DBS Offshore Wind

RWE Renewables UK Dogger Bank South (West) Limited

RWE Renewables UK Dogger Bank South (East) Limited

Dogger Bank South Offshore Wind Farms

Wake Effects - Response to ISH3 Action Points Submission for Deadline 8 (Revision 2) (Tracked)

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01	N/A	N/A	Submitted for Deadline 4.
02	11	2	Correction of minor error on request of the Projcos to indicate how the 55% capacity factor should be used to calculate total energy loss, rather than implying that it had been used as in the original text.

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Glossary

Term	Definition
4C Offshore	A commercial source of information about wind farm projects globally, widely used within the offshore wind sector.
Annual Energy Production (AEP)	The calculated amount of energy a project will produce, typically given in gigawatt-hours per year. See also Capacity Factor.
Awl y Môr	The Awl y Môr (AyM) wind farm, a planned extension to the Gwynt y Môr (GyM) wind farm (see also GyM).
Capacity Factor	The ratio of energy produced (or predicted to be produced) at a wind farm vs the energy it could produce if it ran at full capacity 100% of the time. Convertible to an AEP by multiplying wind farm-capacity by hours per year.
Curtailment	Reducing the power of a turbine or farm for a given wind speed, usually to protect some other component of the power system (turbine, export cable, grid stability, etc).
Dogger Bank South (DBS) Wind Farms	The collective name for the two Projects, DBS East and DBS West.
Environmental Impact Assessment (EIA)	A statutory process by which certain planned projects must be assessed before a formal decision to proceed can be made. It involves the collection and consideration of environmental information, which fulfils the assessment requirements of the EIA Directive and EIA Regulations, including the publication of an Environmental Statement (ES).
ERA5	A freely available global dataset of weather information from present day back to 1940.
EV DAWM	A wake model which extends a model developed by Ainslie in 1998 with a Deep Array Model attempting to account for the effects of large wind farms.
Global Blockage Effect (GBE)	The effect on the atmosphere created when a large wind farm "blocks" the flow of wind. Can be characterized both by slowing of wind (upstream of a wind farm) and acceleration of the wind (often to the sides and behind a wind farm).
Gwynt y Môr	The Gwynt y Môr (GyM) wind farm off the north coast of Wales.
Openwind	An industry standard wind farm modelling software developed by UL.

Term	Definition
Reynolds Averaged Navier Stokes Computational Fluid Dynamics (RANS CFD)	A widely-used and very accurate method of simulating fluid flows, but slow and with large costs to run for a wind farm.
Turbine Interactions/Interaction modelling	Shorthand for turbine-atmosphere interactions. An overarching term to encompass wakes plus other effects e.g. blockage, gravity waves, etc.
TurbOPark	A wake model developed by Orsted.
The Applicants	The Applicants for the Projects are RWE Renewables UK Dogger Bank South (East) Limited and RWE Renewables UK Dogger Bank South (West) Limited. The Applicants are themselves jointly owned by the RWE Group of companies (51% stake) and Masdar (49% stake).
The Projects	DBS East and DBS West (collectively referred to as the Dogger Bank South Offshore Wind Farms).
UL	Formerly Underwriter's Laboratories. A company with a wind consultancy division, which also produces software. See Openwind.
Wake	The area of reduced windspeed behind a wind turbine caused by the removal of momentum and energy by the wind turbine.

Acronyms

Acronym	Definition
AEP	Annual Energy Production
AP	Action Point
AyM	Awl y Môr
DBA	Dogger Bank A wind farm (under construction)
DBB	Dogger Bank B wind farm (under construction)
DBC	Dogger Bank C wind farm (pre construction)

Acronym	Definition
DBS	Dogger Bank South
ECMWF	European Centre for Medium-Range Weather Forecasts
EIA	Environmental Impact Assessment
ES	Environmental Statement
EV	Eddy Viscosity
DAWM	Deep Array Wake Model
GBE	Global Blockage Effect
GyM	Gwynt y Môr
ISH3	Issue Specific Hearing 3
NDA	Non-disclosure agreement
OEM	Original equipment manufacturer
RANS CFD	Reynolds Averaged Navier Stokes Computational Fluid Dynamics

1 Introduction

1. This document responds to Action Points 19 and 22 raised at Issue Specific Hearing 3 (ISH3).

2. As noted during the hearings and the Applicants' submissions, the Applicants do not consider that wake effects are a matter that should be dealt with in the planning system and therefore wake assessment information included in this document is submitted on a without prejudice basis.

3. It is the Applicants' understanding that the Action Points [EV8-010] have been raised by the ExA for the purposes of applying the Environmental Impact Assessment (EIA) Regulations in its recommendation to the Secretary of State.

4. This report is constructed as follows:

- Sections 2, 3, and 4 present the input data, methods and results, respectively. These sections are provided to illustrate that common industry methods and data were used in these assessments provided
- Sections 5 and 6 draw out the conclusions to the modelling, and address Action Point (AP) 22 from ISH3 regarding the original wake assessment conclusion and the Applicants' original Environmental Statement (ES) conclusion.
- Finally, section 7 responds to Action Point 19 from ISH3 in relation to mitigation measures for wake effects.

2 Inputs and Assumptions

5. In assessing the wake interactions between both wind turbines and wind farms a range of input data are required. These predominantly fall into three categories:

- Climatology – the wind and other atmospheric conditions at the site(s) and how they vary throughout the year, including variation in the direction of the wind;
- Wind farm configuration – the layouts of the turbines (as well as any curtailments etc);
- Wind turbine characteristics – the power and thrust curves showing how the turbines respond to the wind.

6. The available sources of these are presented in the following sub-sections.

7. Note that the performance of the wind farms within the simulation, e.g. the capacity factor, are outputs and not inputs. No assumptions have been made about the wind farm performance other than the points outlined above. When calculating the impact of Dogger Bank South (hereafter referred to as 'the Projects') on DBA, a capacity factor of 55%[1] for DBA has been should be used to scale results as the Dogger Bank Projcos have stated this value in their Deadline 3 submissions [REP3-063] which will have taken into account additional information not available to the Applicants, such as electrical losses etc. The Applicants note that the capacity factor for the Projects is confidential. Thus, the total annual energy lost would be [MWh_lost = wake_loss% × 55% × farm_capacity_MW × hours_per_year].

8. In modelling the impact of one wind farm on another, it is not valid to only include those two wind farms in the simulation. Any other wind farms that have a meaningful impact on either of these wind farms must also be included. For example, in this case the impact of DBA on Dogger Bank B (DBB) would likely be reduced by the existence of the Projects. Thus, to assess DBA and DBB, the Projects would also need to be modelled. It is also important to note that wind farms on all points of the wind rose are considered, not just those in the prevailing wind direction.

