5 MW	96
Kraaltjies	649,931	6,358,551	V163-4.5 MW	96
Kraaltjies	648,165	6,359,519	V163-4.5 MW	96
Kraaltjies	647,028	6,361,179	V163-4.5 MW	96
Kraaltjies	647,428	6,360,357	V163-4.5 MW	96
Kraaltjies	650,172	6,359,393	V163-4.5 MW	96
Kraaltjies	647,706	6,361,846	V163-4.5 MW	96
Kraaltjies	647,976	6,360,848	V163-4.5 MW	96
Kraaltjies	648,456	6,360,021	V163-4.5 MW	96
Kraaltjies	649,015	6,364,365	V163-4.5 MW	96
Kraaltjies	648,979	6,362,103	V163-4.5 MW	96

Wind farm	Coordinates [m] WGS84, UTM zone 34S		Wind turbine model	Hub height [m]
Kraaltjies	648,660	6,363,831	V163-4.5 MW	96
Kraaltjies	649,397	6,359,995	V163-4.5 MW	96
Kraaltjies	649,466	6,360,577	V163-4.5 MW	96
Kraaltjies	649,904	6,364,773	V163-4.5 MW	96
Kraaltjies	649,609	6,361,080	V163-4.5 MW	96
Kraaltjies	648,952	6,362,599	V163-4.5 MW	96
Beaufort West	641,871	6,356,808	V163-4.5 MW	96
Beaufort West	642,553	6,358,894	V163-4.5 MW	96
Beaufort West	650,456	6,356,043	V163-4.5 MW	96
Beaufort West	642,092	6,358,520	V163-4.5 MW	96
Beaufort West	652,986	6,354,513	V163-4.5 MW	96
Beaufort West	647,937	6,356,542	V163-4.5 MW	96
Beaufort West	648,477	6,355,073	V163-4.5 MW	96
Beaufort West	646,652	6,357,024	V163-4.5 MW	96
Beaufort West	642,652	6,356,520	V163-4.5 MW	96
Beaufort West	649,073	6,356,073	V163-4.5 MW	96
Beaufort West	642,761	6,358,241	V163-4.5 MW	96
Beaufort West	641,931	6,357,405	V163-4.5 MW	96
Beaufort West	642,233	6,357,890	V163-4.5 MW	96
Beaufort West	646,595	6,357,810	V163-4.5 MW	96
Beaufort West	648,286	6,357,288	V163-4.5 MW	96
Beaufort West	642,571	6,357,202	V163-4.5 MW	96
Beaufort West	650,014	6,355,539	V163-4.5 MW	96
Beaufort West	649,435	6,356,606	V163-4.5 MW	96
Beaufort West	646,203	6,356,444	V163-4.5 MW	96
Beaufort West	641,831	6,356,153	V163-4.5 MW	96
Beaufort West	647,354	6,357,440	V163-4.5 MW	96
Beaufort West	645,614	6,356,989	V163-4.5 MW	96
Beaufort West	648,715	6,354,135	V163-4.5 MW	96
Beaufort West	654,185	6,355,461	V163-4.5 MW	96
Beaufort West	647,388	6,355,386	V163-4.5 MW	96
Beaufort West	647,635	6,356,015	V163-4.5 MW	96
Beaufort West	654,985	6,355,252	V163-4.5 MW	96
Beaufort West	651,175	6,353,995	V163-4.5 MW	96
Beaufort West	653,470	6,355,675	V163-4.5 MW	96
Beaufort West	650,762	6,356,555	V163-4.5 MW	96
Beaufort West	645,600	6,357,822	V163-4.5 MW	96
Beaufort West	649,342	6,354,705	V163-4.5 MW	96
Beaufort West	651,855	6,355,306	V163-4.5 MW	96
Beaufort West	652,330	6,355,936	V163-4.5 MW	96
Trakas	642,437	6,355,857	V163-4.5 MW	96
Trakas	645,771	6,350,748	V163-4.5 MW	96
Trakas	646,548	6,349,157	V163-4.5 MW	96
Trakas	648,195	6,352,755	V163-4.5 MW	96
Trakas	647,487	6,353,816	V163-4.5 MW	96
Trakas	651,338	6,351,562	V163-4.5 MW	96
Trakas	647,011	6,354,544	V163-4.5 MW	96
Trakas	649,846	6,351,750	V163-4.5 MW	96
Trakas	642,021	6,352,105	V163-4.5 MW	96
Trakas	647,211	6,350,964	V163-4.5 MW	96
Trakas	645,114	6,348,975	V163-4.5 MW	96
Trakas	645,283	6,350,223	V163-4.5 MW	96
Trakas	650,784	6,351,012	V163-4.5 MW	96
Trakas	645,190	6,351,490	V163-4.5 MW	96
Trakas	647,543	6,352,250	V163-4.5 MW	96
Trakas	646,734	6,353,051	V163-4.5 MW	96
Trakas	645,028	6,349,676	V163-4.5 MW	96

Wind farm	Coordinates [m] WGS84, UTM zone 34S		Wind turbine model	Hub height [m]
Trakas	649,035	6,353,335	V163-4.5 MW	96
Trakas	641,552	6,353,670	V163-4.5 MW	96
Trakas	646,390	6,352,583	V163-4.5 MW	96
Trakas	646,893	6,349,742	V163-4.5 MW	96
Trakas	642,304	6,354,667	V163-4.5 MW	96
Trakas	642,446	6,355,229	V163-4.5 MW	96
Trakas	645,779	6,348,589	V163-4.5 MW	96
Trakas	642,289	6,352,763	V163-4.5 MW	96
Trakas	650,322	6,352,405	V163-4.5 MW	96
Trakas	646,161	6,351,256	V163-4.5 MW	96
Trakas	641,652	6,353,103	V163-4.5 MW	96
Trakas	646,387	6,351,840	V163-4.5 MW	96
Trakas	649,422	6,350,637	V163-4.5 MW	96
Trakas	645,384	6,354,299	V163-4.5 MW	96
Trakas	646,308	6,353,502	V163-4.5 MW	96
Trakas	648,002	6,351,673	V163-4.5 MW	96
Trakas	646,105	6,355,165	V163-4.5 MW	96
Trakas	641,804	6,354,184	V163-4.5 MW	96
Trakas	647,124	6,350,299	V163-4.5 MW	96
Trakas	652,135	6,352,515	V163-4.5 MW	96
Kwagga 1	656,065	6,356,549	N155-5.7 MW	120
Kwagga 1	659,038	6,355,458	N155-5.7 MW	120
Kwagga 1	654,878	6,356,858	N155-5.7 MW	120
Kwagga 1	650,974	6,357,364	N155-5.7 MW	120
Kwagga 1	655,175	6,357,385	N155-5.7 MW	120
Kwagga 1	656,481	6,355,738	N155-5.7 MW	120
Kwagga 1	651,682	6,357,667	N155-5.7 MW	120
Kwagga 1	652,727	6,356,819	N155-5.7 MW	120
Kwagga 1	655,844	6,357,762	N155-5.7 MW	120
Kwagga 1	658,011	6,355,998	N155-5.7 MW	120
Kwagga 1	657,279	6,357,162	N155-5.7 MW	120
Kwagga 1	652,965	6,357,476	N155-5.7 MW	120
Kwagga 1	654,600	6,356,322	N155-5.7 MW	120
Kwagga 1	658,920	6,358,253	N155-5.7 MW	120
Kwagga 1	653,162	6,358,087	N155-5.7 MW	120
Kwagga 1	657,110	6,357,761	N155-5.7 MW	120
Kwagga 1	657,617	6,356,569	N155-5.7 MW	120
Kwagga 1	659,827	6,357,339	N155-5.7 MW	120
Kwagga 1	660,079	6,358,070	N155-5.7 MW	120
Kwagga 1	659,582	6,356,641	N155-5.7 MW	120
Kwagga 1	655,590	6,356,073	N155-5.7 MW	120
Kwagga 1	656,272	6,357,136	N155-5.7 MW	120
Kwagga 1	659,371	6,356,047	N155-5.7 MW	120
Kwagga 1	656,181	6,358,294	N155-5.7 MW	120
Kwagga 1	658,261	6,357,853	N155-5.7 MW	120
Kwagga 1	655,005	6,358,177	N155-5.7 MW	120
Kwagga 1	657,678	6,358,274	N155-5.7 MW	120
Kwagga 1	653,600	6,357,021	N155-5.7 MW	120
Kwagga 1	654,020	6,357,586	N155-5.7 MW	120
Kwagga 1	658,470	6,356,911	N155-5.7 MW	120
Kwagga 1	658,874	6,357,418	N155-5.7 MW	120
Kwagga 1	656,858	6,356,244	N155-5.7 MW	120
Kwagga 1	651,159	6,358,667	N155-5.7 MW	120
Kwagga 1	652,352	6,358,936	N155-5.7 MW	120
Kwagga 1	653,442	6,358,859	N155-5.7 MW	120
Kwagga 1	650,678	6,359,278	N155-5.7 MW	120
Kwagga 1	650,659	6,359,845	N155-5.7 MW	120

