Scoping analysis of the potential yield of the Hollandse Kust (noord) wind farm and the influence on the existing wind farms in the proximity

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April 2018

ECN-E--18-033

Executive summary

The potential energy yield of the Hollandse Kust (noord) (HKN) Wind Farm Zone and its effect on the energy production of the existing wind farms, Prinses Amalia and OWEZ, is calculated with FarmFlow, ECN's wind farm aerodynamic performance analysis tool.

The HKN wind farm zone consists of a single site which is designated to be developed with a 700 MW offshore wind farm. The site will be tendered to the developers in 2019. It is decided that the site will have a guaranteed nominal power of 700 MW but the development plan can go up to 760 MW (overplanting). The export transmission system will have a guaranteed capacity to transmit at least 700 MW to the national grid on shore. However, under normal conditions, the transmission system is capable to transmit the generated power – minus the internal electrical losses to the national grid. Only when the export cable core temperature increases above a limit temperature the output of the site will be curtailed to 700 MW.

For the HKN wind farm zone, 2 designs have been made. One design consisting of 8 MW wind turbines with a rotor diameter of 164 m and one design consisting of 10 MW wind turbines with a rotor diameter of 196 m. These wind turbine models differ with respect to the rotor power density.

The potential energy production has been calculated and the influence of the HKN wind farm on the production of the existing wind farms in the proximity, the reference case. The wind farms in the proximity are:

- Wind Farm Prinses Amalia, consisting of 60 Vestas V80, 2 MW wind turbines and
- Wind Farm OWEZ, consisting of 36 Vestas V90, 3 MW wind turbines.

The wind resources have been determined at the centre location of the HKN wind farm zone.

The potential energy yield has been determined for the reference case, i.e. the wind farms Prinses Amalia and OWEZ and for:

- HKN consisting of 8 MW wind turbines and with the reference wind farms;
- HKN consisting of 10 MW wind turbines and with the reference wind farms;

In each case the wake losses have been determined for all wind farms.

For the Prinses Amalia wind farm the maximum additional loss due to the HKN wind farm is 2.8%.

For the OWEZ wind farm the maximum additional loss due to the HKN wind farm is 2.1%.

For simplicity no losses due to the internal electrical losses, availability and environmental requirements are taken into account.

Content

1 Introduction

In assignment of the ministry of Economic Affairs and Climate Policy of the Netherlands, a quick scan study has been performed to predict the performance of planned and existing wind farms near the Hollandse Kust Wind Farm Zone, see Figure 1.

Figure 1: The map of the HKN wind farm zone where the dark green area enclosed by HKN is Prinses Amalia wind farm and the dark green area east of HKN area is OWEZ wind farm.

The Hollandse Kust wind farm zone has been split up into five parts, Hollandse Kust Wind Farm Zone zuid (HKZ), noord (HKN) zuidwest (HKZW), west (HKW) and noordwest (HKNW). In this report the potential energy yield of the Hollandse Kust Noord wind farm zone and its effect on existing wind farms is reported. The effects of the additional losses due HKZ wind farm zone has been reported in 2016, see [1].

The HKN wind farm zone consists of a single site that will be developed for a 700 MW nominal power offshore wind farm. The site will be tendered to offshore wind farm developers in 2019.

The wind resources at the locations have been determined on the basis of the KNW wind atlas database that ECN received from KNMI for the years 1999 – 2013. The wind resources have been correlated with measurements at the meteo mast IJmuiden Ver for the entire period that measurements were available.

For the HKN zone two different wind farm designs have been made, one with an 8 MW wind turbine and one with a 10 MW wind turbine. Besides the difference in nominal power also the rotor power density of these two turbines differ. The 8 MW wind turbine has a rotor power density of approximately 380 W/m^2 and the 10 MW has a rotor power density of approximately 330 W/m^2. For each design the potential energy yield has been determined. Next to that the energy yield of the HKN have been determined taking into account the following two existing (reference) wind farms:

- Wind Farm Prinses Amalia, consisting of 60 Vestas V80, 2 MW wind turbines and
- Wind Farm OWEZ, consisting of 36 Vestas V90, 3 MW wind turbines.

In order to determine the additional losses for the reference wind farms due to HKN, both the yield of the present situation and the yield including the new wind farm with both designs, the 8 MW and the 10 MW has been calculated.

The effects of the existing wind farm Luchterduinen is assumed to be negligible due to the larger distance to the HK Noord wind farm zone. The potential effect of HKN on the planned wind farm HKZ is also left out of the analysis by decision of the Ministry of Economic Affairs and Climate.

The designs created for the HKN Wind Farm Zone are made assuming the maximum allowable overplanting, to the closest value of 760 MW, as shown in **Table 1**.

