

MEMO

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**Subject: Borssele Wind Resource Assessment
 Additional tables as supplement to main report**
 To: Frank van Erp, Ruud de Bruijne; RVO

Introduction

RVO commissioned Ecofys to provide a wind resource assessment for the Borssele offshore wind farm zone, as part of its plan to provide a detailed information package for the sites to all participants in the tender for concessions¹. This memo provides some additional tables as a supplement to the main report, as requested by RVO.

Directional Wind Statistics

The mean wind speed for four locations in the Borssele offshore wind farm zone are shown in Table 18 of [1]. Additional directional statistics are given in Appendix B, showing the mean wind speed, frequency and Weibull parameters for 12 direction sectors. These results are given for a height of 100 m at four locations (Borssele I, II, III and IV) in Table 1 to Table 4, plus at two other heights at a central location (80 and 150 m at Borssele III) in Table 5 and Table 6. The four locations refer to four grid points of the KNMI KNW mesoscale model, as explained in Figure 14 of [1]. It is important to note that results are presented with three significant digits, which does not reflect the uncertainty in the values; for a detailed uncertainty assessment of the wind climate, please refer to [1].

¹ Ecofys, 2015, "Borssele Offshore Wind Farm Zone Wind Resource Assessment", WIENL15778, v4.0.

Turbulence intensity

In the absence of on-site measurements, it is acceptable to model the ambient turbulence intensity for the site according to the Charnock equation, which relates turbulence intensity to the roughness of the sea at different wind speeds, as explained in [1]. A comparison to the measured turbulence intensity levels at Meteomast IJmuiden and OWEZ are also shown in [1], demonstrating that the calculated levels are reasonable for offshore conditions. The tables in Appendix B present further detail of the measured turbulence intensity at Meteomast IJmuiden and OWEZ, as a supplement to the graphs in Figure 32 of [1]. The data processing for both datasets is fully described in [1].

The measured turbulence intensity (mean, standard deviation and representative) is shown as a function of wind speed, in Table 7 and Table 9 for the top measurement height of OWEZ and Meteomast IJmuiden respectively. The representative turbulence intensity is also shown as a function of wind speed and wind direction in Table 8 and Table 10 for OWEZ and Meteomast IJmuiden respectively. The representative ambient turbulence intensity is calculated with Windographer 3.3.7 based on the definition in the IEC 61400-1 standard, edition 3, 2005. There are limited measurements in some bins, which can affect the accuracy of the calculated value; therefore, values are marked in italics if the calculation is based on less than 10 data points per bin.

Appendix A – Directional Statistics at Borssele Offshore Wind Farm Zone

Table 1 – Directional wind speed statistics at 100 m for Borssele site I (KNW BORS5)

Direction Sector	Frequency [%]	Mean Wind Speed at 100 m [m/s]	Weibull A [m/s]	Weibull k
345° - 15°	7.0%	7.655	8.643	2.274
15° - 45°	5.9%	7.654	8.612	2.454
45° - 75°	7.5%	8.944	10.078	2.380
75° - 105°	6.3%	8.690	9.786	2.469
105° - 135°	4.7%	8.234	9.293	2.134
135° - 165°	4.7%	8.253	9.309	1.971
165° - 195°	10.3%	10.663	12.030	2.152
195° - 225°	15.3%	11.535	12.972	2.542
225° - 255°	14.0%	10.748	12.093	2.519
255° - 285°	9.6%	9.842	11.098	2.341
285° - 315°	7.4%	8.905	10.062	2.047
315° - 345°	7.3%	8.126	9.186	2.112
All	100%	9.544	10.771	2.190

Table 2 – Directional wind speed statistics at 100 m for Borssele site II (KNW BORS1)

Direction Sector	Frequency [%]	Mean Wind Speed at 100 m [m/s]	Weibull A [m/s]	Weibull k
345° - 15°	7.0%	7.578	8.555	2.274
15° - 45°	5.9%	7.576	8.524	2.454
45° - 75°	7.5%	8.853	9.976	2.380
75° - 105°	6.3%	8.601	9.687	2.469
105° - 135°	4.7%	8.150	9.199	2.134
135° - 165°	4.7%	8.169	9.215	1.971
165° - 195°	10.3%	10.555	11.908	2.152
195° - 225°	15.3%	11.418	12.840	2.542
225° - 255°	14.0%	10.639	11.971	2.519
255° - 285°	9.6%	9.742	10.985	2.341
285° - 315°	7.4%	8.815	9.960	2.047
315° - 345°	7.3%	8.043	9.093	2.112
All	100%	9.447	10.661	2.190

Table 3 – Directional wind speed statistics at 100 m for Borssele site III (KNW BORS0)