Wind farm	Coordinates [m] WGS84, UTM zone 34S		Wind turbine model	Hub height [m]
Kwagga 1	650,669	6,360,509	N155-5.7 MW	120
Kwagga 1	650,631	6,361,237	N155-5.7 MW	120
Kwagga 1	651,615	6,360,151	N155-5.7 MW	120
Kwagga 1	652,653	6,360,067	N155-5.7 MW	120
Kwagga 1	652,956	6,360,678	N155-5.7 MW	120
Kwagga 1	653,988	6,359,435	N155-5.7 MW	120
Kwagga 1	655,180	6,359,157	N155-5.7 MW	120
Kwagga 1	656,787	6,358,964	N155-5.7 MW	120
Kwagga 2	651,751	6,349,524	N155-5.7 MW	120
Kwagga 2	658,062	6,355,040	N155-5.7 MW	120
Kwagga 2	652,425	6,350,150	N155-5.7 MW	120
Kwagga 2	653,172	6,350,648	N155-5.7 MW	120
Kwagga 2	657,988	6,354,391	N155-5.7 MW	120
Kwagga 2	656,086	6,350,654	N155-5.7 MW	120
Kwagga 2	656,313	6,352,584	N155-5.7 MW	120
Kwagga 2	653,468	6,349,555	N155-5.7 MW	120
Kwagga 2	654,829	6,351,772	N155-5.7 MW	120
Kwagga 2	656,822	6,354,865	N155-5.7 MW	120
Kwagga 2	654,718	6,352,794	N155-5.7 MW	120
Kwagga 2	654,178	6,352,203	N155-5.7 MW	120
Kwagga 2	655,724	6,353,723	N155-5.7 MW	120
Kwagga 2	661,663	6,353,571	N155-5.7 MW	120
Kwagga 2	655,477	6,353,134	N155-5.7 MW	120
Kwagga 2	659,042	6,353,978	N155-5.7 MW	120
Kwagga 2	657,352	6,351,577	N155-5.7 MW	120
Kwagga 2	655,502	6,349,683	N155-5.7 MW	120
Kwagga 2	658,444	6,352,979	N155-5.7 MW	120
Kwagga 2	661,900	6,354,227	N155-5.7 MW	120
Kwagga 2	654,003	6,350,121	N155-5.7 MW	120
Kwagga 2	661,163	6,352,942	N155-5.7 MW	120
Kwagga 2	661,022	6,352,285	N155-5.7 MW	120
Kwagga 2	653,826	6,351,307	N155-5.7 MW	120
Kwagga 2	660,734	6,351,439	N155-5.7 MW	120
Kwagga 2	655,024	6,350,303	N155-5.7 MW	120
Kwagga 2	664,236	6,351,196	N155-5.7 MW	120
Kwagga 2	664,068	6,350,552	N155-5.7 MW	120
Kwagga 2	664,042	6,349,866	N155-5.7 MW	120
Kwagga 2	664,402	6,352,008	N155-5.7 MW	120
Kwagga 2	664,353	6,352,779	N155-5.7 MW	120
Kwagga 2	659,808	6,353,342	N155-5.7 MW	120
Kwagga 2	660,663	6,349,642	N155-5.7 MW	120
Kwagga 2	662,770	6,353,529	N155-5.7 MW	120
Kwagga 2	660,202	6,353,940	N155-5.7 MW	120
Kwagga 2	660,137	6,350,593	N155-5.7 MW	120
Kwagga 2	662,511	6,352,944	N155-5.7 MW	120
Kwagga 2	661,356	6,350,505	N155-5.7 MW	120
Kwagga 2	664,816	6,353,374	N155-5.7 MW	120
Kwagga 2	659,603	6,354,764	N155-5.7 MW	120
Kwagga 2	661,808	6,351,116	N155-5.7 MW	120
Kwagga 2	661,882	6,351,793	N155-5.7 MW	120
Kwagga 2	662,342	6,354,763	N155-5.7 MW	120
Kwagga 2	658,525	6,352,286	N155-5.7 MW	120
Kwagga 2	657,562	6,353,843	N155-5.7 MW	120
Kwagga 2	655,974	6,351,894	N155-5.7 MW	120
Kwagga 2	656,626	6,354,268	N155-5.7 MW	120
Kwagga 2	658,675	6,351,683	N155-5.7 MW	120
Kwagga 2	662,943	6,352,352	N155-5.7 MW	120

Wind farm	Coordinates [m] WGS84, UTM zone 34S		Wind turbine model	Hub height [m]
Kwagga 2	660,792	6,354,525	N155-5.7 MW	120
Kwagga 2	665,609	6,353,858	N155-5.7 MW	120
Kwagga 2	663,504	6,349,176	N155-5.7 MW	120
Kwagga 2	662,905	6,351,522	N155-5.7 MW	120
Kwagga 2	659,789	6,352,624	N155-5.7 MW	120
Kwagga 2	657,643	6,350,175	N155-5.7 MW	120
Kwagga 3	668,218	6,349,029	N155-5.7 MW	120
Kwagga 3	667,894	6,349,731	N155-5.7 MW	120
Kwagga 3	671,201	6,349,183	N155-5.7 MW	120
Kwagga 3	669,211	6,350,763	N155-5.7 MW	120
Kwagga 3	671,499	6,349,819	N155-5.7 MW	120
Kwagga 3	671,798	6,347,389	N155-5.7 MW	120
Kwagga 3	672,167	6,348,901	N155-5.7 MW	120
Kwagga 3	671,577	6,347,973	N155-5.7 MW	120
Kwagga 3	667,821	6,351,249	N155-5.7 MW	120
Kwagga 3	669,155	6,352,425	N155-5.7 MW	120
Kwagga 3	666,819	6,353,373	N155-5.7 MW	120
Kwagga 3	668,178	6,347,964	N155-5.7 MW	120
Kwagga 3	670,649	6,348,727	N155-5.7 MW	120
Kwagga 3	668,223	6,354,216	N155-5.7 MW	120
Kwagga 3	666,342	6,349,637	N155-5.7 MW	120
Kwagga 3	666,486	6,352,172	N155-5.7 MW	120
Kwagga 3	666,256	6,352,845	N155-5.7 MW	120
Kwagga 3	668,696	6,348,473	N155-5.7 MW	120
Kwagga 3	666,597	6,354,065	N155-5.7 MW	120
Kwagga 3	667,736	6,351,823	N155-5.7 MW	120
Kwagga 3	667,147	6,349,079	N155-5.7 MW	120
Kwagga 3	667,541	6,352,420	N155-5.7 MW	120
Kwagga 3	666,633	6,351,078	N155-5.7 MW	120
Kwagga 3	666,364	6,350,326	N155-5.7 MW	120
Kwagga 3	669,347	6,349,839	N155-5.7 MW	120
Kwagga 3	670,301	6,350,213	N155-5.7 MW	120
Kwagga 3	666,811	6,354,832	N155-5.7 MW	120
Kwagga 3	671,428	6,346,740	N155-5.7 MW	120
Kwagga 3	672,631	6,349,714	N155-5.7 MW	120
Kwagga 3	667,679	6,350,687	N155-5.7 MW	120
Kwagga 3	668,653	6,346,845	N155-5.7 MW	120
Kwagga 3	667,571	6,347,402	N155-5.7 MW	120
Kwagga 3	667,127	6,346,782	N155-5.7 MW	120
Koup 1	637,111	6,363,980	GW165-6.0 MW	120
Koup 1	635,131	6,364,600	GW165-6.0 MW	120
Koup 1	640,269	6,364,346	GW165-6.0 MW	120
Koup 1	638,713	6,364,093	GW165-6.0 MW	120
Koup 1	635,970	6,364,135	GW165-6.0 MW	120
Koup 1	640,566	6,363,837	GW165-6.0 MW	120
Koup 1	634,917	6,363,768	GW165-6.0 MW	120
Koup 1	639,126	6,363,670	GW165-6.0 MW	120
Koup 1	635,606	6,363,694	GW165-6.0 MW	120
Koup 1	639,693	6,363,348	GW165-6.0 MW	120
Koup 1	641,083	6,363,275	GW165-6.0 MW	120
Koup 1	633,409	6,363,204	GW165-6.0 MW	120
Koup 1	640,443	6,363,145	GW165-6.0 MW	120
Koup 1	637,875	6,362,913	GW165-6.0 MW	120
Koup 1	640,943	6,362,642	GW165-6.0 MW	120
Koup 1	633,436	6,362,662	GW165-6.0 MW	120
Koup 1	635,344	6,362,591	GW165-6.0 MW	120
Koup 1	637,161	6,362,589	GW165-6.0 MW	120

Wind farm	Coordinates [m] WGS84, UTM zone 34S		Wind turbine model	Hub height [m]
Koup 1	638,164	6,362,490	GW165-6.0 MW	120
Koup 1	642,389	6,362,352	GW165-6.0 MW	120
Koup 1	631,816	6,362,311	GW165-6.0 MW	120
Koup 1	634,316	6,362,211	GW165-6.0 MW	120
Koup 1	632,715	6,362,286	GW165-6.0 MW	120
Koup 1	640,847	6,362,053	GW165-6.0 MW	120
Koup 1	641,651	6,362,119	GW165-6.0 MW	120
Koup 1	642,473	6,361,915	GW165-6.0 MW	120
Koup 1	637,687	6,362,473	GW165-6.0 MW	120
Koup 1	635,966	6,361,872	GW165-6.0 MW	120
Koup 2	630,939	6,362,398	GW165-6.0 MW	120
Koup 2	631,052	6,362,873	GW165-6.0 MW	120
Koup 2	629,512	6,363,194	GW165-6.0 MW	120
Koup 2	631,865	6,363,011	GW165-6.0 MW	120
Koup 2	629,114	6,363,393	GW165-6.0 MW	120
Koup 2	631,147	6,363,342	GW165-6.0 MW	120
Koup 2	630,209	6,363,343	GW165-6.0 MW	120
Koup 2	631,831	6,363,628	GW165-6.0 MW	120
Koup 2	628,954	6,363,777	GW165-6.0 MW	120
Koup 2	631,127	6,363,800	GW165-6.0 MW	120
Koup 2	630,343	6,364,030	GW165-6.0 MW	120
Koup 2	631,196	6,364,302	GW165-6.0 MW	120
Koup 2	629,957	6,362,973	GW165-6.0 MW	120
Koup 2	630,424	6,364,643	GW165-6.0 MW	120
Koup 2	628,821	6,364,779	GW165-6.0 MW	120
Koup 2	631,315	6,364,751	GW165-6.0 MW	120
Koup 2	630,181	6,365,151	GW165-6.0 MW	120
Koup 2	630,649	6,365,190	GW165-6.0 MW	120
Koup 2	628,870	6,365,679	GW165-6.0 MW	120
Koup 2	629,199	6,365,971	GW165-6.0 MW	120
Koup 2	630,883	6,365,757	GW165-6.0 MW	120
Koup 2	631,013	6,364,985	GW165-6.0 MW	120
Koup 2	628,703	6,366,161	GW165-6.0 MW	120
Koup 2	629,283	6,366,376	GW165-6.0 MW	120
Koup 2	631,107	6,366,083	GW165-6.0 MW	120
Koup 2	629,283	6,366,769	GW165-6.0 MW	120
Koup 2	629,217	6,367,132	GW165-6.0 MW	120
Koup 2	630,792	6,366,357	GW165-6.0 MW	120
Koup 2	629,015	6,367,440	GW165-6.0 MW	120
Koup 2	628,545	6,367,308	GW165-6.0 MW	120
Koup 2	628,734	6,367,764	GW165-6.0 MW	120
Koup 2	628,044	6,367,908	GW165-6.0 MW	120
Carissa E	653,848	6,372,722	GW165-6.0 MW	120
Carissa E	658,766	6,370,675	GW165-6.0 MW	120
Carissa E	656,761	6,370,959	GW165-6.0 MW	120
Carissa E	653,654	6,364,924	GW165-6.0 MW	120
Carissa E	658,382	6,371,356	GW165-6.0 MW	120
Carissa E	659,347	6,366,660	GW165-6.0 MW	120
Carissa E	659,342	6,367,337	GW165-6.0 MW	120
Carissa E	659,419	6,368,029	GW165-6.0 MW	120
Carissa E	656,953	6,370,101	GW165-6.0 MW	120
Carissa E	655,076	6,370,547	GW165-6.0 MW	120
Carissa E	655,865	6,365,137	GW165-6.0 MW	120
Carissa E	655,222	6,371,777	GW165-6.0 MW	120
Carissa E	659,787	6,370,117	GW165-6.0 MW	120
Carissa E	655,385	6,373,176	GW165-6.0 MW	120
Carissa E	655,843	6,372,531	GW165-6.0 MW	120