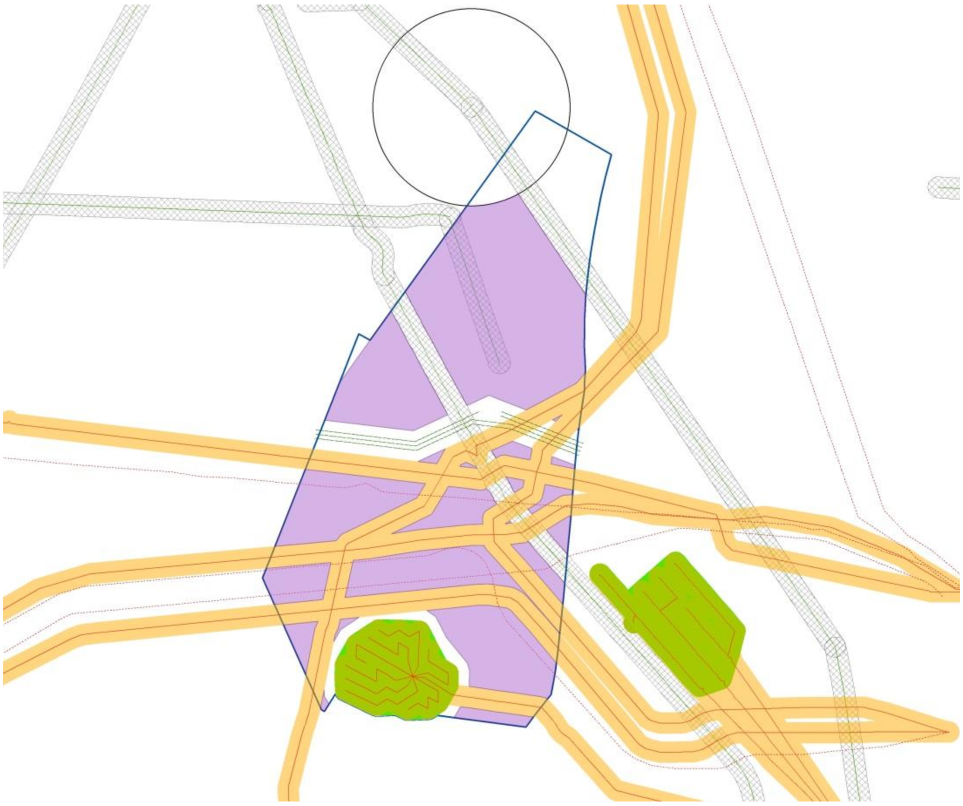

Figure 2: The map of the HKN wind farm zone, showing the OWEZ wind farm in green to the east and the Prinses Amalia wind farm surrounded by the HK Noord wind farm.

As can be seen in **Figure 2** the HKN site is divided into many smaller areas due to cables and gas and/or oil pipeline crossings. This results in a total of 22 smaller areas that can be used to install wind turbines, see **Figure 3**. The design will be performed in such a way that it should be possible to have at least 3 turbines in an enclosed area. If less turbines can be positioned the area is not used at all. Next to that the turbines are always completely inside the area meaning that the tower foot is always at least half a rotor diameter away from the area's boundary.

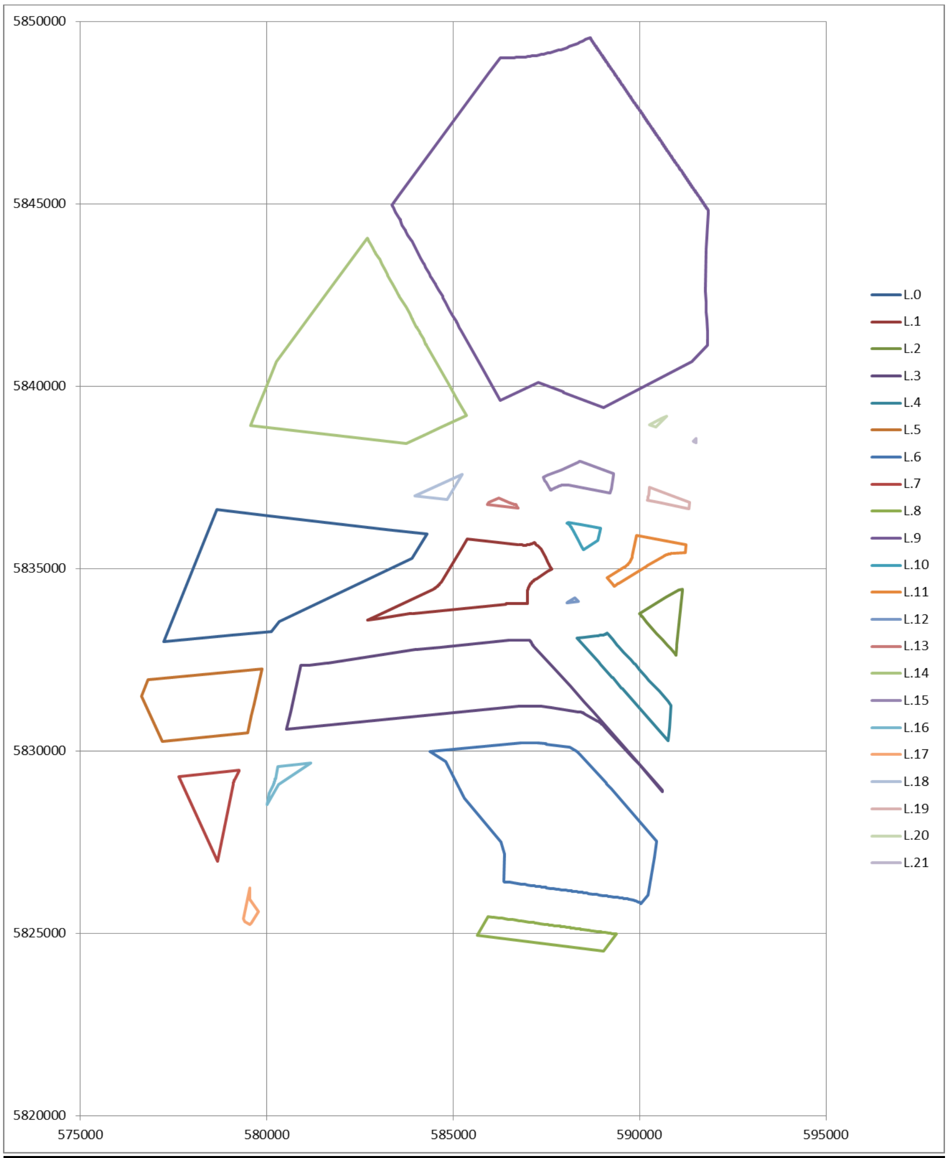

Figure 3: The HKN wind farm zone split up in 22 smaller areas that can be used to install wind turbines.

The characteristics of the wind farms designed using the 8 and 10 MW wind turbines are listed in **Table 1**.

Table 1: The characteristics of the wind farm designs

Wind farm Site	design	WT P_{rated} [MW]	rotor density [W/m²]	WT rotor diameter [m]	WT hub height [m]	Number of WT's	Nominal Power Wind Farm [MW]
HKN	A	8	380	164	112	95	760
	B	10	330	196	128	76	760

The potential energy yield, the capacity factor and the wind farm efficiency is determined for the HKN wind farm zone. The following tasks are performed to determine these effects:

Task 1. Create the wind farm designs for the HKN zone for both turbine types, taking into account that the site boundaries are not crossed at any time.

Task 2. Model the reference wind farms, Prinses Amalia and OWEZ.

Task 3. Determine the wind conditions for the HK noord wind farm zone by determining the wind roses at a centre location of an area enclosing the HKN wind farm zone. The wind resources will be determined at 100 m above MSL that will be interpolated to the location of each wind farm and interpolated to the hub height of the wind turbines in the wind farm considered.