2.1 Wind Data

9. The Projects have been assessed using wind data from the Cavendish LiDAR, with a period of 4.5 years. Lidar data was collected using a ZX300 device, which was installed on the Cavendish platform located at 54.47° N, 1.73° E. The LiDAR measurement campaign was planned as part of the Forewind Consortium comprising several offshore developers, including RWE, which promoted the four original Dogger Bank projects (DBA, DBB, Dogger Bank C (DBC), and Sofia).

10. The data was prepared following industry standard processes, and corrected to the long-term using the European Centre for Medium-Range Weather Forecasts (ECMWF) 5th generation Atmospheric Reanalysis dataset (ERA5). The ERA5 Reanalysis dataset is a freely available dataset, giving wind and weather values for the whole globe since 1940. The dataset is widely used within the wind industry.

11. Data from the nearest ERA5 node to the Cavendish platform lidar measurement with a period of 17 years from 2004 to 2020 was used (a period for which the model is considered stable). The wind rose is depicted in **Figure 1**. Additional inputs for wake modelling including turbulence intensity were taken from a nearby met mast (Dogger Bank West) with similar wind conditions. The stability and the boundary layer height were also taken from ERA5.

[1] Deadline 3 Submissions - DBA Projco, DBB Projco and DBC Projco - 19 March 2025 [REP3-063]

2.2 Wind farms, Layouts and Turbines

12. All wind farms partially or wholly within 100km of DBS that have been consented (at time of writing) have been included in the simulation (see **Figure 1**). The assumed layouts of the included wind farms are as shown in **Figure 2**.

13. The distance of 100km is common practice in RWE's internal methods. Including wind farms at greater distance is unrealistic. Furthermore, the models are not validated beyond ~50km, meaning that for wind farms between 50km and 100km and beyond expert judgment must be applied.

2.2.1 DBS

14. At the time of this assessment the design of the Projects is not finalised, and an envelope of turbine types, sizes and layout options is still under consideration to deliver the lowest cost clean energy. The assumed layout and turbine used for the Projects are considered to provide a realistic "worst case" scenario for wake impacts on DBA.

2.2.1.1 Layout

15. In this assessment a layout of 100 15MW wind turbine generators, with a rotor diameter of 236 meters has been considered. The layout is constrained to the shaded areas in **Figure 2**. As with the layouts for the other Dogger Bank sites (DBA, DBB, DBC, Sofia), it is characterised as a "perimeter layout" in which a rectilinear grid is used for the internal array, and a higher density of turbines is placed around the perimeter. This layout has been carefully designed and will be finalised post-consent.

2.2.1.2 Turbine Type

16. The thrust and power curves used for the Projects, provided under NDA by a wind turbine manufacturer, are considered realistic and appropriate.

2.2.2 DBA

17. DBA has been modelled based on publicly available information. Further details regarding the DBA inputs used are provided in the sub-sections below.

2.2.2.1 Layout

18. The turbine coordinates for DBA have been taken from 4C Offshore.

2.2.2.2 Turbine Type

19. The turbine at DBA has been publicly announced to be the GE 13 MW Haliade turbine. The Applicants have not been provided with the power curves for DBA and would not expect to be provided with these due to NDAs[2].

20. Additionally, it has been assumed that DBA will build 1235 MW of capacity and not curtail due to overplanting or any other operational reason. If the operating strategy of the project is different that may also have a substantial impact on the results. The capacity has been taken from 4C Offshore.

2.2.3 Other Wind Farms

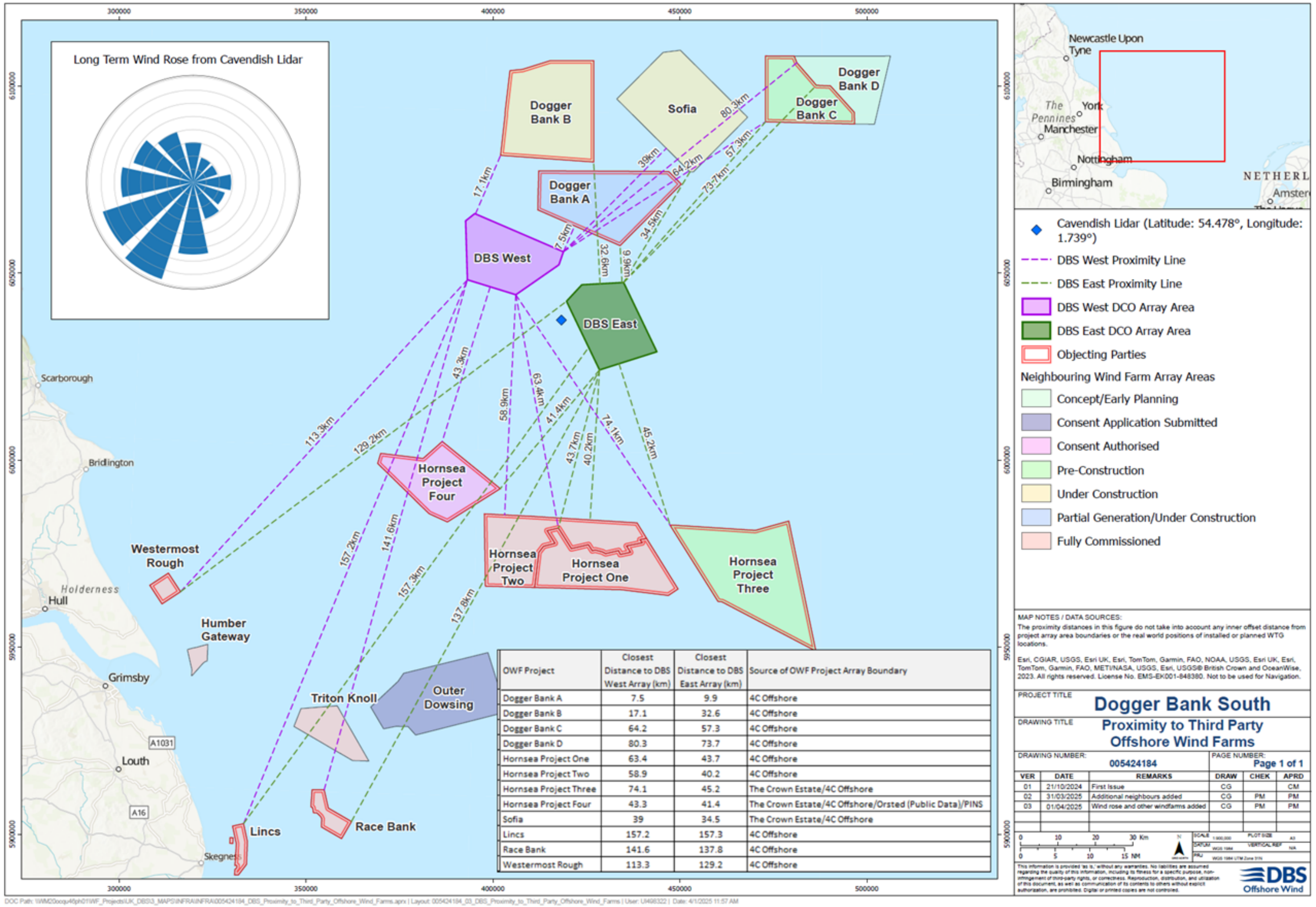
21. A summary of assumptions used for other wind farms included in the modelling (as well as the above wind farms) is given in **Table 1**. Power and thrust curves are those available to RWE under appropriate NDAs.