Wind farm	Coordinates [m] WGS84, UTM zone 34S		Wind turbine model	Hub height [m]
Carissa E	657,456	6,368,353	GW165-6.0 MW	120
Carissa E	655,074	6,369,697	GW165-6.0 MW	120
Carissa E	659,247	6,368,785	GW165-6.0 MW	120
Carissa E	659,279	6,369,510	GW165-6.0 MW	120
Carissa E	657,563	6,366,242	GW165-6.0 MW	120
Carissa E	656,729	6,366,897	GW165-6.0 MW	120
Carissa E	655,916	6,365,861	GW165-6.0 MW	120
Carissa E	655,145	6,368,721	GW165-6.0 MW	120
Carissa E	653,518	6,371,307	GW165-6.0 MW	120
Carissa E	655,184	6,367,412	GW165-6.0 MW	120
Carissa E	657,260	6,367,618	GW165-6.0 MW	120
Carissa E	656,791	6,369,291	GW165-6.0 MW	120
Carissa E	653,894	6,364,196	GW165-6.0 MW	120
Carissa E	651,584	6,372,996	GW165-6.0 MW	120
Carissa E	651,196	6,370,363	GW165-6.0 MW	120
Carissa E	651,209	6,371,449	GW165-6.0 MW	120
Carissa E	651,215	6,372,292	GW165-6.0 MW	120
Carissa E	653,283	6,372,111	GW165-6.0 MW	120
Carissa E	653,369	6,373,420	GW165-6.0 MW	120
Carissa E	649,667	6,373,293	GW165-6.0 MW	120
Carissa E	650,824	6,373,893	GW165-6.0 MW	120
Carissa E	653,406	6,374,094	GW165-6.0 MW	120
Carissa E	653,295	6,369,949	GW165-6.0 MW	120
Carissa E	653,726	6,367,945	GW165-6.0 MW	120
Carissa E	653,919	6,366,874	GW165-6.0 MW	120
Carissa E	653,140	6,365,712	GW165-6.0 MW	120
Carissa E	649,535	6,368,909	GW165-6.0 MW	120
Carissa E	649,004	6,369,873	GW165-6.0 MW	120
Carissa E	648,468	6,370,554	GW165-6.0 MW	120
Carissa E	651,015	6,369,442	GW165-6.0 MW	120
Carissa E	648,792	6,372,104	GW165-6.0 MW	120
Carissa E	649,280	6,372,696	GW165-6.0 MW	120
Carissa E	649,835	6,365,577	GW165-6.0 MW	120
Carissa E	649,947	6,367,047	GW165-6.0 MW	120
Carissa E	650,485	6,367,828	GW165-6.0 MW	120
Carissa E	651,829	6,368,485	GW165-6.0 MW	120
Carissa E	648,651	6,371,443	GW165-6.0 MW	120
Carissa E	652,182	6,367,303	GW165-6.0 MW	120
Carissa E	652,073	6,366,446	GW165-6.0 MW	120
Carissa E	649,858	6,366,393	GW165-6.0 MW	120
Carissa E	653,246	6,369,114	GW165-6.0 MW	120
Carissa SW	639,908	6,371,300	GW165-6.0 MW	120
Carissa SW	639,316	6,371,984	GW165-6.0 MW	120
Carissa SW	640,312	6,370,631	GW165-6.0 MW	120
Carissa SW	638,988	6,375,224	GW165-6.0 MW	120
Carissa SW	638,213	6,372,606	GW165-6.0 MW	120
Carissa SW	637,850	6,371,570	GW165-6.0 MW	120
Carissa SW	636,743	6,371,055	GW165-6.0 MW	120
Carissa SW	638,345	6,370,526	GW165-6.0 MW	120
Carissa SW	636,676	6,372,129	GW165-6.0 MW	120
Carissa SW	636,427	6,372,891	GW165-6.0 MW	120
Carissa SW	638,295	6,373,433	GW165-6.0 MW	120
Carissa SW	636,241	6,373,901	GW165-6.0 MW	120
Carissa SW	636,717	6,375,052	GW165-6.0 MW	120
Carissa SW	637,767	6,369,465	GW165-6.0 MW	120
Carissa SW	638,766	6,365,908	GW165-6.0 MW	120
Carissa SW	635,918	6,365,716	GW165-6.0 MW	120

Wind farm	Coordinates [m] WGS84, UTM zone 34S		Wind turbine model	Hub height [m]
Carissa SW	635,507	6,369,198	GW165-6.0 MW	120
Carissa SW	635,425	6,367,354	GW165-6.0 MW	120
Carissa SW	633,211	6,370,147	GW165-6.0 MW	120
Carissa SW	633,452	6,369,492	GW165-6.0 MW	120
Carissa SW	634,691	6,368,214	GW165-6.0 MW	120
Carissa SW	635,181	6,369,874	GW165-6.0 MW	120
Carissa SW	635,768	6,366,416	GW165-6.0 MW	120
Carissa SW	639,137	6,368,794	GW165-6.0 MW	120
Carissa SW	638,934	6,367,296	GW165-6.0 MW	120
Carissa SW	638,748	6,366,623	GW165-6.0 MW	120
Carissa SW	637,139	6,366,961	GW165-6.0 MW	120
Carissa SW	636,672	6,367,846	GW165-6.0 MW	120
Carissa SW	636,877	6,368,670	GW165-6.0 MW	120
Carissa SW	638,505	6,367,930	GW165-6.0 MW	120
Carissa SW	639,846	6,369,351	GW165-6.0 MW	120
Carissa SW	636,882	6,370,141	GW165-6.0 MW	120
Carissa SW	640,152	6,369,975	GW165-6.0 MW	120
Carissa NW	638,814	6,382,746	GW165-6.0 MW	120
Carissa NW	640,373	6,382,339	GW165-6.0 MW	120
Carissa NW	639,954	6,381,707	GW165-6.0 MW	120
Carissa NW	642,738	6,382,375	GW165-6.0 MW	120
Carissa NW	642,617	6,381,693	GW165-6.0 MW	120
Carissa NW	637,855	6,382,083	GW165-6.0 MW	120
Carissa NW	641,498	6,381,126	GW165-6.0 MW	120
Carissa NW	639,783	6,380,659	GW165-6.0 MW	120
Carissa NW	639,628	6,377,926	GW165-6.0 MW	120
Carissa NW	637,747	6,377,627	GW165-6.0 MW	120
Carissa NW	639,277	6,375,915	GW165-6.0 MW	120
Carissa NW	639,539	6,376,596	GW165-6.0 MW	120
Carissa NW	639,557	6,377,259	GW165-6.0 MW	120
Carissa NW	639,801	6,378,574	GW165-6.0 MW	120
Carissa NW	639,663	6,379,291	GW165-6.0 MW	120
Carissa NW	639,837	6,379,956	GW165-6.0 MW	120
Carissa NW	637,999	6,380,410	GW165-6.0 MW	120
Carissa NW	637,856	6,379,540	GW165-6.0 MW	120
Carissa NW	637,944	6,378,922	GW165-6.0 MW	120
Carissa NW	637,715	6,378,273	GW165-6.0 MW	120
Carissa NW	637,668	6,376,947	GW165-6.0 MW	120
Carissa NW	637,451	6,376,321	GW165-6.0 MW	120
Carissa NW	637,406	6,375,696	GW165-6.0 MW	120
Carissa NW	637,925	6,381,081	GW165-6.0 MW	120
Carissa NW	635,973	6,380,875	GW165-6.0 MW	120
Carissa NW	636,203	6,380,203	GW165-6.0 MW	120
Carissa NW	635,948	6,379,340	GW165-6.0 MW	120
Carissa NW	636,144	6,378,659	GW165-6.0 MW	120
Carissa NW	635,895	6,377,966	GW165-6.0 MW	120
Carissa NW	635,782	6,377,283	GW165-6.0 MW	120
Carissa NW	635,640	6,376,006	GW165-6.0 MW	120
Jessa M	637,366	6,397,681	GW182-6.2 MW	130
Jessa M	638,434	6,398,341	GW182-6.2 MW	130
Jessa M	639,028	6,398,705	GW182-6.2 MW	130
Jessa M	638,381	6,397,771	GW182-6.2 MW	130
Jessa M	637,958	6,397,200	GW182-6.2 MW	130
Jessa M	638,986	6,396,650	GW182-6.2 MW	130
Jessa M	638,976	6,397,145	GW182-6.2 MW	130
Jessa M	639,497	6,397,800	GW182-6.2 MW	130
Jessa M	640,206	6,398,817	GW182-6.2 MW	130

