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Ørsted IPs – Deadline 7 Submission

This submission is made in relation to the examination of the Dogger Bank South Offshore Wind Farm Project (the "**DBS Project**") and is made on behalf of Hornsea 1 Limited, the collective of Breesea Limited, Soundmark Wind Limited, Sonningmay Wind Limited and Optimus Wind Limited (together, the "**Hornsea 2 Companies**"), Orsted Hornsea Project Three (UK) Limited, Orsted Hornsea Project Four Limited, Lincs Wind Farm Limited, Westermost Rough Limited and Race Bank Wind Farm Limited (together, or in any combination, the "**Ørsted IPs**").

The Ørsted IPs note that only Hornsea 1 Limited, the Hornsea 2 Companies and Orsted Hornsea Project Three (UK) Limited continue to hold objections to the DBS Project relating to wake loss.

The purpose of this submission is for the Ørsted IPs to provide comments on the submissions made by the Applicants at Deadline 6, where appropriate. The Ørsted IPs consider that the majority of the points made in the Applicants' submissions have already been addressed via the Ørsted IPs' position on these matters throughout submissions made by the Ørsted IPs in this examination. Therefore, the Ørsted IPs do not propose to repeat, at length, submissions that they have already made – instead, the Ørsted IPs have responded to various points on a document-by-document basis where they consider it necessary and helpful to do so.

Applicants' Written Summaries of Oral Submissions made at Issue Specific Hearing 6 [REP6-055]

In paragraph 6 of this document, the Applicants suggest that the Ørsted IPs' acceptance of the Applicants' wake modelling figures upon the Hornsea 1, Hornsea 2 and Hornsea 3 offshore wind farms extends to the Ørsted IPs' endorsement of the Applicants' wake modelling figures upon the Projcos' assets. The Ørsted IPs do not support this assertion – the Ørsted IPs are simply accepting the use of the modelling figures that relate to their own assets in this examination, due to the limited time remaining since the Applicants provided these, and in an attempt to act reasonably and with pragmatism. As stated throughout the examination, the Ørsted IPs would have preferred an independent assessment of wake loss. These numbers do not necessarily align with the Ørsted IPs' internal modelling. The dispute between the Applicants and the Projcos should be resolved via technical discussions and/or through independent modelling, with the Ørsted IPs not taken to endorse either side.

In paragraph 7 of this document, the Applicants state that "*there has been no custom and practice of substantive engagement on wake loss at the pre-application stage for new offshore wind farm projects*". The Ørsted IPs do not agree with this statement – as previously stated in submissions, there has been such engagement and there are clear reasons why not all of this engagement has been public-facing.

In paragraph 10 of this document, the Applicants state that "*there is an attempt to retrospectively apply a contested interpretation of National Policy Statement ("**NPS**") EN-3 to hold the Applicants to an inappropriate standard <u>which was not accepted to apply at the time</u>*" (emphasis added). The Ørsted IPs disagree with this statement – as previously stated in submission, knowledge of the true extent of far-field wake effects emerged between 2019 and 2021. It is incumbent upon the Applicants to assess all likely significant effects as part of its Environmental Impact Assessment ("**EIA**"), not least very obviously significant economic impacts. As stated in pages 12-14 of the Ørsted IPs' Deadline 6 Submission **[REP6-085]**, consideration of the EIA 'limbs' considered by the Applicants lead to the conclusion, in the Ørsted IPs' view, that effects from wake loss from the DBS Project on the Ørsted IPs' assets is likely to be major (significant), thereby meriting consideration of mitigation and/or compensation. This is only enhanced further by the production of the Financial Impact Assessment at Appendix 1 to this submission, showing total financial losses of between £84m to £295m from the DBS Project alone (rising to £106m to £319m when the cumulative impact of the Outer Dowsing Offshore Wind (Generating Station) Project is factored in). The Ørsted IPs also note that the Applicants' EIA contains numerous assessments of other human environment impacts that are far less significant in economic terms than these figures.