Direction Sector	Frequency [%]	Mean Wind Speed at 100 m [m/s]	Weibull A [m/s]	Weibull k
345° - 15°	7.0%	7.696	8.689	2.274
15° - 45°	5.9%	7.695	8.657	2.454
45° - 75°	7.5%	8.991	10.132	2.380
75° - 105°	6.3%	8.736	9.838	2.469
105° - 135°	4.7%	8.278	9.343	2.134
135° - 165°	4.7%	8.297	9.359	1.971
165° - 195°	10.3%	10.72	12.094	2.152
195° - 225°	15.3%	11.596	13.041	2.542
225° - 255°	14.0%	10.805	12.158	2.519
255° - 285°	9.6%	9.895	11.157	2.341
285° - 315°	7.4%	8.953	10.115	2.047
315° - 345°	7.3%	8.169	9.235	2.112
All	100%	9.595	10.828	2.190

Table 4 – Directional wind speed statistics at 100 m for Borssele site IV (KNW BORS3)

Direction Sector	Frequency [%]	Mean Wind Speed at 100 m [m/s]	Weibull A [m/s]	Weibull k
345° - 15°	7.0%	7.786	8.791	2.274
15° - 45°	5.9%	7.785	8.759	2.454
45° - 75°	7.5%	9.097	10.251	2.380
75° - 105°	6.3%	8.839	9.954	2.469
105° - 135°	4.7%	8.375	9.452	2.134
135° - 165°	4.7%	8.394	9.469	1.971
165° - 195°	10.3%	10.846	12.236	2.152
195° - 225°	15.3%	11.733	13.194	2.542
225° - 255°	14.0%	10.932	12.301	2.519
255° - 285°	9.6%	10.011	11.288	2.341
285° - 315°	7.4%	9.058	10.234	2.047
315° - 345°	7.3%	8.265	9.344	2.112
All	100%	9.707	10.955	2.190

Table 5 – Directional wind speed statistics at 80 m for Borssele site III (KNW BORS0)

Direction Sector	Frequency [%]	Mean Wind Speed at 80 m [m/s]	Weibull A [m/s]	Weibull k
345° - 15°	7.0%	7.582	8.560	2.274
15° - 45°	5.9%	7.596	8.547	2.455
45° - 75°	7.5%	8.858	9.981	2.382
75° - 105°	6.3%	8.571	9.652	2.470
105° - 135°	4.7%	8.132	9.178	2.134
135° - 165°	4.7%	8.170	9.215	1.972
165° - 195°	10.3%	10.508	11.855	2.152
195° - 225°	15.3%	11.253	12.655	2.541
225° - 255°	14.0%	10.568	11.891	2.520
255° - 285°	9.6%	9.755	10.999	2.341
285° - 315°	7.4%	8.862	10.014	2.047
315° - 345°	7.3%	8.049	9.099	2.112
All	100%	9.412	10.621	2.197

Table 6 – Directional wind speed statistics at 150 m for Borssele site III (KNW BORS0)

Direction Sector	Frequency [%]	Mean Wind Speed at 150 m [m/s]	Weibull A [m/s]	Weibull k
345° - 15°	7.0%	7.908	8.928	2.273
15° - 45°	5.9%	7.877	8.863	2.453
45° - 75°	7.5%	9.239	10.411	2.377
75° - 105°	6.3%	9.044	10.185	2.467
105° - 135°	4.7%	8.550	9.649	2.132
135° - 165°	4.7%	8.534	9.627	1.970
165° - 195°	10.3%	11.116	12.540	2.152
195° - 225°	15.3%	12.247	13.772	2.542
225° - 255°	14.0%	11.249	12.658	2.517
255° - 285°	9.6%	10.154	11.449	2.341
285° - 315°	7.4%	9.119	10.303	2.046
315° - 345°	7.3%	8.392	9.487	2.112
All	100%	9.938	11.216	2.175

Appendix B – Measured Turbulence Intensity at OWEZ and Meteomast Ijmuiden

Table 7 – Measured turbulence intensity (mean, standard deviation and representative) as a function of wind speed at OWEZ offshore met mast, at 116 m, for quality-controlled data between July 2005 and June 2006