Table 1: Wind farm parameters used in this study

Wind Farm	Turbine Type	Power Curve Source	Turbine Capacity (MW)	Wind farm Capacity (MW)	Rotor Diameter (m)	Number of Turbines	Hub height (m)	Layout source
Dogger Bank A	Haliade-X 13 MW	GE non-project specific	13	1235	220	95	139	4C Offshore
Dogger Bank B	Haliade-X 13 MW		13	1235	220	95	139	4C Offshore
Dogger Bank C	Haliade-X 14 MW		14	1218	220	87	138	4C Offshore
Sofia	SG 14-222 DD	Project specific information	14	1400	220	100	141	RWE Internal
Hornsea Project 1	SWT-7.0-154	SGRE information from other projects	7	1218	154	174	113	4C Offshore
Hornsea Project 2	SG 8.0-167 DD		8.4	1386	167	165	120.9	4C Offshore

[2] Power curves for the different variations of the turbines are shared by the OEM under NDA, and hence the underlying curves cannot be shared between developers or published here.

Wind Farm	Turbine Type	Power Curve Source	Turbine Capacity (MW)	Wind farm Capacity (MW)	Rotor Diameter (m)	Number of Turbines	Hub height (m)	Layout source
Hornsea Project 3	SG 14-236 DD (15MW power boost)		15	2955	236	197	158	RWE Assumption
Hornsea Project 4	Not Known - assumed same as HP3		15	2400	236	160	158	RWE Assumption
DBS East & West	Representative 15 MW Turbine	Manufacturer Information	15	2 x 1500	236	2x100	152	RWE Assumption



OWF Project	Closest Distance to DBS West Array (km)	Closest Distance to DBS East Array (km)	Source of OWF Project Array Boundary
Dogger Bank A	7.5	9.9	4C Offshore
Dogger Bank B	17.1	32.6	4C Offshore
Dogger Bank C	64.2	57.3	4C Offshore
Dogger Bank D	80.3	73.7	4C Offshore
Hornsea Project One	63.4	43.7	4C Offshore
Hornsea Project Two	58.9	40.2	4C Offshore
Hornsea Project Three	74.1	45.2	The Crown Estate/4C Offshore
Hornsea Project Four	43.3	41.4	The Crown Estate/4C Offshore/Orsted (Public Data)/PINS
Sofia	39	34.5	The Crown Estate/4C Offshore
Lincs	157.2	157.3	4C Offshore
Race Bank	141.6	137.8	4C Offshore
Westermost Rough	113.3	129.2	4C Offshore

Figure 1: Map of wind farms and wind rose

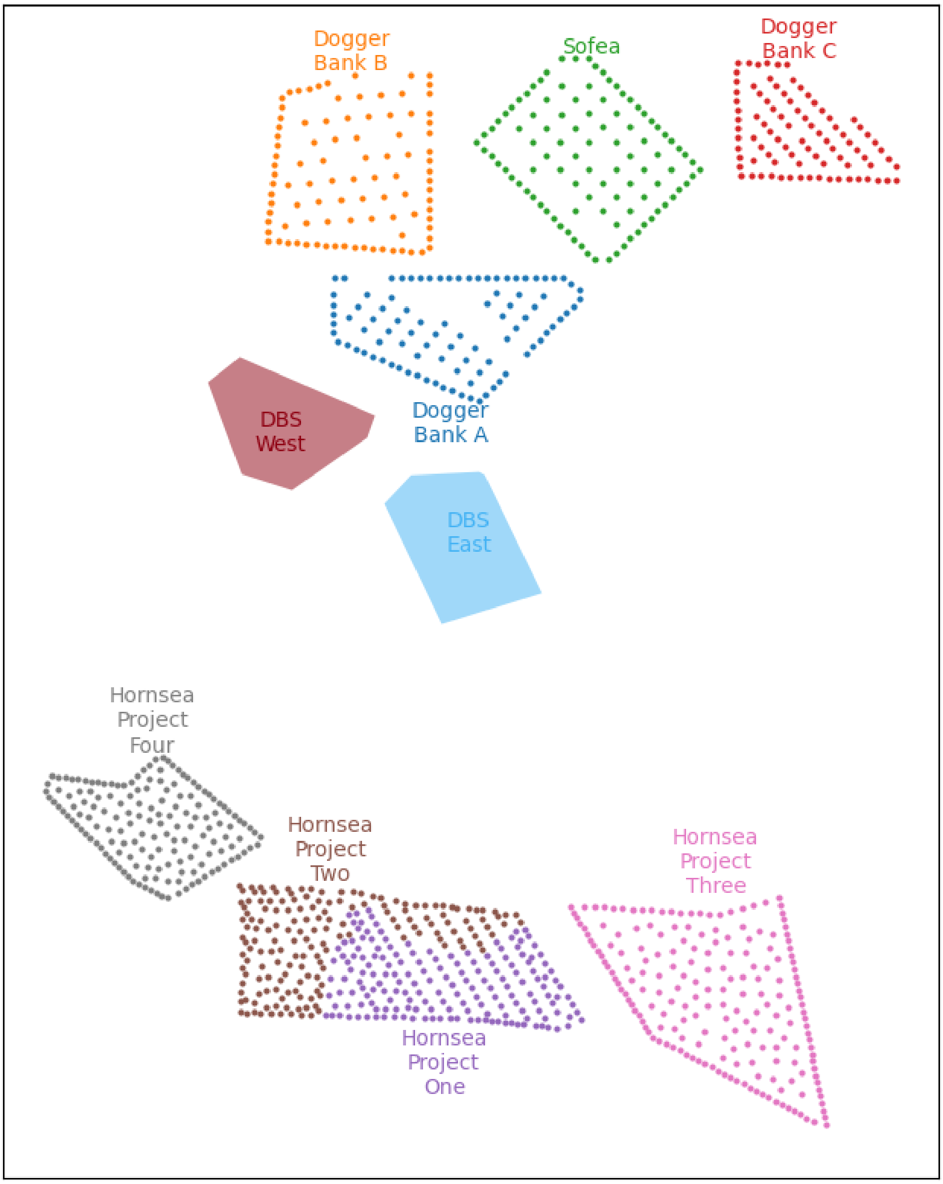


Figure 2: Assumed configuration of receptor wind farms

3 Method

22. The estimates of the wake impact of the Projects on DBA were carried out using methods commonly applied by resource and yield analysts of developers and consultancies. As there is no consensus on which wake model(s) are most appropriate or "industry standard" in all cases, two publicly available models have been run, in addition to the internal RWE model used for the original ES, and the results presented in section 4.