Wind farm	Coordinates [m] WGS84, UTM zone 34S		Wind turbine model	Hub height [m]
Jessa M	639,848	6,397,325	GW182-6.2 MW	130
Jessa M	639,809	6,396,804	GW182-6.2 MW	130
Jessa M	640,777	6,396,987	GW182-6.2 MW	130
Jessa M	640,556	6,397,591	GW182-6.2 MW	130
Jessa M	640,693	6,398,244	GW182-6.2 MW	130
Jessa M	641,773	6,397,170	GW182-6.2 MW	130
Jessa M	641,367	6,398,832	GW182-6.2 MW	130
Jessa M	642,459	6,398,464	GW182-6.2 MW	130
Jessa M	642,801	6,397,615	GW182-6.2 MW	130
Jessa M	643,083	6,398,081	GW182-6.2 MW	130
Jessa M	642,926	6,399,017	GW182-6.2 MW	130
Jessa M	643,635	6,398,587	GW182-6.2 MW	130
Jessa M	645,520	6,400,249	GW182-6.2 MW	130
Jessa M	645,487	6,399,284	GW182-6.2 MW	130
Jessa M	645,549	6,398,630	GW182-6.2 MW	130
Jessa M	645,604	6,398,116	GW182-6.2 MW	130
Jessa M	645,523	6,397,462	GW182-6.2 MW	130
Jessa M	646,319	6,397,746	GW182-6.2 MW	130
Jessa M	646,444	6,397,145	GW182-6.2 MW	130
Jessa M	646,468	6,396,546	GW182-6.2 MW	130
Jessa S	633,542	6,398,042	GW182-6.2 MW	130
Jessa S	633,349	6,398,693	GW182-6.2 MW	130
Jessa S	632,352	6,399,234	GW182-6.2 MW	130
Jessa S	632,238	6,399,744	GW182-6.2 MW	130
Jessa S	633,161	6,400,145	GW182-6.2 MW	130
Jessa S	633,056	6,399,665	GW182-6.2 MW	130
Jessa S	633,329	6,399,193	GW182-6.2 MW	130
Jessa S	634,250	6,399,132	GW182-6.2 MW	130
Jessa S	634,114	6,400,181	GW182-6.2 MW	130
Jessa S	634,466	6,399,704	GW182-6.2 MW	130
Jessa S	633,521	6,400,588	GW182-6.2 MW	130
Jessa S	633,590	6,401,075	GW182-6.2 MW	130
Jessa S	633,409	6,401,548	GW182-6.2 MW	130
Jessa S	633,454	6,402,048	GW182-6.2 MW	130
Jessa S	634,550	6,401,336	GW182-6.2 MW	130
Jessa S	634,950	6,401,936	GW182-6.2 MW	130
Jessa S	635,350	6,401,136	GW182-6.2 MW	130
Jessa S	635,094	6,400,539	GW182-6.2 MW	130
Jessa S	635,358	6,399,240	GW182-6.2 MW	130
Jessa S	636,322	6,398,477	GW182-6.2 MW	130
Jessa S	636,150	6,399,036	GW182-6.2 MW	130
Jessa S	636,050	6,400,236	GW182-6.2 MW	130
Jessa S	636,250	6,401,136	GW182-6.2 MW	130
Jessa S	637,450	6,400,736	GW182-6.2 MW	130
Jessa S	637,450	6,400,036	GW182-6.2 MW	130
Jessa S	637,672	6,398,969	GW182-6.2 MW	130
Jessa S	638,150	6,399,736	GW182-6.2 MW	130
Jessa S	638,350	6,400,236	GW182-6.2 MW	130
Jessa Z	638,273	6,406,349	GW182-6.2 MW	130
Jessa Z	637,769	6,405,810	GW182-6.2 MW	130
Jessa Z	637,330	6,405,355	GW182-6.2 MW	130
Jessa Z	636,992	6,404,799	GW182-6.2 MW	130
Jessa Z	636,936	6,404,235	GW182-6.2 MW	130
Jessa Z	637,125	6,402,691	GW182-6.2 MW	130
Jessa Z	637,129	6,402,150	GW182-6.2 MW	130
Jessa Z	636,942	6,403,483	GW182-6.2 MW	130
Jessa Z	637,834	6,403,126	GW182-6.2 MW	130

Wind farm	Coordinates [m] WGS84, UTM zone 34S		Wind turbine model	Hub height [m]
Jessa Z	637,890	6,404,312	GW182-6.2 MW	130
Jessa Z	638,272	6,404,996	GW182-6.2 MW	130
Jessa Z	638,811	6,405,377	GW182-6.2 MW	130
Jessa Z	638,937	6,405,892	GW182-6.2 MW	130
Jessa Z	639,660	6,404,377	GW182-6.2 MW	130
Jessa Z	638,929	6,403,903	GW182-6.2 MW	130
Jessa Z	638,669	6,403,277	GW182-6.2 MW	130
Jessa Z	638,485	6,402,738	GW182-6.2 MW	130
Jessa Z	638,283	6,402,254	GW182-6.2 MW	130
Jessa Z	638,616	6,401,701	GW182-6.2 MW	130
Jessa Z	639,488	6,402,953	GW182-6.2 MW	130
Jessa Z	639,369	6,402,352	GW182-6.2 MW	130
Jessa Z	639,908	6,403,862	GW182-6.2 MW	130
Jessa Z	640,296	6,402,810	GW182-6.2 MW	130
Jessa Z	640,778	6,402,364	GW182-6.2 MW	130
Jessa Z	639,867	6,401,644	GW182-6.2 MW	130
Jessa Z	639,360	6,401,123	GW182-6.2 MW	130
Jessa Z	639,507	6,400,523	GW182-6.2 MW	130
Jessa Z	640,647	6,401,104	GW182-6.2 MW	130
Jessa Z	641,762	6,401,333	GW182-6.2 MW	130
Jessa Z	640,659	6,400,381	GW182-6.2 MW	130
Jessa Z	641,508	6,400,610	GW182-6.2 MW	130
Jessa Z	641,155	6,399,752	GW182-6.2 MW	130
Jessa Z	642,653	6,400,970	GW182-6.2 MW	130
Jessa Z	642,435	6,399,910	GW182-6.2 MW	130
Jessa Z	643,498	6,400,214	GW182-6.2 MW	130

APPENDIX B – KEY STAFF CURRICULUM VITAE

B-1 Curriculum Vitae

<table>
<tr><td colspan="3">Position: Senior Engineer</td></tr>
<tr><td rowspan="2">Personal information</td><td>Name: Johan Basson</td><td>Date of birth: 20/03/1988</td></tr>
<tr><td colspan="2">Education/ Professional qualifications
Master of Science in Mechanical Engineering, Stellenbosch University, 2014
Bachelor of Mechanical Engineering, Stellenbosch University, 2010</td></tr>
<tr><td rowspan="2">Employment History</td><td colspan="2">Employer, dates of employment, position held, responsibilities relevant to the role:

DNV
May 2016 - present
Position: Project Development Engineer
Description: Responsible for wind resource and energy assessments, wind farm layout design, initial feasibility assessments and the design of monitoring campaigns for projects.

Unique Hydra
April 2014 - April 2016
Position: Junior Pressure Vessel Design Engineer
Description: Performed the engineering design for PVHOs (Pressure Vessels for Human Occupancy) used in the commercial diving industry. Unique Hydra is a diving equipment manufacturer.</td></tr>
<tr><td colspan="2">Total years of relevant experience (current and previous employers): 7</td></tr>
<tr><td rowspan="6">Present employment</td><td colspan="2">Name of employer: DNV</td></tr>
<tr><td colspan="2">Address of employer
DNV South Africa (Pty) Ltd Renewables Advisory
17th floor, Portside Building, 4 Bree Street, Cape Town,
8100, South Africa
Tel: +27 21 418 1891</td></tr>
<tr><td>Job title: Senior Engineer</td><td>Years with present employer: 7</td></tr>
<tr><td colspan="2">Dates of employment, position held,
responsibilities relevant to the role described in clause 2.6.2.2.5 of Part B (Functional and Qualification Criteria Requirements)

DNV
May 2016 - present
Position: Project Development Engineer
Description: Responsible for wind resource and energy assessments, wind farm layout design, initial feasibility assessments and the design of monitoring campaigns for projects.</td></tr>
<tr><td>Telephone +27 21 418 1891</td><td>Contact (manager / personnel officer)
Frederico Tilman</td></tr>
<tr><td>Fax</td><td>E-mail johan.basson@dnv.com</td></tr>
</table>

B-2 Specialist declaration

B-2.1 Specialist information

Specialist Company Name:	DNV South Africa (Pty) Ltd.			
B-BBEE	Contribution level (indicate 1 to 8 or non-compliant)	N/A	Percentage Procurement recognition	N/A
Specialist name:	Johan Basson			
Specialist Qualifications:	BEng in Mechanical Engineering, MscEng in Mechanical Engineering			
Professional affiliation/registration:	N/A			
Physical address:	17th Floor, Portside Unit 1706, 4 Bree Street, Cape Town. 8001, South Africa			
Postal address:	17th Floor, Portside Unit 1706, 4 Bree Street, Cape Town., South Africa			
Postal code:	8001	Cell:		
Telephone:	+27 21 418 1890	Fax:		
E-mail:	Johan.Basson@dnv.com			

B-2.2 Declaration by the specialist

I, Johan Basson_______________, declare that –

- I act as the independent specialist in this application;
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist report relevant to this application, including knowledge of the Act, Regulations and any guidelines that have relevance to the proposed activity;
- I will comply with the Act, Regulations and all other applicable legislation;
- I have no, and will not engage in, conflicting interests in the undertaking of the activity;
- I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the application by the competent authority; and - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority;
- all the particulars furnished by me in this form are true and correct; and
- I realise that a false declaration is an offence in terms of regulation 48 and is punishable in terms of section 24F of the Act.

Signature of the Specialist

DNV South Africa (Pty) Ltd.

Name of Company:

28-08-2023

Date

APPENDIX C - ANALYSIS METHODOLOGY

This chapter details the analysis methodology for a generic project. It is noted that some of the steps outlined may not have been employed in the analysis for the Project.