Wind Speed [m/s]	Occurrences	Frequency [%]	Mean Turbulence Intensity [%]	Standard deviation of Turbulence Intensity [%]	Representative Turbulence Intensity [%]
4	2,884	6.4%	8%	4%	13%
5	3,091	6.8%	7%	3%	11%
6	2,997	6.6%	6%	3%	10%
7	3,511	7.8%	6%	3%	9%
8	4,096	9.0%	6%	2%	9%
9	3,936	8.7%	5%	2%	9%
10	3,732	8.2%	5%	2%	8%
11	3,522	7.8%	5%	2%	8%
12	2,928	6.5%	5%	2%	8%
13	2,550	5.6%	5%	2%	8%
14	2,028	4.5%	5%	2%	8%
15	1,534	3.4%	5%	2%	8%
16	1,038	2.3%	5%	2%	8%
17	635	1.4%	5%	2%	8%
18	632	1.4%	6%	2%	8%
19	488	1.1%	6%	2%	8%
20	347	0.8%	5%	2%	8%
21	169	0.4%	5%	2%	8%
22	90	0.2%	5%	2%	7%
23	37	0.1%	6%	2%	8%
24	13	0.0%	6%	3%	10%
25	6	0.0%	9%	1%	11%
26	18	0.0%	7%	1%	9%
27	10	0.0%	7%	1%	8%
28	1	0.0%	9%	0%	9%
29	1	0.0%	6%	0%	6%
30	1	0.0%	9%	0%	9%

Table 8 – Measured representative turbulence intensity as a function of wind speed and wind direction at OWEZ offshore met mast, at 116 m, for quality-controlled data between July 2005 and June 2006.

Values in *grey and italics* are based on less than 10 data points per bin.

Wind Speed [m/s]	345° - 15°	15° - 45°	45° - 75°	75° - 105°	105° - 135°	135° - 165°	165° - 195°	195° - 225°	225° - 255°	255° - 285°	285° - 315°	315° - 345°	All
4	14%	13%	12%	12%	13%	12%	11%	13%	12%	13%	13%	14%	13%
5	12%	12%	10%	11%	9%	11%	10%	13%	11%	13%	11%	12%	11%
6	12%	11%	10%	8%	8%	8%	11%	8%	9%	11%	13%	11%	10%
7	11%	8%	8%	7%	7%	7%	8%	7%	8%	10%	10%	11%	9%
8	9%	8%	8%	7%	7%	7%	7%	7%	9%	9%	10%	10%	9%
9	9%	8%	8%	6%	7%	6%	7%	8%	8%	9%	10%	10%	9%
10	9%	8%	9%	7%	7%	6%	7%	8%	8%	8%	9%	10%	8%
11	10%	7%	8%	7%	7%	6%	7%	7%	7%	8%	9%	12%	8%
12	12%	9%	8%	8%	8%	7%	7%	7%	8%	8%	9%	10%	8%
13	10%	10%	8%	8%	8%	5%	7%	7%	7%	8%	9%	11%	8%
14	11%	10%	8%	7%	8%	5%	6%	7%	7%	8%	9%	11%	8%
15	11%	7%	7%	8%	7%	6%	6%	7%	7%	7%	9%	13%	8%
16	8%	<i>11%</i>	6%			7%	7%	8%	6%	8%	9%	10%	8%
17	10%	<i>6%</i>				6%	7%	7%	6%	8%	10%	11%	8%
18	<i>13%</i>						8%	7%	7%	9%	11%	10%	8%
19							7%	7%	7%	<i>7%</i>	<i>9%</i>	11%	8%
20	<i>13%</i>						7%	7%	7%	<i>6%</i>	16%	9%	8%
21							<i>8%</i>	7%	7%	7%	<i>13%</i>	13%	8%
22								7%	6%		8%	<i>10%</i>	7%
23	<i>10%</i>							7%	<i>9%</i>		<i>8%</i>	<i>11%</i>	8%
24								<i>8%</i>	<i>7%</i>		<i>8%</i>	<i>14%</i>	10%
25											<i>11%</i>		<i>11%</i>
26											9%	<i>6%</i>	9%
27											8%		8%
28											<i>9%</i>		<i>9%</i>
29											<i>6%</i>		<i>6%</i>
30											<i>9%</i>		<i>9%</i>

Table 9 – Measured turbulence intensity (mean, standard deviation and representative) as a function of wind speed at Meteomast Ijmuiden offshore met mast, at 92 m, for quality-controlled data between January 2011 and December 2014