23. This section gives a brief description of the modelling methods applied.

3.1 Horizontal and Vertical Extrapolation

24. The wind regime was extrapolated horizontally (to the locations of turbines) and vertically (to the hub-height of turbines) using industry standard methods.

3.2 Interaction Modelling

25. Interaction modelling (wakes, blockage, etc) is a constantly developing area of research, and there is no consensus on an "industry standard" approach. As such, results from several commonly used models are presented below.

26. Note that advancements specifically relevant to this work are currently under development, so values calculated in the future are likely to deviate from those presented here. Some examples of such areas of research are:

- improved representation of "rotor equivalent wind"[3];
- the impact of gravity waves[4]; and
- the impact of Coriolis forces reducing the impact of wake[5].

27. A brief overview of the models used is given in the following sections. Unless otherwise stated, the implementation of each model in the energy modelling software OpenWind was used.

28. Note that other commonly applied models were tested such as NO Jensen and Bastankhah. However, these were found to give unrealistically low estimates of the impact of the Projects on DBA (less than 1/3rd the estimates by other models) and have hence not been included in this assessment.

[3] Estimating the impact of the heterogeneous flow over the rotor rather than taking a point estimate of the wind speed at the nacelle. See, for example, Ali, K., Ouro, P., and Stallard, T.: Direct integration of non-axisymmetric Gaussian wind-turbine wake including yaw and wind-veer effects, Wind Energ. Sci., 10, 511–533, [redacted] 2025.

[4] The deflection and rebound of the stable upper atmosphere caused by the thrust of the wind farm which can have significant impact on the "global blockage". See, for example, Rodaway, C., Williams, S.: Large Rotors, the Atmosphere and Gravity Waves: What Are the Risks, Wind Europe Technology Workshop, June 2024

[5] Recent work suggests that farm-farm wakes could be reduced by Coriolis forces associated with the earth's rotation. These effects are currently neglected in engineering wake models. See, for example, Smith, R. B. and Gribben, B. J.: Coriolis Recovery of Wind Farm Wakes, Wind Energ. Sci. Discuss. [preprint], [redacted], in review, 2025.

3.2.1 EV DAWM

29. Ainslie's Eddy Viscosity (EV) model[6] (Ainslie, 1988) is a commonly used commercially available tool for turbine-interaction loss assessment. It is based on a solution of the Navier-Stokes equation and the recovery of the wake depends on the turbulence intensity. More turbulence result in more mixing of the waked wind with the freestream wind around it, so the wake spreads quicker and the wind recovers sooner. The default model settings were used, which represent the validated version of the model.

30. In combination with the standard EV model, a Deep Array Wake Model (DAWM)[7] has been used, which adds a boundary layer wake model developed by the wind energy consultancy division of UL. Each individual turbine is modelled as an area of increased friction between the wind and the ground. The effect is modelled separately from the EV model and then combined by taking the maximum of the roughness effect and the standard wake effect. The deep array effect emerges gradually and naturally as more rows of turbines are added.

31. This implementation of the EV wake model (or similar ones such as the DNV's Eddy Viscosity with Large Wind Farm Correction) are some of the most trusted engineering models available and were used in the design and evaluation of most offshore farms pre ~2018, and are still widely used by consultants.

3.2.2 TurbOPark + Correction

32. TurbOPark is an engineering model developed and published by Ørsted, and has been adopted by several consultancies. For example, this was the model used by Fraser Nash consultancy for the work undertaken for The Crown Estate[8].

33. However, it should be noted that the available implementations of Turbo Park lack a "Global Blockage Effect" (GBE) correction, which is applied by Ørsted when using the model.

34. As illustrated in **Figure 3**, while the wind farm's wake represents the reduced windspeed behind a wind farm due to the removed momentum in generating electricity, GBE is characterised by a deceleration upstream of a farm, and acceleration to the sides and behind. The magnitude of the total impact will depend on the size of the cluster and the atmospheric conditions at the site.

6 [redacted]

7 [redacted]

8 Offshore Wind Leasing Programme, Array, Layout Yield Study, 5 October 2023, Fraser Nash Consultancy [AS-014]

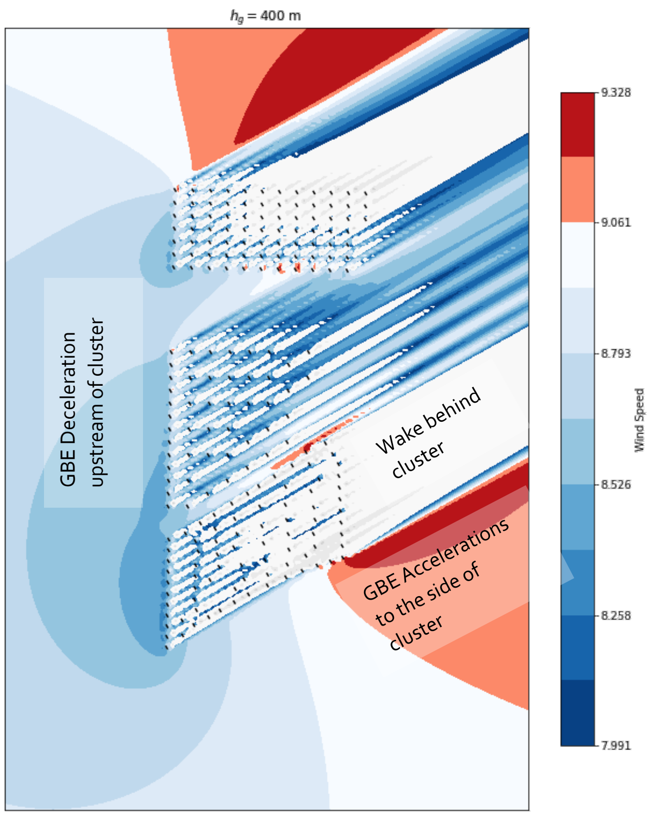


Figure 3: Wake and Blockage

35. It has been found that due to the size of the wind farms, and the atmospheric conditions at the Dogger Bank cluster (DBA, DBB, DBC, Sofia), that GBE will have a significant impact; especially for models such as TurbOPark where the effects are not implicitly captured.

36. As such it is considered inappropriate to use the raw results from TurbOPark in sites where global blockage will play a significant role (as in the Dogger Bank cluster). Thus results here are corrected by applying the Blockage correction used in VV3.4 (see below) which is a very similar implementation to that used by Ørsted.

3.2.3 VV3.4

37. VV is the in-house engineering model used by RWE. Version 3.4 (the version current at the time) was used for the assessment reported in the original ES [APP-130]. This model is commercially confidential. It uses a similar Eddy Viscosity wake model to the EV models listed above, but a bespoke coupling between the individual wakes and the GBE. This results in a slower running model, but increased accuracy.

38. The blockage model applied (and used for the TurbOPark Correction) is a Rankine Half Body based correction with a "semi-hard lid" applied at the top of the atmospheric boundary layer. This is generally similar to the approach presented by Ørsted at various conferences.