C-1 Wind data analysis process overview

The analysis of the wind data involves several steps, which are summarized below:

- The raw wind speed data from the site is processed and evaluated to identify periods with missing or erroneous data due to instrument failures, icing, or other factors.
- Missing or additional wind speed and direction data at the primary anemometer and wind vane at each site mast are reconstructed from data recorded at the same mast where available, or from others on-site masts, to create a full record for the site period (site period wind speed and direction).
- The on-site measurements are correlated with the reference stations, and the results evaluated, to develop an estimate of reference period wind speeds at measurement height.
- Uncertainties in the site period wind speeds and reference period wind speeds, as well as the relationships between the two are analyzed to access what wind speeds estimate the long-term wind speeds with the lowest bias and uncertainty.
- The measurement height estimate of long-term wind speeds is extrapolated to hub height using power law wind shear exponent and associated uncertainties assessed.
- Long-term hub height wind speed and direction frequency distribution estimates at each measurement location are derived using the most appropriate method based on data that have been measured, reconstructed or adjusted to the mast long-term wind speed.
- The wind regime at the proposed turbine locations is accessed using wind flow models and DNV experience and judgment.
- The uncertainties in the resulting hub-height wind speeds and frequency distribution at the turbine locations are assessed.

C-1.1 Met mast data processing and validation

Meteorological data should be provided in a raw form, preferably encrypted. Sufficient documentation should be provided to ensure the data integrity.

Meteorological data are subject to a quality checking procedure by DNV to identify records which were affected by equipment malfunction, icing, and other anomalies. These records are considered invalid and excluded from the analysis.

C-1.1.1 Calibration procedures

When calibration certificates from a Measnet-accredited facility have been supplied, DNV applies these in converting the raw data into wind speeds. For those anemometers where calibration data are not provided, DNV applies a model specific calibration.

The Otech Engineering and Svend Ole Hansen calibration facilities in Vermont, USA, prior to 1st May 2015 were not part of the MEASNET network, and DNV considers that these were not appropriate for energy production analyses. The Svend Ole Hansen calibration facilities in Copenhagen, Denmark, belong the MEASNET network.

In these cases, DNV retrospectively applies the individual anemometer calibrations and adjusts the measured wind speeds using the proposed correction factors.

C-1.1.2 Issues observed in specific sensors

All data from NRG #40 anemometers are evaluated for evidence of a problem described in a technical note from NRG issued in Spring 2008 [C-1]. In this technical note, NRG described the problem, which manifests itself as intermittent under speeding or dragging. After investigation, NRG concluded that the degrading and under speeding was due to a phenomenon known as "dry friction whip". All anemometers manufactured by NRG after 1 January 2009 featured modifications aimed at reducing or eliminating the occurrence of this behavior. The conclusions of NRG's investigation and the subsequent design changes are discussed in more detail in [C-2], presented by NRG at the AWEA annual conference in early May 2009. DNV typically examines potentially effected wind data to identify and remove periods of data affected by this issue. Any periods which are clearly affected are removed from the analysis and the additional uncertainty in the wind speeds is been included in this analysis.

Incorrectly calibrated reference temperature sensors were identified at the wind tunnel providing calibration services for the #40C anemometer. Raw temperature data collected by the miscalibrated probes resulted in incorrect anemometer calibration reports. This applies to calibration certificates issued for #40C anemometers calibrated from 24 January 2013 through 1 August 2013.

There is evidence that the behavior of on-site Thies Classic anemometers is different from that observed in the wind tunnel [C-4]. Studies show that Thies Classic anemometers record higher wind speeds than other anemometers widely used in wind measurement campaigns, and it was therefore considered appropriate to apply a 2% reduction on wind speed data recorded by Thies Classic anemometers. It is recommended that parallel wind measurements are performed using a suitable anemometer that is calibrated and mounted according to IEC criteria [C-5], in order to quantify this effect.

C-1.1.3 Agreement with the IEC 61400-12:2005 standard

An analysis of the porosity of each mast is made, and the corresponding drag coefficient value (Ct) for each mast is presented in Appendix D. Based on the recommendations of IEC [C-5] for a lattice mast, the anemometer booms must be tubular and be oriented perpendicularly to the prevailing wind direction. The Ct value is used to determine the length of the horizontal booms supporting the anemometer, in proportion to the width of the equilateral triangle that defines the cross section of the tower, so that the speed deficit is below 0.5 %. For the vertical distance between the anemometer cups and horizontal booms, it is recommended that this is equivalent to at least 15 times the diameter of the booms. It is also recommended that the vertical boom does not have a slope greater than 5 degrees, and that each sensor is be installed on separate booms with a vertical separation of at least two meters.

To minimize mast effects in the measured wind speed data, the data recorded at levels with redundant instruments are “selectively averaged”. In direct sectors where an anemometer is affected by the wake of the mast, the unaffected anemometer is selected; in direction sectors where both anemometers are valid, the measurements are averaged.

C-1.2 Remote sensing data processing and validation

In order to evaluate the quality of a remote sensing device, several parameters may be reviewed. These include:

- Carrier-to-noise ratio (CNR)
- Signal-to-noise ratio (SNR)
- Wiper count
- Availability
- Amplitude signal
- Signal level
- Noise
- Echo suppression
- Valid count or recovery rate
- Standard deviation

- Turbulence intensity
- Beam component wind speed

Of these the CNR or SNR provides vital information about the quality of the beam propagation. The CNR or SNR generally decreases with height. If a significant number of points derivate from this, it can indicate signal noise contamination.

The first order quality control is generally an automatic procedure that is carried out by the manufacturer's online software program. Data are then filtered with in-house software using following data quality tests:

- Data with poor reliability, quality, or availability are removed;
- Horizontal wind speed (0 to 60 m/s) and direction validation (0 to 360°);
- Vertical wind speed validation (between -2 and 2 m/s); and
- Horizontal and vertical standard deviation validation (<5 m/s).

Following automated data processing, all remote sensing datasets are checked manually to ensure that the results are sensible. This included an assessment of the consistency between measurement heights and consistency relative to the associated met mast anemometry, if possible.

C-1.3 Data correlation and prediction

The period of data available at the site masts can be extended through establishing relationships between two data sets, using correlations, and using these relationships to reconstruct the missing data at the site. In the correlation step, concurrent wind data from a "target" sensor and a "reference" sensor are compared. The reference sensor may be on the same mast or at a different measurement location. The reference sensor is chosen to be one for which wind records are available for the period being reconstructed. The concurrent measured wind data are then used to establish the correlation between the winds at the two locations. This correlation is then used to reconstruct data at the "target" location from the "reference" location.

The following methods are used to complete gaps or extend the period of record available at a mast.

C-1.4 Ten-minute or hourly reconstruction method

In the correlation of 10-minute or hourly data, the concurrent data are correlated by comparing wind speeds at the two locations for each of twelve 30° direction sectors, based on the wind direction recorded at the "reference" location. This correlation involves two steps:

- Wind directions recorded at the two locations are compared to determine whether there are any local features influencing the directional results. Only those records with speeds in excess of 5 m/s at both locations are used.
- Wind speed relationships are determined for each of the direction sectors using a principal component analysis (PCA) forcing the adjustment through the origin. For correlations with substantial scatter, large offsets and/or poor coverage across wind speed bins, not forcing may provide a more reliable result.

In order to minimize the influence of localized winds on the wind speed relationship, the data are screened to reject records where the speed recorded at the "reference" location falls below 3 m/s or an equivalent level at the "target" location. The directionally averaged wind speed relationship is used to adjust the 3 m/s wind speed level for the "reference" location to obtain this equivalent level for the "target" location, to ensure unbiased exclusion of data. The wind speed at which this level is set is a balance between excluding low winds from the analysis and still having sufficient data for the analysis. The level used excludes only winds below the cut-in wind speed of a wind turbine which do not contribute to the energy production.

The result of the analysis described above is series of wind speed relationships, each corresponding to one of twelve direction sectors. These relationships are used to factor the wind data measured at the “reference” mast location, thereby obtaining reconstructed wind data for the period of missing data at the “target” mast location.

To retain as much measured data as possible, the reconstructed wind data are only used to fill in gaps in the measured data series.

C-1.5 Correlation check

To check the quality of a correlation between the reference and target, the concurrent measured and reconstructed wind data at the target are compared. If the energy content of the reconstructed time series is similar to the energy content of the measured time series, the data are considered well correlated. In case the two are not similar, the correlation is reconsidered and alternative options are investigated.

C-1.6 Daily reconstruction method

In the correlation of daily wind speeds, only wind speed data are correlated, and not the wind direction data. For this reason, this method is used to estimate the long-term wind speeds but not the frequency distributions. The concurrent daily mean wind speeds are compared in one of two ways:

- If there is a seasonal trend between the target and reference, the daily correlation can be divided into 12 separate correlations, based on the calendar month. In this “Daily-by-Month” method, 12 separate correlations are established.
- If there is no seasonal trend, or less than a year of concurrent data, a single “all-data” daily correlation is derived.

The result of the analysis described above is either a single correlation slope and offset or a set of twelve correlation slope and offset values, each corresponding to one of twelve calendar months. These slope and offset values are applied to the wind data measured at the “reference” mast location, thereby obtaining reconstructed daily wind data for the period of missing data at the “target” mast location.

The long-term mean wind speed at the location of the site masts are derived using measured data and reconstructed data. The frequency distribution is derived from the measured and reconstructed data for the on-site period and adjusted to the long-term wind speed.

C-1.7 Monthly reconstruction method

In the correlation of monthly wind speeds, only wind speed data are correlated, and not the wind direction data. For this reason, this method is used to estimate the long-term wind speeds but not the frequency distributions. The concurrent monthly mean wind speeds are compared, in order to establish a single correlation slope and offset. These slope and offset values are applied to the wind data measured at the “reference” mast location, thereby obtaining reconstructed monthly wind data for the period of missing data at the “target” mast location.

The long-term mean wind speed at the location of the site masts is derived using measured data and reconstructed data. The frequency distribution is derived from the measured and reconstructed data for the on-site period and adjusted to the long-term wind speed.