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Paragraph 10 also states that other Leasing Round 4 Projects "*did not act differently from the Applicants*". This is, the Ørsted IPs consider, driven by the same motivation of seeking to avoid significant mitigation and/or compensation outcomes. Paragraph 10 also refers to the Applicants acting in accordance with "*accepted practice*" and that there are "*no accepted mitigation options*" – on the first point, the Ørsted IPs have already stated that the accepted practice is that private wake loss agreements have been entered into (the Ørsted IPs have covered this in previous submissions relating to the Walney Extension, and also note again that Hornsea 1 publicly dropped its wake loss objection against the DCO application for Hornsea 2), and the second point can be rebutted by noting that: (i) physical mitigation options have been implemented in, for example, German waters[1]; and (ii) financial compensation is an accepted form of mitigation for a number of offshore wind farms located across English waters.

In paragraph 11 of this document, the Applicants state that The Crown Estate ("**TCE**") is "*on record stating that an important consideration for setting buffer distances was the consideration of wake effects*". The Ørsted IPs provided the relevant TCE submission from the examination of the Outer Dowsing Offshore Wind (Generating Station) Project in Appendix 1 to the Ørsted IPs' Deadline 1 Submission **[REP1-086]**, in which TCE actually state that "*the buffer/stand-off between wind farms (unless developers consent to closer proximity) is a separation distance to enable developers to develop, operate and maintain wind farms by allowing for a range of factors including amongst other matters, wake effects, navigation, and safety"*. Furthermore, in that same submission, TCE stated that they "*acknowledge that inter-farm wake effects can extend beyond these buffer distances. TCE also notes that the spatial and temporal variability of wind speed means that it is complex to accurately predict the wake impact on nearby wind farms, which may depend on factors beyond distance – e.g. prevailing wind direction and wind farm layout*".

In paragraph 12 of this document, the Applicants state that if the "*generic research*" had identified "*mitigation steps which were reasonable then they would be adopted by the Applicants*". The Ørsted IPs do not consider that it is for the Applicants alone to decide what is "*reasonable*" – what is (or is not) reasonable from a project-to-project perspective is not necessarily the same as what is (or is not) reasonable from a UK-wide, Net Zero perspective. Further, the Ørsted IPs again note that the Applicants did not undertake a wake loss assessment on the Ørsted IPs assets until Deadline 5 of this examination. It is disingenuous of the Applicants to suggest that the reason they have delayed this step until this stage is because they did not believe that there was any "*reasonable*" mitigation that could be employed, irrespective of the findings of any wake modelling that they could have undertaken.

In paragraph 14 of this document, the Applicants state that "*there is no guidance or custom and practice on this*", referring to the weighting of mitigation measures against other design considerations. The Ørsted IPs note, as stated in their Deadline 6 Submission **[REP6-085]**, that there are a range of instances whereby financial compensation is used to deal with economic impacts, including, for example, fisheries compensation. In the Ørsted IPs' view, there is no reason why wake loss should be excluded from this.

In paragraph 16 of this document, the Applicants state that "*wake effects remain a novel issue*". The Ørsted IPs dispute this claim – this has been hotly contested in all relevant DCO examination since the Awel y Mor decision, i.e. since the industry understanding regarding the true extent of far-field wake effects took a material leap forward between 2019 and 2021. The Applicants go on to state that they "*have followed the accepted approach to wake effects*" – again, the Ørsted IPs note that refusing to undertake a wake loss assessment until late in a DCO examination is not an "*accepted approach*". The Applicants also state in this paragraph that they "*remain of the view that wake effects were well understood when the buffer distance was set by TCE for Round 4 in 2019*". The Ørsted IPs have rebutted this point in previous submissions (and, indeed, within this submission), but again wish to note that TCE set the buffer distances of 7.5km for Leasing Round 4 Projects prior the evolution of the industry's understanding of wake effects – the majority of the

[1] As stated in a submission made into the examination of the Mona offshore wind farm, BP have previously advocated for mitigation for wake effects arising from proposed new wind farms at their own sites, proposing measures included delaying tendering for the sites (to reduce temporal overlap with BP's developments) and reducing the power density of the sites – as a result of these submissions, the capacity of a proposed site was reduced by 50% (from 2GW to 1GW).

research provided by Ørsted on this issue is from the last 6 years. Additionally, it is noted that in the last 6 years both Ørsted and RWE (two of the largest offshore wind operators in Europe), and in collaboration with DNV, have made public statements demonstrating that industry knowledge of this issue is evolving considerably. In 2019, Ørsted issued a market update (in relation to its long-term financial targets) on the true extent of far-field wake effects, which highlighted that the negative impacts of wake effect had been underestimated and which is provided at Appendix 3 to this submission. Ørsted's share price took a significant hit when this market update was communicated, so it is disingenuous of the Applicants to imply that far-field wake effects were "*well understood*" prior to that. Following this market update, further work was undertaken to understand the actual observed wake impacts, the results of which were presented by Ørsted in 2023. Following this, in 2024, RWE/DNV presented its own report regarding the implications of long-distance wake effects from large offshore clusters, which is provided at Appendix 4 to this submission.