3.3 Interannual Variability

39. It is conventional to estimate the yield (and wake) of a wind farm for an "average year" (variations in annual generation are generally normally distributed, hence here average = mean = median). However, natural variation in the wind conditions between years can lead to a significant variation in generation, which must also be considered when assessing yield risk.

40. Here, interannual variability has been estimated using the VV3.4 wake model to calculate the yield of DBA for each of the 17 years[9] of ERA5 wind data. The annual variability, expressed as a percent, is then the standard deviation of these 17 independent yield values divided by the mean. Further discussion of interannual variability is provided in section 6.4.

4 Results

41. The estimated reduction on the annual energy production (AEP) of DBA arising from DBS, derived from the three wake models, is presented in **Table 2**.

42. The AEP in a given year will fluctuate significantly due to the natural variability of the wind. The standard deviation of inter-annual variability has also been estimated and is presented in **Table 2**.

Table 2: Results on the impact of DBS on the AEP of DBA; and the interannual variability of DBA. Note: external wakes are commonly assumed to have a standard error uncertainty of ±25%

	EV DAWM	TurbOPark (Corrected)	VV3.4
Impact of DBS on DBA [%]	1.94	1.97	2.06
Interannual Variability [%]	5.4 (Assumed)		5.4

[9] Individual years are statistically independent thus the standard deviation calculated here is a non-biased estimator of the true variability.

5 Conclusion

43. Wake modelling is an actively developing area of both science and industry practice. There are multiple active research projects to inform both industry and policy makers in the UK[10] in Europe [11] and in the US[12] and as such this is not a settled science with clear best practice.

44. The results in **Table 2**, for the "worst case" buildout scenario presented, cluster around 2%. It is assumed that an AEP loss on the order of 2% from DBS East and West on DBA.

45. These results are only a central estimate and are uncertain. It is standard in the industry to take a percentage of the wake loss as the measure of uncertainty. As there is no consensus on the appropriate percentage, the Applicants have adopted 25%, which is a commonly accepted percentage among consultants in the industry. Furthermore, no validation is available for turbines or clusters of this size. Applying 25% of the loss as an uncertainty factor would give plus or minus 0.5% as the uncertainty range around the central estimate of 2%.

46. The Applicants consider it is important to understand this in the context of the interannual variability which arises from the natural variation of the weather.

47. **Table 2** shows that the interannual variability (from natural variation in the weather) is 5.4%. Thus, the 2% impact from the Projects is well within the natural variability of the weather.

48. The result of this is that it would take on the order of 20 years of measurement of the annual production of DBA to be able to show, to a 95% confidence, that the impact of DBS was not zero. Its impact is such that it would be 'lost in the noise' of the natural variation of the wind.

49. The result of 2% loss is applicable to DBA, and all other projects will have substantially lower losses, given the extra distances involved, as shown in **Figure 1**. DBA is both the closest wind farm to the Projects (8km) and in the main wind direction. The second closest project (DBB) is more than twice as far from DBS (17.1km, see **Figure 1**), and due to DBA being between the Projects and DBB, it will see more wake loss from DBA rather than the Projects for most wind directions. The Hornsea projects, being more than five times further away from the Projects than DBA, and in a much less frequent wind direction, will see a tiny fraction of this loss.

[10] POUNDS: [redacted]

[11] EuroWindWakes: [redacted]

6 Impact

50. For convenience, Action (AP) 22 from ISH3 [EV8-010] states: "*ES Chapter 16 [APP-130] refers to the effects from wake loss on Dogger Bank A as being negligible in comparison to the wind resource available. Explain, with reference to definitions in Tables 16-6, 16-7 and 16-8 of ES Chapter 16 how this conclusion was reached*".

51. The response to this Action Point is without prejudice to the Applicants' position in relation to the EIA Regulations, its withdrawal of the conclusion of the wake assessment from the ES, and reissuance of Chapter 16.

6.1 Interpretation of EIA Sensitivity and Magnitude Definitions

52. The definitions of sensitivity, magnitude, and significance of effect were derived for the use in assessing physical interactions such as direct damage to a receptor. This is in line with the historical interpretation of the EIA requirements, and these definitions have not been challenged.

53. In Tables 16-6, 16-7 and 16-8 of ES Chapter 16, examples such as "an electrical or telecommunication cable with ability to undertake redundancy planning" are given, indicating the expectation was that the risk to be assessed would be physical damage that required mitigation to safeguard against total failure of the receptor.

54. It is therefore not easy to apply these definitions to wind farm wakes and their transient, indirect impact. There is also little precedent or guidance as to how to apply these definitions to wind farm wakes as this is clearly a novel issue that is developing quickly.

55. With an overall impact in the order of 2% (or less for wind farms other than DBA) on generation, it is implausible that external wake could be considered equivalent to a physical damage risk such as a failed telecommunication cable.

56. A more appropriate alternative would be to consider the wind farm's capability to handle the natural variation in available wind resource (e.g. annual weather variations, climate change, or other wind farm wakes).

57. It is a requirement that all wind farms be able to continue successful operation under these naturally uncertain fluctuations, and thus the "pathway to impact" that should be considered is the implication to this capability.

6.2 Receptors

58. The relevant receptors are the four Dogger Bank wind farms as well as the Hornsea projects. This assessment has quantified the impacts only at DBA as, as due to its proximity, it will be most impacted. All other receptors will be significantly less impacted (at least an order of magnitude in the case of the Hornsea projects). Thus, if the impact on DBA is not significant in EIA terms then so will the conclusion for all other wind farms.

6.3 Sensitivity

59. "Interference" is taken to mean direct interference with the receptor. The wake effects dimension of an offshore wind farm fall into an unusual category which, as noted, there is no guidance or custom or practice. The Applicants' headline position is that this cannot properly be regarded as an 'environmental effect'. Forced to bring it within this framework, the Applicants consider that the sensitivity to wake effects in an EIA context, the most applicable rating would be **Low**. This takes account of the context of The Crown Estate's buffer system, which has taken account of wake effects as a factor in the distance set.

6.4 Magnitude

60. The impact magnitude is assessed to be **negligible**. As shown above, the loss (worst case scenario wind farm buildout) is estimated to be ~2%. This is below the background level of environmental fluctuation in energy yield simply from variations in weather, which is 5.4%.

61. As such, after the Projects have been constructed, DBA is still expected to see above pre DBS generation estimates over 35% of the time. The probability that the Projects will see above-average yield in a given year will reduce by only 15%.

62. As stated already in paragraph 48 it would take on the order of 20 years of measurement of the annual production of DBA to be able to show, to a 95% confidence, that the impact of the Projects was not zero. Its impact is such that it would be 'lost in the noise' of the natural variation of the wind.