Task 4. Calculate the wind farm yields for both the 8 and 10 MW wind turbine types

a. For the reference situation, only the existing wind farms, OWEZ, Prinses Amalia;
b. For HK noord scenario A with 8 MW wind turbines, without the existing wind farms;
c. For HK noord scenario B with 10 MW wind turbines, without the existing wind farms;
d. For HK noord scenario A, including the existing wind farms;
e. For HK noord scenario B, including the existing wind farms;

Task 5. Calculate the wind farm efficiencies and capacity factors for each site for both turbine types;

Task 6. Calculate the additional losses for the existing wind farms due to the new wind farms for both turbine types.

The results of the designs and calculations can be found in this report.

The wind farm wake analysis is performed with ECN's FARMFLOW model. The FARMFLOW model is developed by ECN to predict the wind turbine wake effects of offshore wind farms. The tool comprises a wake model that has been verified with measurements and compared to other models in numerous (benchmark) projects. See Appendix B for a more extensive description of the model and the verification documents.

The results of the analysis are the gross P_{50} energy yield after subtracting the wake losses of the existing wind farms without and with the new wind farms present. The difference between the yields of the two situations is the additional energy losses due to the presence of the HKN wind farm.

Next to that also the energy yields of the HKN with the 8 and the 10 MW wind turbines are calculated.

2

The wind turbine models

For the HKN wind farms two different wind turbines models are used, one with a rated power of 8 MW and one with a rated power of 10 MW. The rotor power density, i.e. the ratio of the nominal or rated power over the rotor area, also differs between the two wind turbines. The 8 MW design has a rotor power density of approximately 380 W/m^2 and the 10 MW model has a rotor power density of approx. 330 W/m^2. This results in an 8 MW wind turbine with a rotor diameter of 164 m and a 10 MW wind turbine with a rotor diameter of 196 m. The hub height of the turbines is determined by half the rotor diameter +30 m, to be sure that the rotor blades will not be affected by splash water of waves hitting the foundation.

The wind turbines characteristics of the wind turbines in the existing wind farms are modelled on the basis of publicly available data, power curve and thrust coefficient curve.

The characteristics of the virtual wind turbine models used in the analysis can be found in Appendix A.

The characteristics of the wind turbines used in the existing wind farms, Prinses Amalia, Vestas V, and OWEZ, Vestas V90, can also found in Appendix A.

3

The existing wind farms

The existing wind farms are modelled in FarmFlow on the basis of the information received from the Ministry of Economic affairs and Climate Policy, see **Figure 4**

OWEZ

The OWEZ wind farm is the first Dutch offshore wind farm in the North Sea. The OWEZ wind farm has a nominal power of 108 MW and it comprises of 36 Vestas V90 3 MW wind turbines. Its location is near the town of Egmond aan Zee.

Prinses Amalia

The Prinses Amalia wind farm, located on the south boundary of the HKN wind farm zone. The wind farm has a nominal power of 120 MW and consists of 60 Vestas V80 2 MW wind turbines.

Table 2: The existing offshore wind farms, information from the www.4coffshore.com website.

Project	Build/commission date/	Wind Farm Area	P_{rated} WT	D_{rotor}	H_{hub}	Nominal WF power	# WTs
		Km^2	MW	m	m	MW	
OWEZ	2006	24	3	90	70	108	36
Prinses Amalia	2006 - 2008	14	2	80	59	120	60

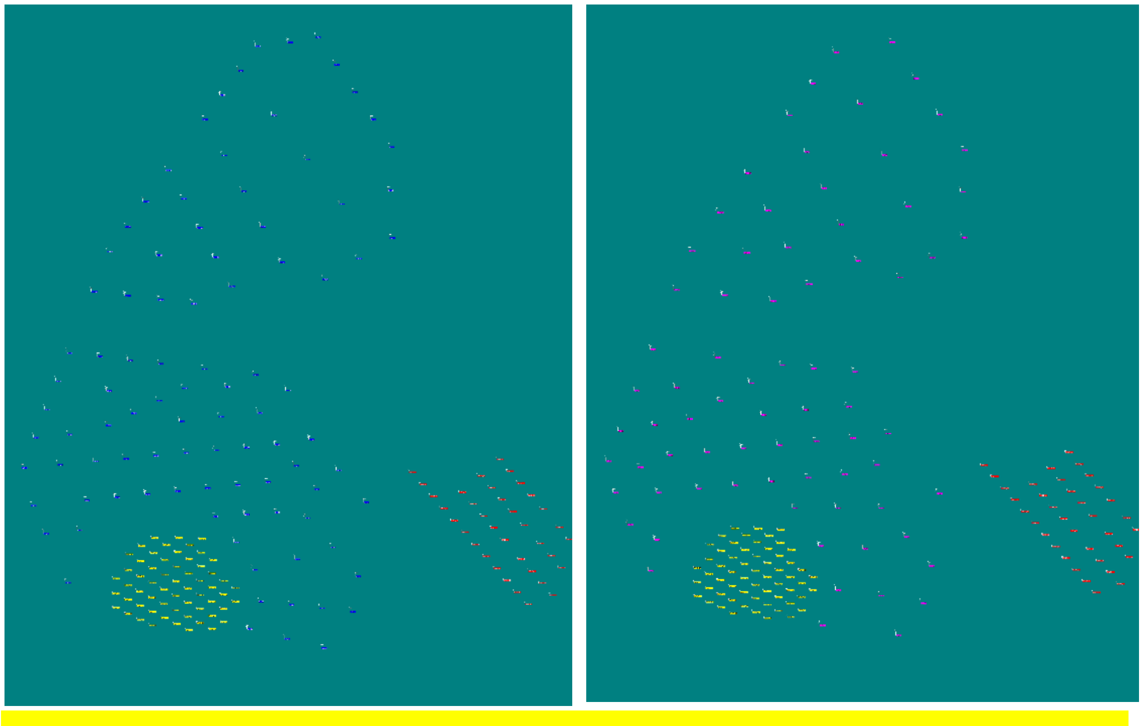

Figure 4: The HKN wind farm designs, enclosing OWF Prinses Amalia (yellow) and showing the location of the OWF OWEZ (red), on the left the HKN with 8 MW wind turbines and on the right with 10 MW wind turbines.