In paragraph 17 of this document, the Applicants state that a new system for wake effects would give rise "*to a host of complex technical and policy issues*". The Ørsted IPs note that ensuring wake losses are agreed upon (through modelling), and financially compensated for, is not particularly complex – in fact, this has been common practice (albeit typically for offshore wind farms that are located closer together) for many years.

In paragraph 18 of this document, the Applicants state that "*there is no history of routinely including wake effects within an ES*". As stated, the Ørsted IPs note that the issue of far-field wake effects became apparent from 2019. It was incumbent upon the Leasing Round 4 Projects, and the Five Estuaries Project (a 2019 extension leasing round project), to develop and implement routine assessments of what has, since then, been a clear and obvious impact (a far more significant impact than the majority of human environment impacts that are routinely assessed as part of offshore wind farm EIAs, including within the Applicants' EIA); however, these projects elected not to establish this routine. This ties in with a rebuttal to a point made by the Applicants in paragraph 20 that they have "*adhered to normal industry standards*" – as stated, post-2019 an improved understanding of far-field wake effects became apparent, and it was incumbent upon offshore wind farm developers to react to this, i.e. such industry standards ought to have shifted to accommodate this improved understanding.

In paragraph 24 of this document, the Applicants state that the lack of mention of financial compensation in the consultation letter issued by the Secretary of State on the Mona Offshore Wind Farm Project is "*consistent with the previous SoS decision at Awel y Mor and the drafting in the emerging changes to EN-3*". The Ørsted IPs disagree – the Awel y Mor requirement does not preclude a financial settlement (indeed, this may be the likely outcome preferred over physical mitigation), and furthermore the draft NPS EN-3 makes a direct reference to financial compensation at paragraph 2.8.233, where it states that "*there is no expectation that wake effects can be wholly removed between developments, or that inter-project compensation arrangements are a necessary means to mitigate the impact of wake effects, <u>although developers may opt to take such approaches outside of the planning process</u>*" (emphasis added).

In paragraph 31 of this document, the Applicants state that the protective provisions proposed by the Projcos and the Ørsted IPs are "*completely unsupported by policy*" and "*entirely novel*". The Ørsted IPs consider these statements to be inaccurate, for the reasons set out in previous submissions (by the Projcos and the Ørsted IPs), including regarding the EIA 'limbs' considered by the Applicants and the appropriateness and justification of the protective provisions demonstrated by the figures in the Financial Impact Assessment at Appendix 1 to this submission, alongside the fact that examples of compensation via such protective provisions (and alternative commitments made within Environmental Statements and other parts of DCOs) exist through the routine protection of, for example, fisheries and Network Rail.

<u>Applicants' Comments on Responses to ExQ2 [REP6-051]</u>

At page 80 of this document, the Applicants state that they "*reject the claim that inter-project compensation agreements are commonplace within the industry outside of the situation where a* *new project is located within the relevant TCE buffer*". The Ørsted IPs note that compensation settlements covering wake losses, that are incurred both within and outwith TCE buffer zones, have been entered into on numerous occasions across UK waters. In each case, this outcome is both necessary and pragmatic. For wake losses incurred beyond TCE buffer distances, the existence of common ownership across waked and waking projects has, to date, typically driven pragmatic compensation outcomes. However, the UK offshore wind industry is currently grappling with a new situation whereby it has become apparent that five proposed Leasing Round 4 Projects and one proposed 2017 Extension Round project will impose significant wake effects well beyond the buffer distances imposed by TCE while, at the same time, common ownership across these projects is not in place to drive pragmatic compensation outcomes. In lieu of this, protective provisions, such as those proposed by the Ørsted IPs, are necessary to safeguard the business cases of both existing (waked) and proposed (waking) offshore wind farms from future unmitigated wake loss impacts. Requiring wake loss mitigation and/or compensation, that protects the interests of waked projects that have been leased through earlier leasing rounds, is the only means of ensuring that wake loss impacts are accurately priced-in to consumer bills.