6.5 Significance

63. Given the **low** sensitivity and **negligible** magnitude of the receptor identified above, the significance of potential effect of wake loss is considered to be **negligible** (**Table 3**). Even if the magnitude were regarded as Low or the sensitivity was regarded as medium, the conclusion would be minor adverse. This is not significant in EIA terms, and as such mitigation is not required (as noted in section 6.7.3.4 of **Chapter 6 EIA Methodology** [APP-076]).

Table 3: Significance of effect matrix (as Table 6-8 in Chapter 6 Environmental Impact Assessment Methodology [APP-076])

		Adverse Magnitude			
		High	Medium	Low	Negligible
Sensitivity	High	Major	Major	Moderate	Minor
	Medium	Major	Moderate	Minor	Minor
	Low	Moderate	Minor	Minor	Negligible
	Negligible	Minor	Negligible	Negligible	Negligible

`

7 Mitigations

64. As noted above, the Applicants' without prejudice conclusion of significance of effect of the external wakes of the Projects on DBA is **negligible**, and hence not significant in EIA terms and requiring no mitigation.

65. Despite this conclusion, multiple mitigation methods have been proposed, primarily in academia, and reviewed, and results are presented in this section as requested by the ExA during ISH3 in response to AP19.

7.1 Reasonable Mitigation

66. It is clear that should a wake mitigation be applied, it must be "reasonable". No appropriate definition of what would be a "reasonable mitigation" exists, but the following three criteria adopted here are given in **Table 4**.

Table 4: Criteria for a Reasonable Mitigation

Criterion	Description
1: Meaningful Impact	A reasonable mitigation must have a meaningful impact, i.e. a reduction from 2% loss to 1.99% loss would be a benefit that is within the error margins of the modelling methods and unlikely to be realised in reality (and may be reversed if a different wake model were used).
2: Net Positive	A reasonable mitigation would not significantly harm the net generated renewable energy; e.g. to take an extreme example, if a wind farm must curtail its capacity factor by half to bring a 1% gain to another, that would not be considered reasonable.

Criterion	Description
3: Possible and Available	A reasonable mitigation must be proven possible and implementable with available technology by the date of construction of the wind farm.

67. The Applicants' overall conclusion is that there is no current technology or approach that can be applied to mitigate the wakes of one wind farm on another which does not result in a significant overall loss of generation.

7.2 Proposed Mitigations Methods

68. Several commonly considered mitigation methods have been proposed and assessed. The proposed methods are shown in **Table 5** and assessed in the following sections.

Table 5: Wake Mitigation Methods

Mitigation	Description
Buffer Distance	Increasing the space between two wind farms, modifying the footprint of one or both wind farms.
Layout Modification	Changing the placement of the turbines within the wind farm footprint.
Reduced Size and Capacity	Building only part of the new wind farm.
Wake Control	Methods such as wake steering and induction control.
Wake Re-energisation	Methods in which the turbine thrust is cycles to increase turbulence in the wake.
Wind Farm Curtailment	Reducing the generation of the upstream wind farm, normally by modifying the turbine's blade pitch.

7.3 Buffer Distance

69. The distance between the footprint of two wind farms is the "buffer". Increasing this buffer will reduce the wake interaction between two wind farms. However, when the total available space is constrained, increasing this buffer can only be done by reducing the available space for the existing wind farm, increasing the internal wakes at the new wind farm.

7.3.1 Assessment Method

70. RWE has undertaken substantial work to examine wake mitigation strategies in the context of the design of extension projects, and especially at the Awel y Môr (AyM) wind farm. AyM is a planned wind farm off the north coast of Wales, west of Liverpool. It is an extension to the existing wind farm Gwynt y Môr (GyM). Both schemes are majority-owned by RWE, and AyM has no specified buffer to GyM.

71. RWE conducted an in-depth investigation of the optimal buffer between AyM and GyM to attempt to mitigate wake effects.

72. The initial steps of the study compared the performance of wake models, including VV3.4, TurbOPark and RWE's in-house RANS CFD (a highly-accurate but very slow form of modelling).

73. In a series of experiments different footprints for AyM were examined, exploring increasing the buffer distance to GyM. Within the constraint that the outer boundary of the project area remains the same, and the number of turbines must remain the same, the buffer distances that were tested ranged from approximately 1km (representing the normal distance between turbines within a wind farm) and approximately 6km. In total 101 different configurations of AyM were assessed for their energy production and the impact on GyM.

74. In **Figure 4** three representative layouts are shown with buffers of approx. 1km, 3km and 6km. The 1km case is taken as the "baseline" against which the others are compared. The top axis shows the "remaining impact", i.e. the amount of the wake loss caused by AyM on GyM that has been mitigated. The lower axis shows the impact on AEP at both AyM and GyM.

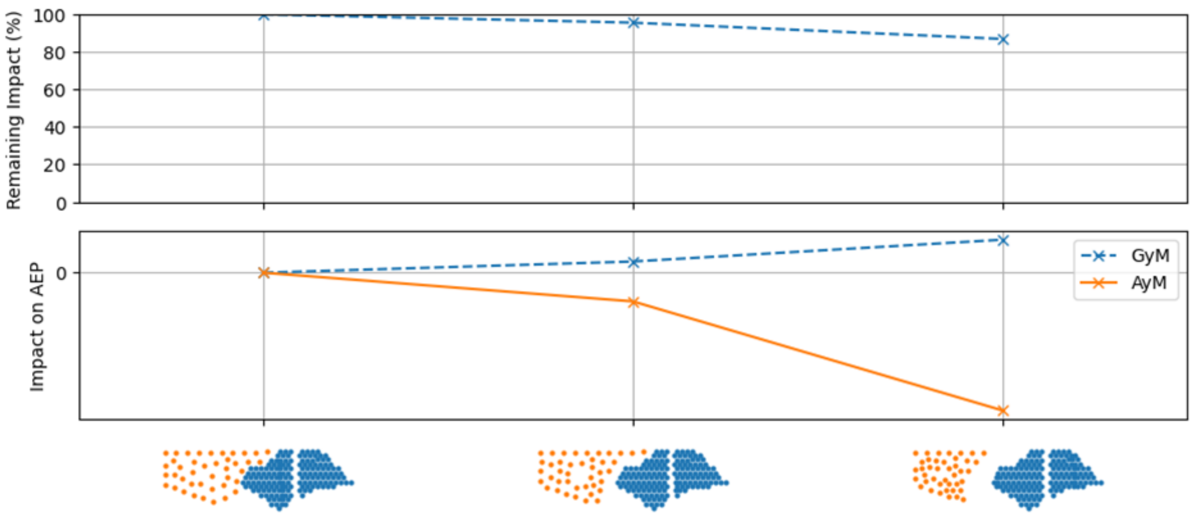


Figure 4: Energy Changes at GyM and AyM due to buffer distance changes

7.3.2 Conclusion on Buffer Distance

75. **Figure 4** shows that:

- Increasing the buffer distance between neighbouring farms has a minimal impact on the total wake loss, with the "remaining impact" being the majority of the impact even after the maximum tested mitigation; and
- The mitigation has a net negative impact, with the energy lost to AyM by mitigation being significantly larger than the gain at GyM.