4

The undisturbed wind conditions at the HKN Wind Farm Zone

The wind conditions at the HKN Wind Farm zone are based on a database of the Harmony model based weather forecast created by KNMI and analysed by ECN. A full period of 15 years, 1999 – 2013, has been used to derive the long term wind data. The wind conditions are correlated for short period with actual wind measurements at the location of the IJmuiden Ver meteo mast at an altitude of 90 m above MSL.
Due to the large differences in hub heights the wind conditions are determined at three different heights above MSL, i.e. at 65 m (average of V80 and V90 hub height) and at 112 m and 128 m above MSL, being the hub heights of the 8 and 10 MW wind turbines. The resulting wind roses for the different heights are shown in **Table 3** to **Table 5** and **Figure 5** to **Figure 7**.

Table 3: The Weibull data for 12 sectors at a height of 65 m. The air density is 1.235 kg/m^3

	Sector	Frequency	Weibull A	Weibull k	Wind speed	Power density
	[-]	[%]	[m/s]	[-]	[m/s]	[W/m^2]
1	N	6.749	10.058	2.149	8.909	462.97
2	NNE	6.326	8.536	2.232	7.562	257.22
3	NEE	6.812	8.641	2.530	7.670	262.24
4	E	7.479	8.309	2.623	7.383	250.63
5	SEE	4.884	8.591	2.534	7.626	184.61
6	SSE	5.256	7.893	2.369	6.997	161.50
7	S	7.081	8.844	2.363	7.839	306.08
8	SSW	13.680	10.773	2.237	9.543	1112.90
9	SWW	15.720	12.288	2.373	10.891	1810.50
10	W	9.869	11.918	2.373	10.564	1037.30
11	NWW	8.670	10.256	2.124	9.085	637.23
12	NNW	7.480	9.719	2.167	8.609	459.69
	All	100.00	10.087	2.210	8.940	752.17

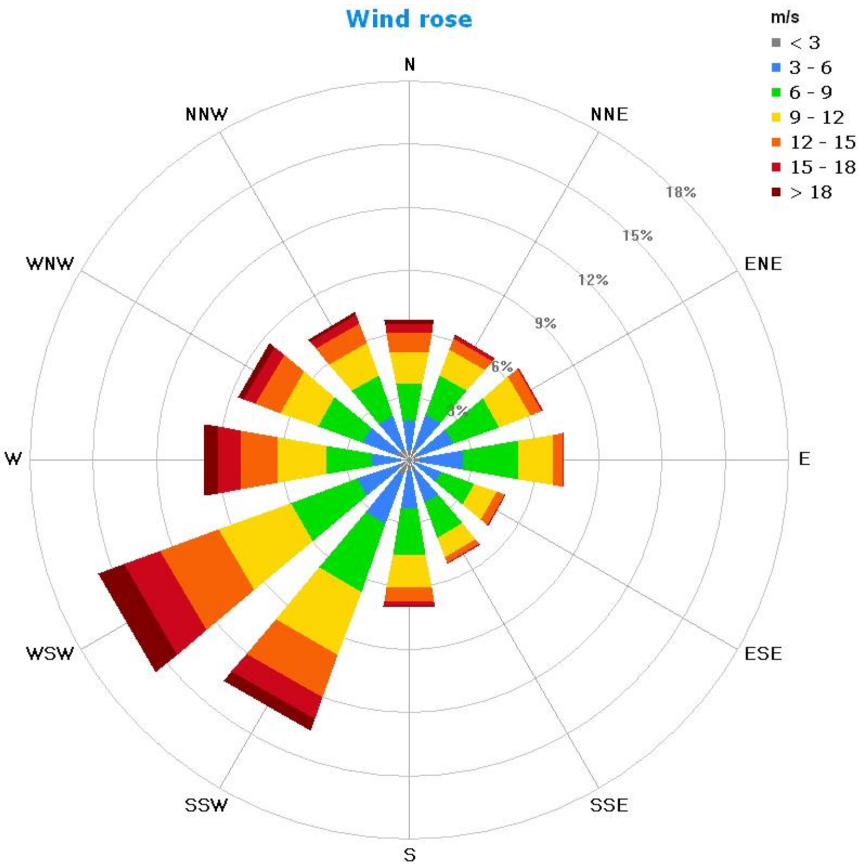

Figure 5: The wind rose at 65 m height

Table 4: The Weibull data for 12 sectors at a height of 112 m. The air density is 1.231 kg/m^3

	Sector	Frequency	Weibull A	Weibull k	Wind speed	Power density
	[-]	[%]	[m/s]	[-]	[m/s]	[W/m²]
1	N	6.283	10.807	2.146	9.572	533.21
2	NNE	6.420	8.892	2.153	7.877	303.26
3	NEE	6.791	9.096	2.395	8.064	315.11
4	E	6.933	9.258	2.555	8.220	324.85
5	SEE	5.321	9.375	2.508	8.319	261.89
6	SSE	4.911	9.049	2.360	8.021	226.79
7	S	7.216	9.440	2.234	8.362	394.72
8	SSW	14.110	11.502	2.158	10.187	1435.60
9	SWW	15.540	13.230	2.385	11.727	2217.20
10	W	10.120	12.793	2.399	11.341	1300.30
11	NWW	8.823	10.901	2.156	9.655	765.20
12	NNW	7.538	10.190	2.153	9.026	535.01
	All	100.00	10.837	2.200	9.603	937.00