C-1.8 Wind speed and frequency distribution deseasoning method

In order to avoid the introduction of seasonal bias into estimates of the annual mean wind speed, as well as wind speed and direction distributions from seasonally uneven data coverage, the following procedure is followed:

- The mean wind speed or distribution for each month is determined from the average of all valid data recorded in that month, over the period. This is taken as the monthly mean, thereby assuming that the valid data are representative of any missing data.

- The mean of the monthly means (weighted by the number of days in a month) is taken, in order to determine the annual mean ("mean of means").

C-1.9 Impact of trees

Where obstacles to the flow, such as trees in proximity to a mast or turbine, are present, it is necessary to consider these trees as not only roughness elements, but also as obstacles, in the wind flow model. In this regard, the following methodology has therefore been adopted, for both evergreen and deciduous trees, as well as palm trees:

1. Areas of forestry and land cover have been analyzed to establish both the location and height of trees. It is considered that areas of representative forest height greater than 5 m vertically displace wind flow to the same extent. For areas of representative forest height below 5 m, it is considered that the displacement of the flow is reduced, and in these cases the presence of this forest is considered through profiling of the project area roughness.

2. For the mast and turbine locations, an effective reduction in the hub height has been estimated to account for the influence of trees as an obstacle to the wind flow. The selection of these heights is based on the effective flow displacement height of the trees, the proximity of the mast or turbine to the trees, and the frequency of occurrence of the relevant wind directions. The following relationship is used to find the effective flow displacement height for each direction sector at each mast and turbine location:

$$d = d_{tree} - D/50 \qquad \text{C-1.9}$$

where d is the effective flow displacement height;

d_{tree} is the flow displacement height of the surrounding trees; and

D is horizontal distance from surrounding trees.

3. By weighting each sector's effective flow displacement height by the frequency of winds in each sector, a weighted displacement height is calculated for each individual site mast and turbine.

4. The current forest cover found at the site with a 50 m turbine site clearing is assumed in the analysis.

C-1 Hub-height wind speed and direction distributions

C-1.10 Shear power law

The boundary layer power law shear exponents at the site masts are derived from the available measurements. The power law relates the ratio of measured wind speeds, U_1/U_2, to the ratio of the measurement heights, z_1/z_2, using the wind shear exponent, α, as follows:

$$\frac{\overline{U}(z_1)}{\overline{U}(z_2)} = \left(\frac{z_1 - d}{z_2 - d}\right)^{\alpha} \qquad \text{C-1.10}$$

where α is power law wind shear exponent,
$\overline{U}$ is the mean wind speed,
Z is the height above ground level, and
d is the effective flow displacement height, if any.

The boundary-layer power law shear exponent was derived for each mast location using the ratios of measured concurrent wind speed data recorded at multiple measurement heights, following the exclusion of wind speed data below 3 m/s.

C-1.11 Time series shear method

The boundary-layer power law shear exponent is derived between two measurement heights for each ten-minute, or hourly, time step. A time series of wind speed at the target hub-height is calculated by extrapolating the upper measurement height using the instantaneous boundary-layer power law shear exponent. These exponents are then used to extrapolate the measured data recorded in the main sensors to the rotor hub-height. For cases where instantaneous shear exponent values are not available, generic values are used for the date and time of record. The Mean of Monthly Means procedure is used to avoid the introduction of bias into the annual mean wind regime prediction from seasonally-uneven data coverage at each mast as discussed in Appendix C-1.8, thereby resulting in the measured frequency distribution at hub-height.

C-1.12 Directional shear method

The relationship between two, or more, heights on a mast is established for each of twelve 30° direction sectors, using the technique described in Appendix C-1.7. These relationships are used to derive the boundary-layer power law shear exponent in each of the twelve direction sectors, which are then used to extrapolate data recorded at the upper measurement height to the target hub-height, on a directional basis.

The annual average wind speed frequency and direction distributions at measurement height are determined from the site period wind speed data using the mean of monthly means approach described in Appendix C-1.8. The resulting distributions are then scaled to the predicted long-term hub height wind speed(s). This method is employed when data recorded is affected by shadow of the measurement mast.

C-1.13 Annual shear method

The relationship between two, or more, heights on a mast is established using the concurrent mean of monthly means technique described in Appendix C-1.8. These relationships are used to derive the boundary-layer power law shear exponent, which is then used to extrapolate data recorded at the upper measurement height to the target hub-height.

C-2 Wind flow modelling

Project wind speed is typically modelled using either the WAsP model or a CFD model, as described in the following sections. Other models may be applied in cases where significant errors are either already apparent or expected from these models. These models may be exposure-based models, experience-based models or other models that DNV expects will reduce uncertainty or bias in the results. The primary output from the models is a set of wind speed ratios between the initiating masts and other masts (or turbine locations) for each of twelve 30° direction sectors. For any given pair of masts, a prediction error is determined for each direction sector, then a root-mean-square (RMS) of the twelve prediction errors is performed, weighted by the directional frequency distribution, in order to calculate an overall directional speed-up error.

C-2.1 WAsP approach

In order to calculate the variation of mean wind speed over the site, the computer wind flow model, WAsP 10.2 is used. Details of the model and its validation are given by Troen e Petersen [C-7].

The inputs to the model are maps of the topography and surface roughness length of the site terrain and surrounding area. A digital map of an area extending at least 10 km from the site, in all directions, is normally used, and the inputs for this project are listed in Section 2 of the main body of the report. Although the domain size is much larger than the area of the site itself, such an area is necessary, since the flow at any point is dictated by the terrain several kilometers upwind.

Wind flow is affected by the roughness of the ground. The surface roughness length of the site and surrounding area has been estimated, as detailed in Section 2 of the main body of the report, following the Davenport classification [C-8].

The wind flow calculations are carried out for 30 degree steps in wind direction corresponding to the measured wind rose and results were produced as speed-up factors relative to the mast location for a grid encompassing the site area.

To determine the long-term mean wind speed at any location, the speed-up factor for each wind direction is weighted with the measured probability previously derived for the mast location. All directions are then summed to obtain the long-term mean wind speed at the required location.

C-2.1.1 Forestry representation within the WAsP approach

When there are areas of forestry on the proposed wind farm site, it is necessary to consider the effect of these obstacles on the wind flow model [C-6]. DNV has developed and validated a forestry modeling approach to be used when modeling the wind flow using WAsP [C-9].

For forestry a flow displacement of equal height is assumed for trees over 5 m in height. Forestry less than 5 m in height is assumed to not cause a flow displacement and is modeled as a terrain roughness only.

For each mast and turbine location, an effective reduction in the measurement or hub height is estimated to account for the influence of trees as an obstacle to the wind flow. The selection of these heights is based on the displacement height of the trees, the proximity of the mast or turbine to the trees and the frequency of occurrence of the relevant wind directions.

Where appropriate, an indicative energy loss factor profile is derived to account for the changes in forestry over the period of operation of the wind farm that is being evaluated due to expected tree growth or felling. This profile does not include the effect of future variability in wind conditions considered. However, the wind variability is considered in the uncertainty analysis.

C-2.2 DNV freestream CFD modelling

The DNV CFD methodology produces simulations of the Atmospheric Boundary Layer (ABL) for wind power applications; it is based around STAR-CCM+, a commercial computational fluid dynamics (CFD) software package. The CFD software solves the time averaged equations of mass and momentum conservation. An energy conservation equation is also solved when modeling atmospheric stability. The DNV CFD methodology has been validated for a number of academic cases and well over 100 real wind farm sites [C-7]. These studies show that on average the DNV CFD method offers substantially improved wind speed predictions as compared with WAsP.

The CFD approach requires significantly more computational resource than a classical WAsP analysis, as the calculations are significantly more complex. A flow domain is created and defined by a set of boundary conditions which control the air flows in and out of the domain. A 3D mesh is created within the domain and the conservation and turbulence equations are solved at each discrete point on the mesh. Due to this construction, the model is subject to discretization errors and can only evaluate wind from a single direction at a time. Hence, a separate simulation is undertaken for a number of directions, typically in intervals of 6 to 25 degrees, depending on the direction and direction frequency at the site. The results are averaged to derive 30-degree direction sector speed-ups from the masts to the turbine locations. These speed-ups are then combined with the measurement-based wind resource at each mast to predict the wind resource at each turbine location.

The turbine and mast locations are at least 10 km away from the edge of the computational domain for each calculation. The horizontal spacing of the mesh near points of interest is 12.5 to 50 m, depending upon the complexity of the local terrain. Mesh independence studies have shown that such tight mesh spacing is necessary to resolve flows at microscale.

For sites where atmospheric stability significantly affects wind speeds, DNV employs a stability-enabled CFD analysis. The spatial variation of wind speed over topography is often very different during stable atmospheric conditions as compared to unstable conditions. Traditional wind flow models that assume a neutral atmosphere can provide reasonable predictions of unstable and near-neutral flows, but the predictions of stably stratified flows are comparatively poor. Thus, the stability-enabled CFD analysis, includes two sets of CFD calculations: a neutral CFD analysis to represent unstable and near-neutral flows and a stable CFD analysis, which directly models buoyancy effects, to represent stable flows. The results from the two sets of calculations are combined to produce an overall wind flow model for the site. Extensive validation has demonstrated that the stability-enabled CFD analysis provides significantly improved wind speed predictions at sites where stability effects are important [C-8].

C-2.2.1 Forestry representation within the DNV freestream CFD approach

Where appropriate, the CFD model used by DNV includes a canopy model designed to reproduce within the Reynolds-averaged Navier-Stokes (RANS) simulations the turbulence generation and aerodynamic drag associated with forestry and can therefore model the resulting flow perturbation [C-11]. Canopy model source terms are added to the governing equations within the volume occupied by the forestry, i.e. between ground level and the approximate height of the canopy, as described in [C-12] and [C-13]. Inputs to the canopy model include tree height, coefficient of drag, and foliage density of the forestry. At the current stage, flow modeling in forestry is a topic of active research in the wind energy industry and the presence of site forestry increases the level of uncertainty compared to flow modeling on sites with less significant vegetation.