76. Therefore it fails to meet criteria 1 and 2 of a "reasonable mitigation" presented in **Table 4**.

77. These results are in broad agreement with the study performed by Fraser Nash for The Crown Estate [AS-014], which examines a similar concept in section 2.1.3, finding that net generation drops as a buffer between projects is increased.

7.4 Layout Modification

78. It has been proposed that modifying the layout of a wind farm, within the same footprint could partially mitigate the wake impact on a 2nd wind farm with minimal impact on the first wind farm's production.

7.4.1 Assessment Method

79. The Applicants tested this approach on DBS West and DBA. Only DBS West was considered initially as it was the closer of the two DBS Projects to DBA. No further work was undertaken due to the conclusions from DBS West. The work was done using RWE's in-house layout optimisation tools to run two optimisations:

- Modify the layout of DBS West to maximise the power from DBS West (baseline case, this has been the standard process within the industry); and
- Modify the layout of DBS West to maximise the sum of power from DBS West and DBA.

80. After running this optimisation using a high-speed wake model, the two resulting layouts were then tested in higher-fidelity models.

81. The impact (improvement in yield at DBA) was of the order of ±0.1%, and was negative for some wake models. Thus, it was concluded that the maximum benefit that could be seen was too small to model with existing tools.

7.4.2 Conclusion on Layout Modification

82. The impact of modifying the layout of one wind farm on the wake loss at another over the distance between DBS and DBA is so insignificant that it cannot be reliably reproduced with different wake models. Therefore it fails to meet criteria 1 and 2 of a "reasonable mitigation" in **Table 4**.

7.5 Reduced Size and Capacity

83. One approach to reduction of wind farm wakes is to reduce the footprint and capacity (i.e. overall size) of the "upstream" farm. RWE undertook an analysis to investigate the viability of reducing the capacity of the Projects (by approx. 50%) to reduce the impact on DBA.

7.5.1 Assessment Method

84. This work was predominantly undertaken using the model described in section 3.2.1 (results for which are presented below).

85. Results from three simulations were used here (with reference to **Figure 2**):

- "Baseline" : in which DBS was fully built out (all farms in **Figure 2** as well as DBD)
- "DBS East Only" : as "Baseline" with DBS West removed
- "DBS West Only": as "Baseline" with DBS East removed

86. **Table 6** shows the delta between the baseline and other configurations.

87. As can be seen in **Table 6**, the "benefit" to DBA from the reduced footprint at the Projects is vastly outweighed by the reduced generation of the Projects. The "Loss Ratio" is the loss seen at the Projects relative to the benefit seen at DBA. For the DBS West Only case, the factor is 186, i.e. for every 1MWh gained at DBA, 186MWh are lost at DBS.

Table 6: Impact on AEP of reduced buildout of DBS on DBA

Scenario	Impact on DBS [%]	Impact on DBA [%]	Loss Ratio [-]
DBS East Only	49.75	0.66	186
DBS West Only	49.69	1.30	94

7.5.2 Conclusions on Reduced Size and Capacity

88. Although this method is able to significantly reduce the wake impact at DBA, thus meeting criterion 1, it results in such a significant net loss to generation (approx. half the capacity of the Projects) that it fails to be a reasonable mitigation method for criterion 2 in **Table 4**.

7.6 Wake Control

89. Various wind farm control strategies have been proposed to mitigate wakes, predominantly in academia. The majority of these have been proposed for "internal wakes" i.e. between individual turbines within a single wind farm, rather than between neighbouring wind farms.

90. The following two methods have now reached field trials:

- Wake Steering, in which a leading turbine is misaligned to the wind to cause the wake to move horizontally, missing a downstream turbine; and
- Induction Control, in which a leading turbine is partially de-rated to reduce its impact on a downstream turbine.

91. In both cases, the objective in the literature has been to mitigate internal wakes (i.e. between turbines a few 100m apart) and there is little possibility of applying these approaches between wind farms (minimum 7.5km apart).

92. Wake steering is generally modelled to be able to move the wake horizontally less than a rotor diameter (~100m) which will have negligible effect on turbines 10s of km apart.

93. In all literature modelling, these methods have shown the overall impact (reduced wake) is very small, with numbers of less than 1% gain on AEP being common[13].

94. Finally, it must be noted that there have been no successful demonstrations of these technologies in commercial generation conditions offshore, and these technologies remain unavailable to operators.

7.6.1 Conclusions on Wake Control

95. With reference to **Table 4**, as the benefit from wake control is small (<1%) these methods fail criterion 1. Further, as they are not yet proven in the field and are not available from the OEMs, they fail on criterion 3.

7.7 Wake Re-energisation

96. A recent method to mitigate wake effects involves increasing turbulent structures to enhance mixing of energetic flow above wakes. This requires varying turbine thrust through techniques like "pulsing" blade pitch, which increases fatigue loads and necessitates a complete redesign of turbines and controllers. These methods remain untested outside simulations and show limited success over long distances (and only small gains over small distances), thus they won't be industry-ready for at least 15 years[14].

[13] E.g. Simley, E., Millstein, D., Jeong, S., and Fleming, P.: The value of wake steering wind farm flow control in US energy markets, Wind Energ. Sci., 9, 219–234, [redacted] 2024.

[14] For a review of such methods, see, for example, Yalla, G. R., Brown, K., Cheung, L., Houck, D., deVelder, N., and Hamilton, N.: Spectral proper orthogonal decomposition of active wake mixing dynamics in a stable atmospheric boundary layer, Wind Energ. Sci. Discuss. [preprint], [redacted] in review, 2025.

7.7.1 Conclusions on Wake Re-energisation

97. With reference to **Table 4**, as with wake control, these methods are only likely to have a minimal impact if any, and thus fail on criterion 1. Furthermore, they are even further from commercial availability and would require turbine re-designs, failing on criterion 3.

7.8 Wind Farm Curtailment

98. Wind farm curtailment is an approach in which the turbines are controlled to operate at a lower level for a given wind speed (e.g. extract half as much power at 10m/s), normally by changing the pitch of the blades. The following approaches are available:

- Partial or Full curtailment (e.g. 50% or 100% reduction in power)
- Curtailment at all times or "directional curtailment" in which the curtailment is only applied is specific directions.

99. Directional curtailment is a common control strategy used to mitigate the impacts of loads between closely spaced turbines (100s of m), or to reduce noise impact on high-sensitivity receptors (onshore). RWE are aware of no field trials or even academic literature proposing such an approach to mitigate wake losses – especially between wind farms.

100. It should be noted that although wakes are modelled a coherent structure behind a turbine (a good representation of the average impact), real wakes are far more transient and meander with large flow structures within the wind. Thus, it is not realistically possible to predict if a turbine's wake will impact another turbine or even another wind farm tens of kilometres downstream, or if it will meander around the side. As such, directional curtailment would result in extreme penalties in overall generation.