Wind Speed [m/s]	Occurrences	Frequency [%]	Mean Turbulence Intensity [%]	Standard deviation of Turbulence Intensity [%]	Representative Turbulence Intensity [%]
4	7,743	5.0%	8%	5%	14%
5	9,220	5.9%	7%	4%	11%
6	11,290	7.2%	6%	3%	10%
7	12,580	8.1%	6%	3%	9%
8	12,301	7.9%	5%	3%	9%
9	12,581	8.1%	5%	2%	8%
10	11,848	7.6%	5%	2%	8%
11	11,520	7.4%	5%	2%	8%
12	10,574	6.8%	5%	2%	8%
13	9,553	6.1%	5%	2%	8%
14	7,880	5.1%	5%	2%	8%
15	6,510	4.2%	5%	2%	8%
16	5,008	3.2%	6%	2%	8%
17	3,753	2.4%	6%	2%	8%
18	3,019	1.9%	6%	2%	8%
19	2,527	1.6%	6%	1%	8%
20	1,980	1.3%	7%	2%	9%
21	1,417	0.9%	7%	1%	9%
22	861	0.6%	7%	1%	9%
23	454	0.3%	7%	2%	9%
24	228	0.1%	7%	1%	9%
25	131	0.1%	8%	1%	9%
26	106	0.1%	8%	1%	9%
27	105	0.1%	8%	1%	9%
28	92	0.1%	8%	1%	9%
29	39	0.0%	8%	1%	9%
30	22	0.0%	8%	1%	9%
31	7	0.0%	8%	2%	10%
32	3	0.0%	8%	1%	9%
33	1	0.0%	9%	0%	9%
34	3	0.0%	9%	0%	9%
35	1	0.0%	11%	0%	11%

Table 10 – Measured representative turbulence intensity as a function of wind speed and wind direction at Meteomast Ijmuiden offshore met mast, at 92 m, for quality-controlled data between January 2011 and December 2014. Values in *grey and italics* are based on less than 10 data points per bin.

Wind Speed [m/s]	345° - 15°	15° - 45°	45° - 75°	75° - 105°	105° - 135°	135° - 165°	165° - 195°	195° - 225°	225° - 255°	255° - 285°	285° - 315°	315° - 345°	All
4	14%	12%	14%	13%	14%	13%	14%	14%	13%	13%	13%	13%	14%
5	12%	11%	12%	12%	13%	11%	10%	10%	11%	11%	12%	11%	11%
6	10%	11%	11%	11%	11%	10%	9%	9%	9%	11%	10%	10%	10%
7	10%	9%	9%	10%	9%	10%	9%	8%	8%	10%	10%	10%	9%
8	10%	9%	9%	9%	9%	8%	8%	8%	8%	9%	10%	10%	9%
9	9%	9%	8%	8%	7%	10%	8%	7%	8%	8%	9%	10%	8%
10	9%	8%	9%	9%	7%	7%	8%	8%	8%	8%	9%	9%	8%
11	10%	9%	8%	8%	7%	7%	7%	7%	7%	8%	9%	9%	8%
12	9%	8%	7%	8%	7%	7%	7%	7%	7%	8%	8%	10%	8%
13	9%	8%	7%	8%	7%	7%	7%	7%	7%	8%	8%	9%	8%
14	9%	9%	8%	7%	7%	7%	7%	7%	8%	8%	8%	9%	8%
15	10%	8%	8%	7%	7%	8%	7%	7%	8%	8%	8%	9%	8%
16	9%	7%	8%	7%	7%	8%	7%	7%	7%	8%	9%	9%	8%
17	10%	9%	8%	7%	7%	10%	7%	7%	8%	8%	10%	9%	8%
18	10%	8%	8%	8%	7%	8%	8%	7%	8%	8%	10%	10%	8%
19	10%	9%	7%	7%	7%	8%	8%	8%	8%	8%	10%	10%	8%
20	11%	8%	9%	8%	<i>8%</i>	7%	8%	8%	8%	8%	10%	9%	9%
21	8%	8%	9%	<i>7%</i>	10%	8%	8%	8%	8%	10%	11%	10%	9%
22	<i>8%</i>	<i>7%</i>	8%		<i>8%</i>	8%	8%	8%	9%	9%	9%	10%	9%
23	<i>7%</i>		<i>7%</i>		<i>8%</i>	10%	9%	8%	8%	9%	10%	11%	9%
24					<i>5%</i>	<i>6%</i>	10%	9%	8%	10%	11%	10%	9%
25							9%	9%	9%	9%	9%	11%	9%
26							9%	9%	11%	8%	<i>9%</i>	<i>11%</i>	9%
27							8%	9%	9%	<i>8%</i>	<i>9%</i>		9%
28							9%	9%	9%		<i>13%</i>		9%
29							8%	8%	<i>11%</i>	<i>9%</i>	<i>9%</i>		9%
30							8%	<i>8%</i>	<i>10%</i>	<i>7%</i>			9%
31								<i>10%</i>	<i>11%</i>				<i>10%</i>
32								<i>8%</i>	<i>10%</i>				<i>9%</i>
33									9%				<i>9%</i>
34								9%	9%				<i>9%</i>
35										<i>11%</i>			<i>11%</i>