C-2.3 Vortex FARM© approach

Where appropriate, the Vortex FARM© wind speed map was used to predict the variation in wind speed over the site. This is a validated mesoscale model based on the WRF model, developed at NCAR. The input source of raw reanalysis data is the ERA-5 dataset. The output map is obtained through mesoscale wind flow modelling for the Project area with a maximum size of 500 km2. Topography data comes from the Shuttle Radar Topography Mission (SRTM) and land cover data is obtained from the ESA Global Land cover product.

C-3 Gross energy output

The gross energy production is the energy production of the wind farm obtained by calculating the predicted free stream hub height wind speed distribution at each turbine location and the manufacturer-supplied turbine power curve. In defining the gross energy output, it is assumed that there are no wake interactions between the turbines and no energy loss factors are applied. This calculation undertaken within the WindFarmer computational model [C-14], [C-15] includes adjustments to the power curve to account for differences between the predicted long-term annual turbine location air density and the air density to which the power curve is referenced.

C-4 Losses and net energy output

Net energy output is estimated by deducting expected losses from the gross energy output estimated. DNV uses a standard detailed set of six energy loss factors which aims to ensure that all potential sources of energy loss are considered by the relevant parties. For some projects certain loss factors will not be relevant in which case an efficiency of 100% is assumed. Additionally, some losses may only be sensibly estimated when comprehensive information is available from a project and review of such documentation is within the scope of DNV's work. To add clarity for the reader around the level of detail considered, DNV has three categories of loss estimates used in Energy Assessments. These are:

- DNV Standard: These are values that DNV has estimated are appropriate for typical projects in the region of the world in which a project is located. There may be regional difference in this estimate.
- Project Specific: These are values for which DNV has made a project specific estimate based on data supplied such as wind, terrain or wind turbine technology data. The basis of this estimate is provided in the body of the report.
- Not Considered: These are values for which making estimate has either not been included in the Scope of Work DNV has been authorized to complete or relevant information was not provided by the Customer.

The loss factors used to estimate the derivation of the wind farm net energy output prediction are described below. For each loss factor a general description of the loss, its typical values, and associated uncertainties are given.

C-4.1 Turbine interaction modelling

Wind turbines extract kinetic energy from the wind and downstream there is a wake from the wind turbine where wind speed is reduced. As the flow proceeds downstream there is a spreading of the wake and the wake recovers towards free stream conditions. The wake effect is the aggregated influence on the energy production of the wind farm which results from the changes in wind speed caused by the impact of the turbines on each other.

When modelling the interaction of turbines within a wind farm, wake models used within the wind industry generally only consider the reduction of wind speeds downstream of a turbine. There is evidence however that turbine interaction also includes lateral as well as upstream effects, which together contribute to a resistance, or blockage, on the wind flow, deflecting some of the flow above and around the wind farm. Consequently, the first-row turbines may produce less than they each would operating in isolation.

C-4.1.1 WindFarmer approach

Where appropriate, these turbine interaction effects are calculated using the WindFarmer computational model. The eddy viscosity model within WindFarmer is employed using a site-specific definition of the turbulence intensity as an input, combined with a Large Wind Farm Wake Model developed by DNV [C-14], [C-15], [C-16].

When the inter turbine spacing is below a distance equivalent to two rotor diameters, the Closely Spaced Turbine wake model, which is also part of WindFarmer, may also be employed.

The WindFarmer approach to turbine interaction losses also considers the Blockage Effect Estimator Tool (BEET).

C-4.1.1.1 The Blockage Effect Estimator Tool (BEET)

An alternative to site-specific CFD simulations is the use of the BEET. From a set of basic inputs, the BEET tool outputs a correction factor formulated to offset blockage-related bias in wakes-only models. This fast-running model has been trained on output from CFD results from a range of generic wind farms simulated on flat terrain. Comparisons between the BEET model and CFD results at a number of real wind farms indicate that it is capability of providing a reasonable estimate of what a site-specific CFD analysis would predict in many situations. However, there are some situations where there is elevated risk that the BEET output will depart from that of DNV CFD analysis:

- It does not consider wind direction in the analysis. The impact of blockage is generally less sensitive to direction than wakes, but it is not insensitive to direction. The uncertainty of BEET predictions is, thereby, likely to be higher at sites with unidirectional or bi-directional wind roses.
- The generic wind farm results behind the BEET predictions correspond to flat sites and coherent, consistently spaced layouts. A limited number of checks indicate that the tool is nevertheless capable of providing reasonable estimates in complex terrain and/or irregular layouts, but we do not expect that to always be the case.
- Not set up to distinguish between multiple wind farms
- Limited in its ability to handle site-specific atmospheric stability conditions.
- The CFD results behind the BEET tool correspond to onshore-like meteorological conditions. We now have preliminary results suggesting that the blockage corrections could be larger at offshore sites, where the atmospheric boundary layer is in general thinner.

This list describes situations where the uncertainty of the BEET calculation is elevated relative to other situations. A site-specific CFD analysis can reduce uncertainty in such situations.

C-4.1.2 DNV CFD modeling of the turbines interaction effect

Where appropriate, the Project wind farms are simulated in a numerical environment using DNV's implementation of Siemens StarCCM+ CFD engine [C-17]. The three-dimensional simulation domain is based on DNVs tailored steady-state RANS model with k-ε turbulence closure, that has been successfully applied and validated for freestream atmospheric wind flow simulations at more than 200 wind farms around the world, as described by Corbett et al. [C-18][C-19].

The solver equations and the inflow boundary conditions are customized and enabled to simulate thermal effects within and above the atmospheric boundary layer. This customized model is described in detail by Bleeg et al. [C-20][C-21].

The top boundary condition of the domain is a slip wall set to a constant potential temperature. The inflow atmospheric boundary layer profiles of velocity, potential temperature, and turbulence quantities derived from a combination of similarity theories and precursor simulations [C-20].

The lower boundary of the domain is defined using a digital terrain model (DTM) and/or by publicly available data For the ground boundary condition, the model uses a standard wall function approach based on the classic law-of-the-wall. The standard wall functions were modified to account for aerodynamic surface roughness as defined in the ground coverage map.

The computational domain is covered with an unstructured mesh. The horizontal base mesh resolution varies from 2.5 m to 200 m, depending on the proximity to points of interest. Finer vertical mesh resolution within a progressive prism layer that spans from 0 meters up to 1800 meters above ground level (AGL) is also implemented in order to capture the thermal gradients within atmospheric boundary layer. Mesh independence studies were conducted to confirm mesh convergence.

The base CFD is then extended to simulate the presence and operation of wind turbines. To achieve that, actuator disks are used to represent the turbines within the CFD numerical domain, as described by Bleeg et al. [C-22].

These actuator disks consist of extra refined cubic mesh cells with edge lengths equal to 5% of the turbine rotor diameter (20 cells across the rotor diameter and 5 cells across the disk thickness). The axial and tangential body forces applied to the cells derive from power and thrust coefficient (C_t) curves provided for the analysis.

The sales power curves are functions of the freestream wind speed (U_∞) at each turbine location. More specifically, (U_{disk}). is equivalent to the horizontal wind speed component at hub height that would be observed without the presence of the given wind turbine. Unlike in most analytical wake models, (U_∞) cannot be readily determined within a continuous three-dimensional RANS wind farm simulation, especially because of the upstream influence of the turbine rotors. The performance curves (power, C_t and rotor speed) are thus converted to be a function of a different quantity: the average axial velocity over the rotor's swept area (U_{disk}). This quantity can be readily determined from within the RANS simulations and, in addition, better represents the influence of the local flow on power and thrust.

A subset of single-turbine CFD simulations is carried out to convert the performance curves to functions of (U_{disk}). for each turbine model. Each simulation corresponding to a different hub-height wind speed. In these simulations, the inlet U_∞. values are known, and actuator disk forces are thereby set according to curves specified as functions of U_∞. After each solution, the corresponding mean value of $U_{disk})$ is recorded. The outcome of this procedure is a set of curves (power, C_t, and rotor speed) specified as functions of $U_{disk})$.

The wind farm CFD simulations are then set up using these performance curves and actuator disks that are configured to precisely represent each turbine geometry. Three different sets of numerical simulation cases are calculated:

Case "a": All selected wind turbines are operating;

Case "b": Only one selected turbine is operating in isolation. Neighboring turbines are stationary.

Case "c": No wind turbines are operating. (this is equivalent to a freestream simulation);

The numerical simulation cases (“a,b,c”) are repeated considering a number different inlet wind directions at 5 degree intervals for a selection that encapsulates the most frequent wind direction sectors for the site. A constant inlet reference wind speed vertical profile is considered, which spans from 0m to 17000 m AGL.

Simulations in case “b” are repeated for different turbines operating in isolation until numerical convergence is achieved. This is measured by ensuring that numerical residuals were down to the order of 1e-3. The horizontal mean velocity component is also monitored at all turbine positions in order to ensure numerical convergence.

Finally, post processing procedures are carried out with all directional simulations in order to extract the following scalar results, shown in Table C-1.

Table C-1 Scalar variables extracted from numerical simulations

$U_{\infty-C_t}\left[\frac{m}{s}\right]$	$U_{\infty}\ interpolated\ from\ Ct\ performance\ curve\ as\ a\ function\ of\ U_{disk}.$
$U_{\infty-P}\left[\frac{m}{s}\right]$	$U_{\infty}\ interpolated\ from\ Power\ performance\ curve\ as\ a\ function\ of\ U_{disk}.$
Ct_{disk}	$C_t\ interpolated\ from\ performance\ curve\ as\ a\ function\ of\ U_{disk}.$
$Power\ [W]$	$Power\ interpolated\ from\ performance\ curve\ as\ a\ function\ of\ U_{disk}.$
$Rotor\ speed\ table\ \left[\frac{rad}{s}\right]$	$Rotor\ speed\ interpolated\ from\ performance\ curve\ as\ a\ function\ of\ U_{disk}.$
$Rotor\ speed\ VD\ \left[\frac{rad}{s}\right]$	$Rotor\ speed\ from\ virtual\ disk.$

a. Note: U_{∞} is the wind speed that would be used to look up the OEM power curve.

The extracted variables are then processed for all directional CFD simulations in order to calculate the aerodynamic loss factors for each wind farm. In this study aerodynamic effects refer to the combined effect of wind turbine wake and blockage (flow induction) zones.