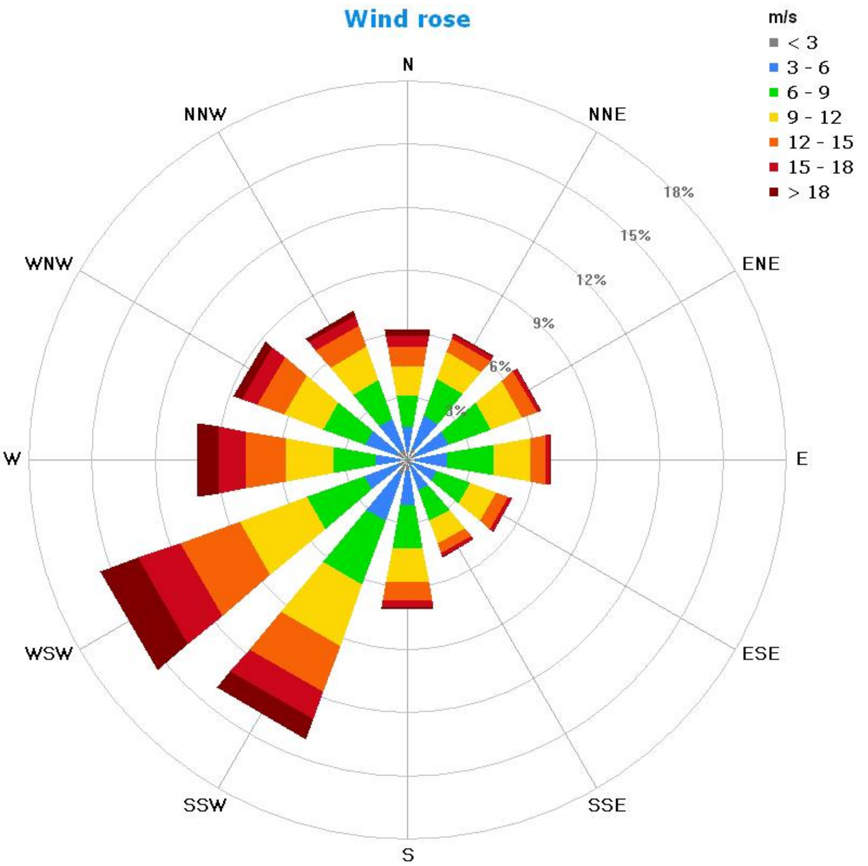

Figure 6: The wind rose at 112 m height

Table 5: The Weibull data for 12 sectors at a height of 128 m. The air density is 1.231 kg/m³

	Sector	Frequency	Weibull A	Weibull k	Wind speed	Power density
	[-]	[%]	[m/s]	[-]	[m/s]	[W/m²]
1	N	6.283	10.942	2.133	9.692	556.46
2	NNE	6.420	9.003	2.163	7.975	313.41
3	NEE	6.791	9.138	2.367	8.100	322.20
4	E	6.933	9.345	2.534	8.295	335.77
5	SEE	5.321	9.495	2.493	8.425	273.09
6	SSE	4.911	9.197	2.347	8.151	239.02
7	S	7.216	9.481	2.200	8.398	405.08
8	SSW	14.110	11.651	2.148	10.319	1498.30
9	SWW	15.540	13.418	2.365	11.892	2327.10
10	W	10.120	12.999	2.395	11.523	1365.60
11	NWW	8.823	11.026	2.152	9.766	793.07
12	NNW	7.538	10.276	2.146	9.102	550.24
	All	100.00	10.966	2.200	9.717	978.43

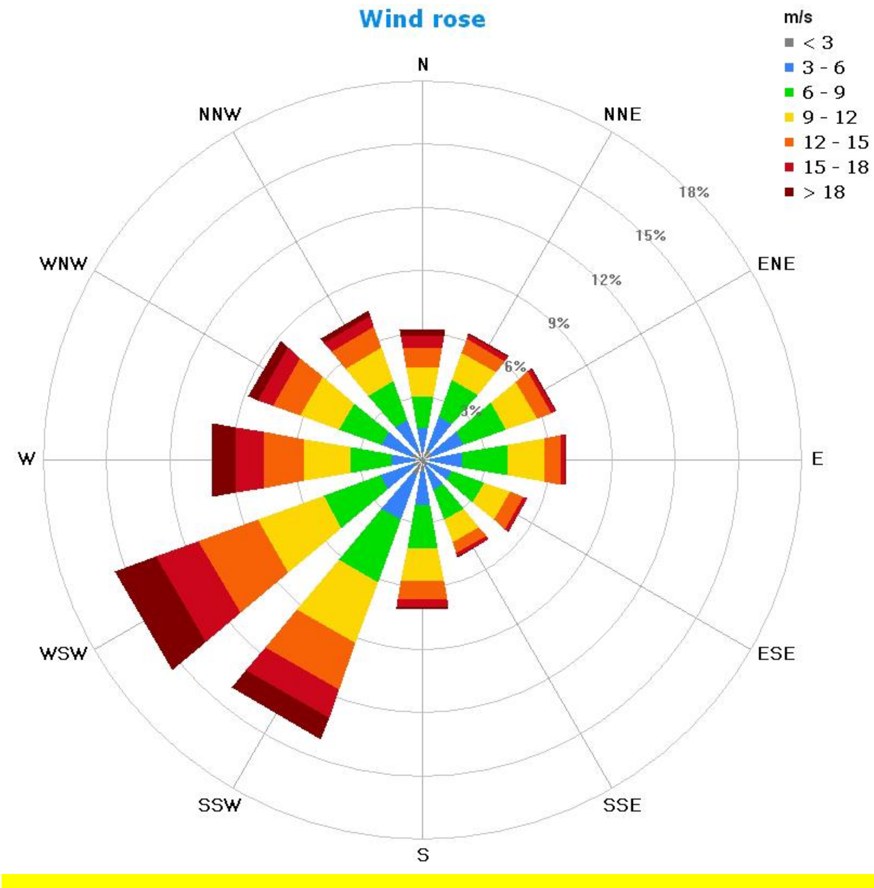

Figure 7: The wind rose at 128 m height

5

The HKN wind farm designs

Due to the fact that the wind farm HKN are still in the planning phase and consequently not yet designed, two designs have been made where the spacing of the wind turbines is as large as possible to reduce wake effects and not taking (local) conditions as e.g. water depth into account.
For both designs created, the foundations are all at least half a diameter from the site boundary so that the rotor blades don't cross these boundaries.

The location HKN is subdivided into 22 smaller areas due to many crossings of cables or pipelines see **Figure 2**. Sub areas are not always sufficiently large to have 3 or more wind turbines and those areas are not used.