7.8.1 Assessment Method

101. Despite the above, in addition to the buffering studies performed at AyM, sector management was briefly assessed. A strategy of curtailment was assessed, where all AyM turbines were switched off for wind directions where they would wake GyM (**Figure 5**). This curtailment strategy resulted in a roughly 45.8 GWh loss to AyM and a 1.2 GWh gain at GyM, a completely disproportionate impact, reflecting that this strategy was never intended for wake mitigation.

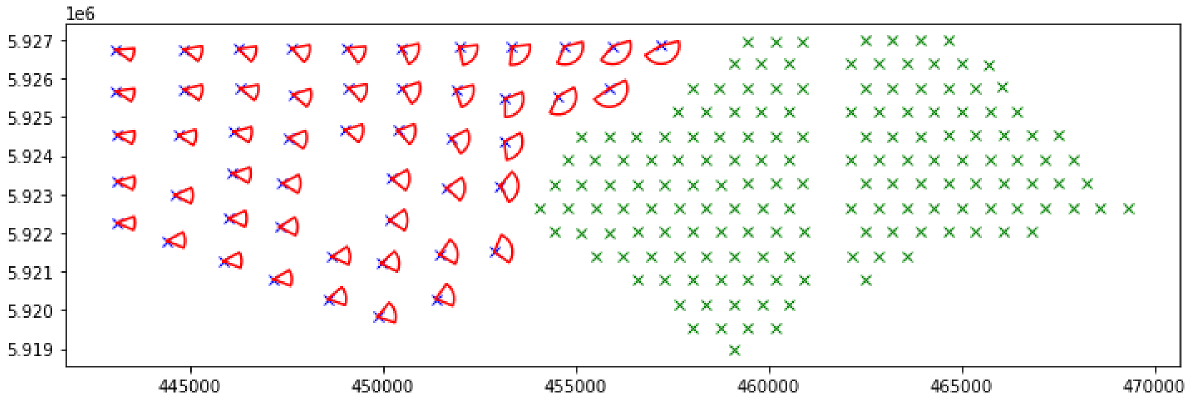


Figure 5: Modelled sectors for which AyM turbines were curtailed

102. Note that the same conclusion will hold for other curtailment strategies. Partial directional curtailment will have a lower but still net-negative impact. Curtailing for wider directions would have a larger and still net-negative impact.

7.8.2 Conclusions on Wind Farm Curtailment

103. It has been shown that curtailment would result in a significant net loss in power, thus failing criterion 2 (**Table 4**). Furthermore, to apply such methods over large distances requires accurate real-time modelling of where the wake from each turbine will flow to ensure curtailment is only applied when the wake would result in a loss. This is far beyond the current state-of-the-art in wind farm control thus failing criterion 3 (**Table 4**).

7.9 An Illustrative Historic Example

104. The implausibility of mitigations is illustrated, for example, in the configuration of the DBA and DBB wind farms. As illustrated in **Figure 6**, both wind farms have followed the now common "perimeter layout" approach in which a high density of turbines are placed around the perimeter, and a lower density within the interior.

105. If it were practically feasible to enhance the AEP of the combined wind farm without adverse effects, considering that DBA and DBB share identical ownership, it would be anticipated that modifications would be made to the nearby regions of the two wind farms. For instance, this could involve reducing the density along that portion of the perimeter and thereby creating a single perimeter layout for the combined farms. This consideration arises despite the closer proximity of DBA and DBB compared to the Projects, making such optimisations more achievable.

106. The Applicants consider that this example supports their position on the lack of reasonable wake mitigation strategies for wake effects between offshore wind farms.

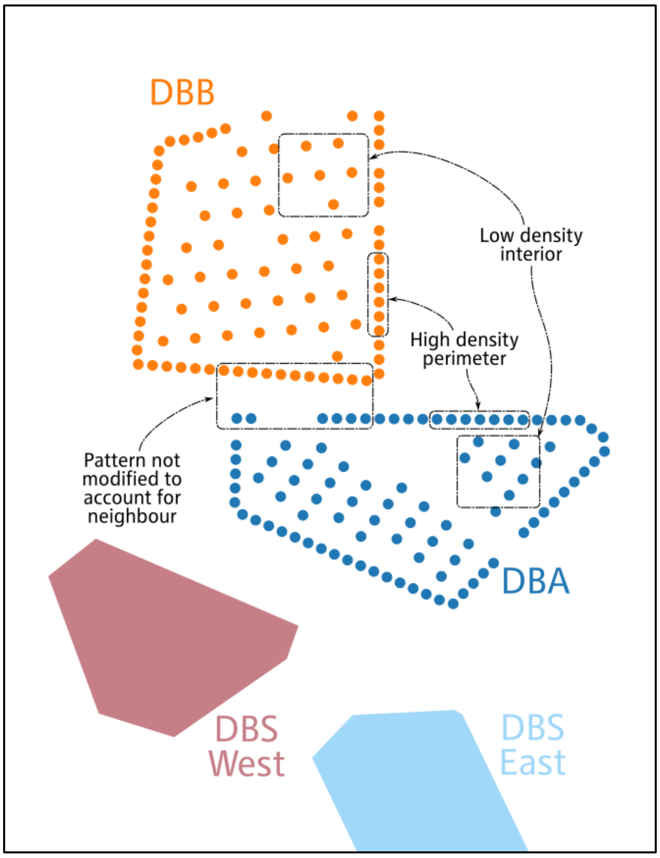


Figure 6: DBA and DBB Layouts

7.10 Mitigation Conclusions

107. The assessment of the wake mitigation methods assessed above are summarised in **Table 7**. As can be seen, all proposed mitigations fail to meet the requirements of a "reasonable mitigation", either having insignificant impact, net negative impact, not being available/possible, or a combination of these.

108. Several criteria are marked as "unknown" as the impact is so small, or the state of the science so immature, that it is currently not possible to evaluate the criterion.

Table 7: Assessment of Wake Mitigation Methods

Mitigation	Criterion 1: Meaningful Impact	Criterion 2: Net Positive	Criterion 3: Possible and Available
Buffer Distance	Fail	Fail	Pass
Layout Modification	Strongly Fail	Unknown	Pass
Reduced Size and Capacity	Pass	Strongly Fail	Pass
Wake Control	Fail	Unknown	Fail
Wake Reenergisation	Fail	Unknown	Fail
Wind Farm Curtailment	Fail	Fail	Fail

109. Thus, of the options theoretically available (those that pass criterion 3), all either have, at best, marginal effects, i.e. reducing the ~2% wake loss to ~1.9% (and probably less impact) or have a significant detrimental impact on net generation (e.g. only building half of the Projects).

110. The remaining options (those that fail criterion 3) require advancements in the state-of-the-art and/or would require redesigns to the turbine technology to support the increase forces (increasing the cost of the turbines) and hence will not be available to the Projects, and would have massively negative impacts to the generation at the Projects.

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