These aerodynamic loss factors are estimated both in % wind speed, using the variable $'U_{\infty-P}'$, and also in % energy using the variable $'Power'$. These are only valid for the wind directions and inlet wind speeds that were considered for the CFD numerical simulations. Additional post processing steps were used to integrate these results over all possible wind speed and wind direction levels, thus extrapolating the aerodynamic loss factors to represent long-term conditions.

The software Wind Farmer: Analyst [13] (WFA) is then used to extrapolate CFD loss factors for the long-term wind resource conditions. In order to achieve that, the following steps are carried out:

Step 1: A wake loss table from the Wind Farmer results is created, where the wake loss is a function of wind speed (in increments of 0.5 m/s) and direction sector (30 degrees wide).

Step 2: The CFD results are taken to calculate an integrated average of the wakes-only loss and simulated wind speed over 12 sectors. The outputs are two vectors with 12 elements (each element corresponds to a wind direction sector). One vector is for average freestream wind speed. The other vector is for average wakes-only loss.

Step 3: The vectors are compared with the Wind Farmer table and come up with a new 12-element vector. This time the elements correspond to a scale factor. If the scale factor were to be multiplied for a given sector by the Wind Farmer wakes-only losses for that sector, the wakes-only loss for the sector interpolated at the average CFD-simulated freestream wind speed would match the sector-average CFD prediction.

Step 4: Those scale factors are applied to the Wind Farmer results so that the resulting table represents a CFD-predicted wakes-only loss table. The table matches CFD at the wind speeds where CFD was run and the variation in the loss with wind speed is based on the Wind Farmer predictions.

The CFD calculations are repeated for different inlet wind directions. The calculations are also repeated for a subset of cases where all turbines were operational (case “a”), where only one turbine operates in isolation (case “b”), and where all turbines are shut down (case “c”).

By subtracting the mean wind speed field calculated for cases “a” (wind farm operating) from the ones calculated for cases “c” (freestream), it is possible to isolate the effect of the wind turbines in the atmospheric wind flow. Wind turbine results are then grouped into individual wind farms.

In some instances, individual wind turbines can present an energy gain as output of wind farm CFD simulations, i.e., an interaction loss adjustment factor higher than 100%, indicating that some wind turbine positions are benefited with a more advantageous wind exposure when new neighboring wind turbines are simulated. It is important to highlight that such energy gains are usually very low and cause a marginal impact on overall results.

C-4.1.3 Turbine interaction effect internal

This is the effect that the wind turbines within the wind farm being considered have on each other.

C-4.1.4 Turbine interaction effect external

This is the effect that the wind turbines from neighboring wind farms (if any), assumed by DNV to be operational on the date of this assessment, have on the wind farm being considered. These are calculated in the same way as internal turbine interaction effects.

C-4.1.5 Future turbine interaction effect

This is the effect that the wind turbines from neighboring wind farms (if any), which are assumed by DNV not to be operational on the date of this assessment, but which may be built in the future, have on the wind farm being considered. The effect of these may be estimated and taken into account if sufficient information is available.

C-5 References

[C-1] NRG Systems, “NRG Technical support bulletin 008”, 22 May 2008

[C-2] Clark, S.H. et al., “Investigation of the NRG #40 Anemometer Slowdown”, Proceedings of the AWEA Conference, Chicago 2009.

[C-3] Svend Ole Hansen, “Wind tunnel calibration of cup anemometers – reduced uncertainties, Revision no.1”, April 2012.

[C-4] Axel Albers, “Open Field Cup Anemometry”, DEWI, 19 August 2001.

[C-5] IEC 61400-12-1, “Wind turbines - Part 12-1: Power performance Measurements of electricity producing wind turbines, Annex G”, 2005.

[C-6] Cook, N.J., “The Designer’s guide to wind loading of building structures: Part 1”, London: Butterworths, 1985.

[C-7] Troen, I., Petersen, E.L., “European Wind Atlas”, Risø National Laboratory, Denmark, 1989.

[C-8] ESDU, “Wind speed profiles over terrain with roughness changes”, Item No. 84011 Amendments A to D, ESDU International: London, 1993.

[C-9] Corbett, J.F., Landberg, , “Optimising the parameterisation of forests for WAsP wind speed calculations: A retrospective empirical study”, EWEA 2012 Conference, April 2012”

[C-10] Manning, J., Woodcock, J., Corbett, J-F., Whiting, R., Bleeg, J., Landberg, L., Tindal, A. – Validation and challenges of CFD in complex terrain for real world wind farms, EWEC 2011.

[C-11] Bechmann, A., et.al. – Results of the Blind Comparison, Bolund Workshop, December 3-4, 2009, Risø DTU National Laboratory for Sustainable Energy.

[C-12] Corbett, J-F., Whiting, R., Woodcock, J., Landberg L., Tindal A. – CFD can consistently improve wind speed predictions and reduce uncertainty in complex terrain, EWEA 2012.

[C-13] Bleeg, J., et al. “Modeling Stable Thermal Stratification and Its Impact on Wind Flow Over Topography.” AWEA WindPower 2012.

[C-14] Medici, D., Digraskar, D., Bleeg, J., Corbett, J.F., “Investigating the treatment of forestry in CFD wind flow models”, CanWEA 2012 conference, October 15, 2012, Toronto, Canada.

[C-15] Svensson, U., Häggkvist, K., “A two-equation turbulence model for canopy flows”, J. Wind Eng. Ind. Aerodyn. 35 (1990) 201–211.

[C-16] Costa et al, “Computer simulations of atmospheric flows over real forests for wind energy resource evaluation”, J. wind Eng. Ind. Aerodyn,94 (2006), pp 603-620.

[C-17] Siemens PLM Software. User Guide for STAR-CCM+ version 14th. Plano, TX, USA, 2020.

[C-18] Corbett, J. F.; Horn, U.; Bleeg, J.; Dnyanesh, D.; Whiting, R. A Systematic Validation of CFD Flow Modelling for Commercial Wind Farms Sites. Proceedings from EWEA, Barcelona, Spain. 10-13 March 2014.

[C-19] Corbett, J. F.; Poenariu, A.; Horn, U.; Leask, P. An Extensive Validation of CFD Flow Modelling. Proceedings from DEWEK, Bremen, Germany. 18-19 May 2015.

[C-20] Bleeg, J.; Digraskar, D.; Woodcock, J.; Corbett, J. F. Modeling Stable Thermal Stratification and Its Impact on Wind Flow over Topography. Wind Energy, Wiley Online, 14 Jan. 2014, https://onlinelibrary.wiley.com/doi/10.1002/we.1692/.

[C-21] Bleeg, J.; Digraskar, D.; Horn. U.; Corbett, J. F. Modelling stability at microscale, both within and above the atmospheric boundary layer, substantially improves wind speed predictions. Proceedings from EWEA, Paris, France, 2015.

[C-22] Bleeg, J.; Purcell, M.; Ruisi, R.; Traiger, E. Wind Farm Blockage and the Consequences of Neglecting Its Impact on Energy Production. Energies, vol. 11, no. 6, p. 1609, 2018. DOI:10.3390/en11061609.

APPENDIX D – SIVEST IMPACT RATING

D-1 Sivest impact rating table

ENVIRONMENTAL PARAMETER	ISSUE / IMPACT / ENVIRONMENTAL EFFECT/ NATURE	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION									RECOMMENDED MITIGATION MEASURES	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION								
		E	P	R	L	D	I / M	TOTAL	STATUS (+ OR -)	S		E	P	R	L	D	I / M	TOTAL	STATUS (+ OR -)	S
Construction Phase																				
Operational Phase																				
Wind energy resource	Wake impact on planned neighbouring wind farms	2	4	1	1	3	2	22	-	Low	Enter into wake compensation discussions with any operational neighbouring wind farms with the intent to sign an agreement where both parties agree.	2	4	1	1	3	1	11	-	Low
Decommissioning Phase																				
								0										0		
Cumulative																				
								0										0		

D-2 Sivest impact rating methodology

D-2.1 Environmental parameter

The environmental aspect affected by the operation of wind farm is the available wind energy resource.

D-2.2 Issue / Impact / Environmental effect / Nature

Operational wind turbines extract energy from the available wind resource, therefore reducing the wind energy resource available to neighbouring wind farms. The impact is quantified as a percentage loss in energy production.

D-2.3 Extent (E)

Assuming the neighbouring wind farms are within a 35 km radius od the Project, the extent of the impact is local/district. A score of 2 is, therefore, assigned.

D-2.4 Probability (P)

Assuming that both the Project and a neighbour operate simultaneously, the wake impact will certainly occur. A score of 4 is, therefore, assigned.

D-2.5 Reversibility (R)

Assuming that the Project turbines will be removed once the end of the operational lifetime of the Project has been reached, the impact is completely reversible. A score of 1 is, therefore, assigned.

D-2.6 Irreplaceable loss of resources (L)

Since the resource being consumed, wind energy, is completely renewable, the impact will result in no irreplaceable loss. A score of 1 is, therefore, assigned.

D-2.7 Duration (D)

Since the impact is limited to the period where both the project and a neighbouring wind farm are operating simultaneously, the effects of the impact are limited to the concurrent operational periods of the wind farms. This period is uncertain given the uncertainties in the developmental stages of the planned wind farms. However, this concurrent period cannot exceed the operational lifetime of the Project of 20 years. Therefore, the duration of the impact is considered long term (10-50 years). A score of 3 is, therefore, assigned.

D-2.8 Intensity / Magnitude (I / M)

The Project is estimated to cause non-zero reduction in generation at some planned neighbouring wind farms. However, the estimated reduction is small. Therefore, the impact is considered to have a medium intensity. A score of 2 is, therefore, assigned.

However, if suitable wake compensation agreements are entered into, the intensity is mitigated to a low level. A score of 1 would, therefore, be assigned.

D-2.9 Significance (S)

The significance of the impact is defined as the sum of the extent, probability, reversibility, irreplaceability and durations scores, factored by the magnitude/intensity score. The resulting significance characteristic is 22, which indicates a low negative impact. The significance characteristic can be reduced to 11 by entering onto wake compensation agreements with operational neighbouring wind farms.

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