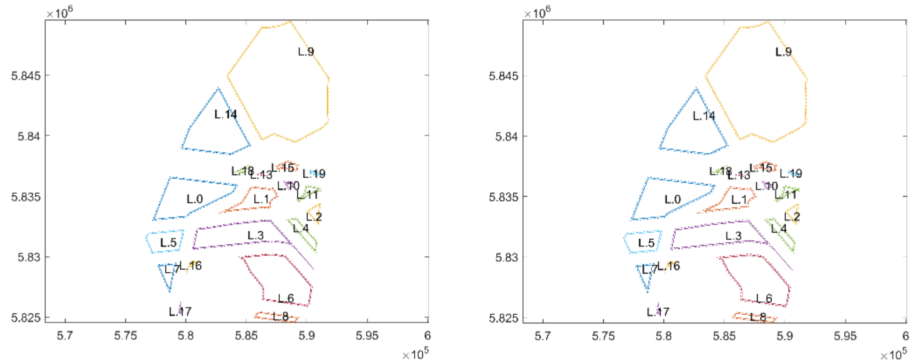

Figure 8: The HKN wind farm zone, showing on the left the allowable area for 8 MW wind turbines and on the right the allowable area for 10 MW wind turbines..

Two different designs are created. It is assumed that both designs should have the maximum number of wind turbines allowed within the given overplanting margin of 760 MW. This results in designs with a nominal power of 760 MW, i.e. 95 x 8 MW wind turbines, and 76 x 10 MW wind turbines, see **Table 1**.

The designs are shown in **Figure 9**.

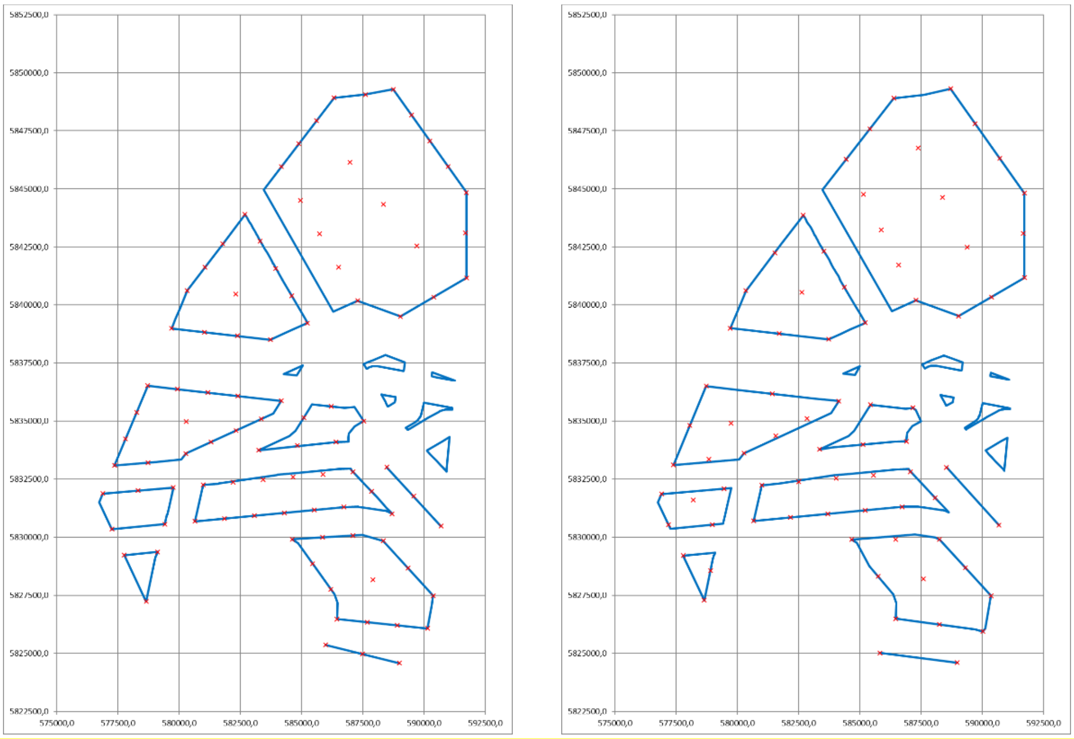

Figure 9: The HKN wind farm zone design with 8 MW wind turbines (left) and 10 MW wind turbines (right).

6

Results

6.1 The yield of the existing wind farms, the baseline case.

The gross yield of the existing offshore wind farms has been calculated with FARMFLOW with and without the presence of the wind farms in the HKN Wind Farm zone. No losses due to availability of system components or losses due to electrical system are taken into account. Assuming that all losses other than the wake losses have a small influence on the total system performance it is assumed that this is acceptable considering the nature of the study.

The baseline situation is the present situation with only the existing wind farms. The yield and capacity factor calculated is listed per wind farm in

Table 6: The calculated energy yield of the existing wind farms, the baseline case and the yield of the HKN wind farm without the wake effects of the existing wind farms

		OWF Prinses Amalia	OWF OWEZ	OWF HKN	
# WT's	[-]	60	36	95	76
Type of WT		Vestas 80	Vestas 90	8MW	10MW
Rated power of the wind farm	[MW]	120	108	760	760
Energy yield	[MWh]	446.250,	393.028,	3.337.424,	3.681.764,
Capacity factor	[%]	42,45	41,54	50,13	55,30
Full load hr's	[hr's]	3719	3639	4391	4844

6.2 The yield of the existing wind farms and the new HKN wind farm

The gross yield of the two existing wind farms is recalculated including the HKN wind farm for both scenario's, with an 8 MW wind turbine and a 10 MW wind turbine, see **Table 7**.

The table shows the energy yield for each wind farm and the reduction in yield due to the new wind farms. The additional losses for the HKN wind farm are the losses compared to the yield for HKN as if the existing wind farms are not there.

Table 7: The yield of the base line wind farms + HKN

		OWF Prinses Amalia		OWF OWEZ		OWF HKN	
		8MW	10WM	8MW	10WM	8MW	10WM
Energy yield	[MWh]	433.799,	434.791,	384.796,	386.911,	3.298.918,	3.650.751,
Capacity factor	[%]	41,27	41,36	40,67	40,90	49,55	54,84
Full load hr’s	[hr's]	3615	3623	3563	3583	4341	4804
Additional loss	[%]	2,79	2,57	2,09	1,56	1,15	0,84

7 Conclusions

The analysis of the baseline situation shows that the gross energy yield for the existing wind farms will be reduced due to the building and operation of the HKN wind farm. Not surprisingly the OWF Prinses Amalia will suffer the highest losses, due to the fact that the Prinses Amalia wind farm is largely enclosed by the HKN wind farm.

The maximum calculated loss for the Prinses Amalia wind farm is 2.8%. For the OWEZ wind farm the maximum calculated loss is 2.1%.