Page 80 of this document also contains a statement from the Applicants that "*there are no circumstances in which an imposed financial compensation mechanism would be an 'attractive solution' for the Applicants*". The Ørsted IPs are surprised by this statement – financial compensation would presumably be more attractive to the Applicants than the imposition of physical mitigation requirements that could potentially be more costly. In some cases, financial compensation can offer the most appropriate way of addressing an issue that may be difficult to mitigate through physical mitigation. As stated above and in previous submissions, this is, in principle, no different from the financial compensation commitments that are routinely put in place to address impacts on other sea users, for example commercial fishers and shipping operators, in instances where available physical mitigations come with inherent limitations.

At page 87 of this document, the Applicants state that "*comparison to background levels of variation is established practice, and accepted as an indication that an effect is not significant*". The Ørsted IPs dispute this interpretation of significance in an EIA context – for example, a fisher's catch may fluctuate significantly from day to day, but that evidence is not used to argue that (for example) an average 4% loss of that fisher's revenue, for the rest of their operational lifetime, is not significant.

At page 90 of this document, the Applicants state that "*the planning system does not exist to protect the commercial interests of competitors*". The Ørsted IPs wish to note that the planning system also does not exist to permit the imposition of uncompensated revenue losses upon competitors. Page 90 of this document also contains a statement from the Applicants that draft NPS EN-3 "*rules out financial compensation in relation to future offshore wind applications*" – again, as stated above, draft NPS EN-3 actually states, at paragraph 2.8.233, that "*there is no expectation that wake effects can be wholly removed between developments, or that inter-project compensation arrangements are a necessary means to mitigate the impact of wake effects, <u>although developers may opt to take such approaches outside of the planning process</u>*" (emphasis added).

At pages 97-98 of this document, the Applicants state that "*to impose an unexpected financial compensation obligation on Round 4 (or extension) projects through the planning system in the retrospective way proposed would damage investor confidence in the UK offshore wind market and TCE's seabed licensing process, which has been at the heart of the success of UK offshore wind. TCE's profits are paid to the Treasury, meaning there is public interest on both sides of his matter (the CfD regime driving reduced costs to consumers; TCE profits being paid to the Treasury for use in the public interest)*". However, earlier in the same response, the Applicants state that "*the effects from future wind farms was a clear generic risk which all wind farm developers would have needed to take into account*". These positions are in direct contradiction, as effects from future wind farms remain a risk today. It would suggest that the Applicants will be including large wake risk premiums in their CFD bid price to account for the likely future unknown wake effects from future leasing rounds, thereby driving up costs to consumers. The Applicants would have to use imperfect information to estimate the extent and timing of these future effects.

If the future effects are not realised, the Applicants would make a profit at the expense of the UK electricity consumer, and if the future effects are worse than predicted then the Applicants' asset will not perform as expected. This system of estimating future effects and building them into CFD prices is inefficient and carries more risk of undermining investor confidence, due to potential negative shocks every time TCE allocates a new lease area.

At page 101 of this document, the Applicants state that the Secretary of State has rejected the principle of financial compensation, using the example of the Awel y Mor decision. The Ørsted IPs note, again, that the Awel y Mor requirement does not preclude a financial settlement as an alternative outcome to the design provisions set out in the requirement.

Page 101 also contains a statement from the Applicants that "*any project-specific financial compensation scheme included in a DCO gives rise to a wide range of public interest considerations*". The Ørsted IPs note that, in response to a letter from the Secretary of State dated 12 May 2025 in relation to the examination of the Mona offshore wind farm, the applicant in that case included (on a without prejudice basis) in its response (dated 23 May 2025) a draft DCO requirement on wake loss that contained the option of a private settlement as one limb of this draft requirement.

The Applicants also ask, in relation to the spectrum of assessment outcomes, "*which point on the spectrum should be selected?*". The Ørsted IPs note that it is standard practice that waking and waked projects each pick a reputable, independent wake modelling consultant and the difference between their findings is split. The Applicants also state that "*there would need to be government guidance on this to ensure a fair and consistent approach, which does not exist. It should not be left to an expert on a single project*". The Ørsted IPs note that the issue of wake loss compensation has been amicably resolved across the UK on numerous occasions using a range of approaches, and the Ørsted IPs see no issue with the use of independent experts.