Although the OWEZ wind farm is more often in the direction of the main wind resources seen from the HKN location the additional losses for the OWEZ wind farm are slightly lower than for the Prinses Amalias wind farm. This is most likely due to the fact that OWEZ is at a larger distance to the HKN wind farm compared to Prinses Amalia which h is actually enclosed by the HKN wind farm zone.

Other reasons that influence the results are that the wind turbines at Prinses Amalia wind farm have a lower hub height of 59 m while the hub height of the OWEZ wind farm is 70 m compared to the hub height of the wind turbines used to design the HKZ wind farms, of 112 m (8 MW) and 128 m (10 MW).

8

References

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[2] B.H. Bulder and E.T.G. Bot. Quick scan of energy production and wake losses of the Borssele Wind Farm Zone including losses for nearby Belgian Wind Farms. Technical Report ECN-E–15-015, ECN, Westerduinweg 3, Petten, August 2015.

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[5] Sergej van de Bilt and Eric Arends. Notitie Reikwijdte en Detailniveau milieueffect-rapporten kavelbesluiten I en II Hollandse Kust (zuid). Pondera Consult, Januari 2016.

Appendix A. The characteristics of the wind turbines

The wind turbine models used for the HKN wind farms in the FARMFLOW analysis have the following power and axial force curve:

Table 8: The wind turbine power curve and axial force coefficients for the wind turbines used to model the HKN wind farms

	8 MW 164 m wind turbine		10 MW 196 m wind turbine	
U [m/s]	P [kW]	C_T [-]	P [kW]	C_T [-]
3	0	0,8126	170	0,8800
4	184	0,8130	503	0,8500
5	577	0,8140	1043	0,8400
6	1127	0,7920	1847	0,8400
7	1871	0,7850	2970	0,8400
8	2872	0,7850	4453	0,8400
9	4146	0,7850	6250	0,8100
10	5642	0,7760	8117	0,7200
11	7022	0,7340	9520	0,6400
12	7760	0,5200	9947	0,4400
13	7967	0,3800	9997	0,3300
14	7997	0,2940	10000	0,2600
15	8000	0,2350	10000	0,2100
16	8000	0,1920	10000	0,1700
17	8000	0,1590	10000	0,1400
18	8000	0,1340	10000	0,1200
19	8000	0,1140	10000	0,1000
20	8000	0,0980	10000	0,0900
21	8000	0,0850	10000	0,0800
22	8000	0,0750	10000	0,0700
23	8000	0,0660	10000	0,0600
24	8000	0,0590	10000	0,0500
25	8000	0,0520	10000	0,0500

Table 9: The wind turbine power curve and axial force coefficients for the wind turbines used to model the OWEZ and Prinses Amalia wind farms

	V90 - 3MW OWEZ		V80 - 2 MW Prinses Amalia	
U [m/s]	P [kW]	C_T [-]	P [kW]	C_T [-]
3.2	0.	0.874	0.	0.818
4.	77.	0.874	66.6	0.818
5.	190.	0.836	154.	0.806
6.	353.	0.805	282.	0.804
7.	581.	0.805	460.	0.805
8.	886.	0.808	696.	0.806
9.	1273.	0.796	996.	0.807
10.	1710.	0.729	1341.	0.793
11.	2145.	0.658	1661.	0.739
12.	2544.	0.572	1866.	0.709
13.	2837.	0.494	1958.	0.409
14.	2965.	0.376	1988.	0.314
15.	2995.	0.296	1997.	0.249
16.	3000.	0.240	1999.	0.202
17.	3000.	0.199	2000.	0.167
18.	3000.	0.167	2000.	0.140
19.	3000.	0.142	2000.	0.119
20.	3000.	0.122	2000.	0.102
21.	3000.	0.105	2000.	0.088
22.	3000.	0.092	2000.	0.077
23.	3000.	0.081	2000.	0.067
24.	3000.	0.072	2000.	0.060
25.	3000.	0.064	2000.	0.053
25.5	1500.	0.0405	1000.	0.0335
26.	0.	0.	0.	0.

Appendix B. The HKN areas and location of 8 and 10 MW designs

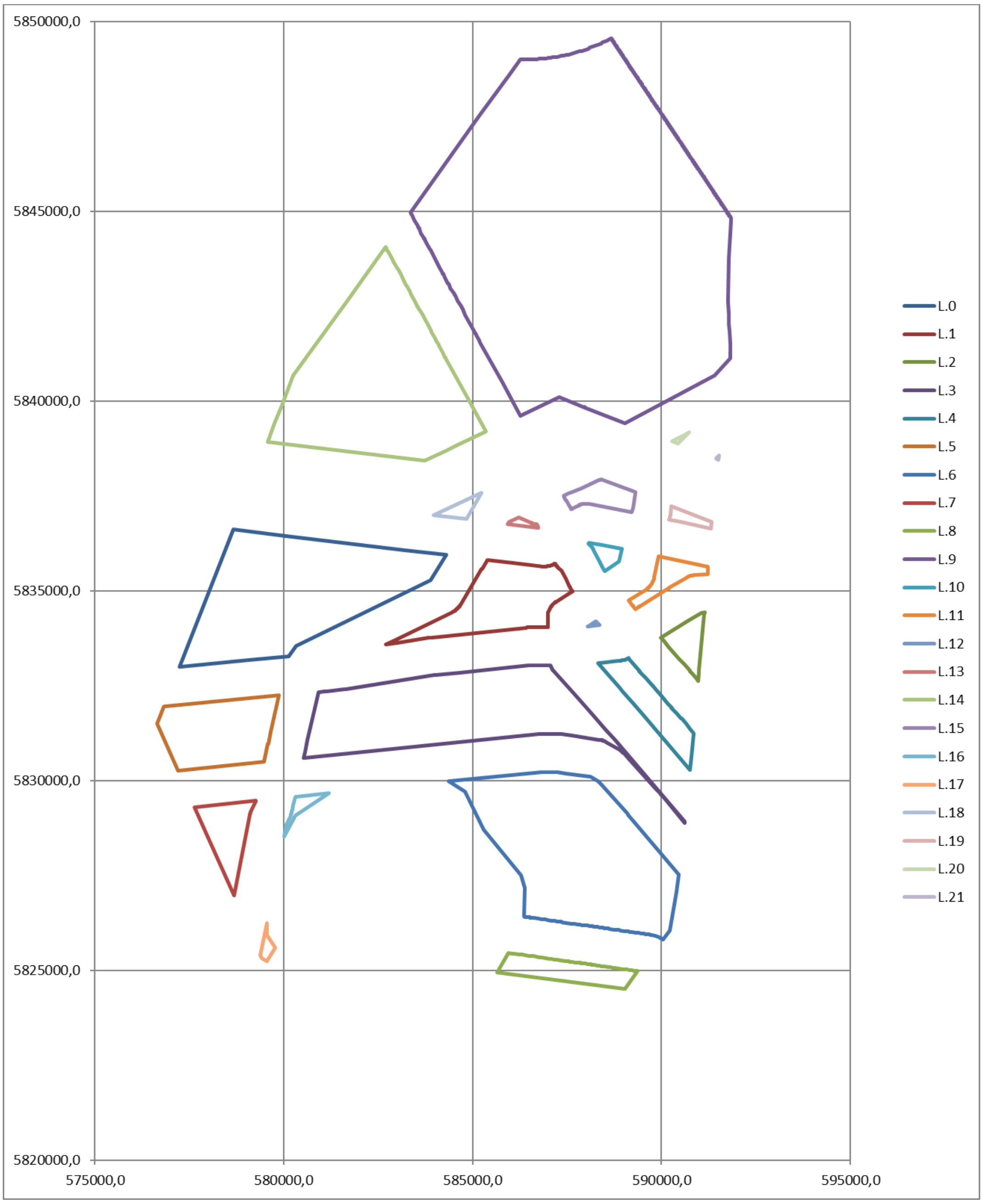

Figure 10: The HKN site split up into 22 separate areas

The tables with the coordinates of each area are listed in the Excel attachment to this report. The locations of the wind turbines of the 8 and 10 MW designs are also listed in the excel attachment to be downloaded from the ECN website.

Appendix C. Lay-out of the existing wind farms

Table 10: The lay-out of the OWEZ Wind Farm, in UTM coordinates, consisting of 36 Vestas V90-3MW with a hub height of 70 m.

Turbine	X	Y	Turbine	X	Y
#	[m]	[m]	#	[m]	[m]
1	597181.9	5826380	19	595384.9	5829940
2	596756.9	5826863	20	594959.9	5830424
3	596339.9	5827338	21	594534.9	5830908
4	595914.9	5827822	22	598548.9	5827853
5	595490.9	5828305	23	598119.9	5828338
6	595065.9	5828789	24	597695.9	5828826
7	594633.9	5829281	25	597038.9	5829572
8	594208.9	5829764	26	596560.9	5830116
9	593783.9	5830248	27	596135.9	5830600
10	593366.9	5830739	28	595710.9	5831084
11	592933.9	5831216	29	595285.9	5831568
12	592508.9	5831700	30	598868.8	5828998
13	598189.9	5826748	31	598446.9	5829486
14	597764.9	5827232	32	597796.9	5830224
15	597339.9	5827715	33	597312.9	5830776
16	596914.9	5828199	34	596887.9	5831260
17	596234.9	5828973	35	596462.9	5831744
18	595809.9	5829457	36	596037.9	5832228

Table 11: The lay-out of the Prinses Amalia Wind Farm, in UTM coordinates, consisting of 30 Vestas V80-2MW wind turbines with a hub height of 59 m.

Turbine	X	Y	Turbine	X	Y
#	[m]	[m]	#	[m]	[m]
1	580549	5826228	31	584439	5827608
2	581045	5825990	32	584906	5827318
3	581541	5825752	33	585373	5827027
4	582037	5825515	34	581587	5828734
5	582483	5826385	35	582059	5828452
6	582970	5826130	36	582531	5828170
7	583457	5825875	37	583004	5827888
8	583944	5825620	38	583476	5827606
9	584432	5825365	39	583948	5827323
10	580529	5826802	40	584420	5827041
11	581021	5826556	41	584892	5826759
12	581513	5826310	42	585364	5826477
13	582004	5826064	43	581070	5828385
14	582496	5825818	44	581547	5828111
15	582988	5825571	45	582026	5827839
16	583480	5825325	46	582502	5827566
17	584024	5829007	47	582980	5827293
18	583073	5829056	48	583457	5827020
19	583534	5828757	49	583934	5826747
20	583996	5828458	50	584412	5826473
21	584457	5828159	51	582490	5826971
22	582105	5829063	52	582972	5826707
23	582572	5828772	53	583454	5826443
24	583039	5828481	54	583937	5826179
25	583505	5828191	55	584419	5825915
26	583972	5827900	56	584902	5825651
27	584889	5826200	57	580533	5827405
28	581043	5827763	58	581021	5827150
29	581525	5827499	59	581508	5826895
30	582007	5827235	60	581995	5826640

Appendix D. FarmFlow

For the accurate prediction of wind turbine wake effects in (large) offshore wind farms, ECN has developed the software tool . FARMFLOW calculates the average velocities and turbulence levels inside a wind farm. A boundary layer model is used for the calculation of the free stream wind speed and can be used for assessments for different atmospheric stability conditions. Currently FarmFlow is extended to include an assessment of mechanical loads on the wind turbines.

For the validation of FARMFLOW, a large amount of accurate experimental data from Nordex N80 2.5MW wind turbines from ECN Wind Turbine test station Wieringermeer (EWTW) has been used. Additionally, experimental data from three large offshore wind farms have been applied.

The calculated wake velocity deficits and turbulence intensities agree very well with experimental data for all wind speeds and ambient turbulence intensities. Excellent agreement between calculated and measured turbine performance is found. FARMFLOW tends to slightly overestimate the generated turbulence intensity.

The wake model in FARMFLOW is based on a 3D parabolised Navier-Stokes code, using a k-epsilon turbulence model to account for turbulent processes in the wake. The ambient flow is modelled in accordance with the method of Panofsky and Dutton[1].
The free stream wind as a function of height is calculated for a prescribed ambient turbulence intensity and Monin-Obukhov length, which takes the atmospheric stability into account.

[1] Atmospheric turbulence: models and methods for engineering applications / Hans A. Panofsky, John A. Dutton

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