Page 101 also contains a statement from the Applicants that "*if financial compensation is to be imposed through the planning system, it would have to be the result of a government-led process of consultation and development of the objectives, principles and mechanisms to deliver such a system*". The Ørsted IPs note that the proposed protective provisions would allow waking projects to proceed in a timely fashion, subject to them making waked projects whole. Nothing overly complicated, or particularly novel, is being suggested.

Across pages 101 and 102 of this document, the Applicants pose several questions in relation to the proposed protective provisions. The Ørsted IPs have responded to these in turn:

Question from the Applicants	**Ørsted IPs' Response**
1. If an affected project, for example, has itself caused wake loss to a prior project, will it be expected to compensate that project? If not, how, can that be justified? That point is precisely in play in the Five Estuaries application, where EA2 is claiming compensation but is not offering to compensate Galloper and Greater Gabbard for its future wake effects on them.	Compensation should be payable to projects leased in previous leasing rounds only (compensation should not be payable across projects within the same leasing round). A requirement to compensation cannot be retrospectively applied in situations whereby waked projects have not put forward successful wake loss objections through now closed planning processes (a mechanism does not exist to facilitate this).
2. What percentage of the claimed loss would be payable? 100%? 50%? On what justification? Enough to overcome claimed concerns about viability? If viability-related,	It is expected that the waked projects will be made whole if compensation is paid over the lifetime of the waked project, for example with payments made annually in arrears. Deductions may be agreed for an approach

Question from the Applicants	Ørsted IPs' Response
then what principles are to be applied as regards acceptable profit?	that is based on an up-front lump sum payment.
3. When should payments be made? Orsted has put forward protective provisions into the Outer Dowsing application which impose a single advance commuted sum. Is that a justifiable approach?	The Ørsted IPs note that the version of protective provisions provided in the examination of the Outer Dowsing Offshore Wind (Generating Station) Project is different to those provided in relation to the DBS Project, as the position has developed.
4. What discount percentage should be applied in relation to future revenue streams?	This is irrelevant to an annual in arrears payment approach which simply reflects price x generation x wake loss.

<u>Applicants' Responses to Rule 17 Letter dated 9 June 2025 [REP6-057]</u>

At page 16 of this document, the Applicants state that "*DBS is much further from Dogger Bank A ("**DBA**") than Awel y Mor from Gwynt y Mor*". The Ørsted IPs do not consider that the difference in distances of c.5km and c.7.5km is "*much further*" (nor, indeed, particularly different) in the context of wake effects.

At page 17 of this document, the Applicants refer back to the Frazer Nash Study to conclude that "*DBS would suffer a reduction in energy production from reducing its array area, but the only farm to potentially benefit would be DBA, as all others are beyond 10km*". The Ørsted IPs consider that, rather than referring back to the generic Frazer Nash Study, it is incumbent upon the Applicants to model mitigations for the DBS Project, instead of relying on theoretical examples.

<u>Applicants' Responses to June 2025 Hearing Action Points [REP6-056]</u>

All of the extracts of this document to which the Ørsted IPs wish to respond are found on page 8. Firstly, the Applicants state that the circumstances of this examination are "*highly unusual and novel*" – the Ørsted IPs note that similar concerns have been debated across multiple DCO examinations to date, so they cannot see why the DBS Project is so unusual and novel.

Secondly, the Applicants refer to a "*lack of history of wake assessments*". The Ørsted IPs note that there is a long history of wake assessments being undertaken privately. The Applicants also refer to the "*absence of guidance on wake assessments*", to which the Ørsted IPs note that despite the fact that there is no specific industry guidance on, for example, assessing restrictions imposed by offshore wind farms on heli-access/egress to/from helideck-equipped oil & gas platforms, these complex technical assessments have, for a number of years, been undertaken as part of offshore wind farm EIAs as a matter of course.

Thirdly, the Applicants assert that wake loss "*was not envisaged as being part of effects subject to the mitigation hierarchy when the CNP policy was introduced*". The Ørsted IPs do not agree with this statement – wake loss is simply another economic impact (of many), with not all needing to be (or intended to be) specifically name-checked.

Lastly, the Applicants state that "*the SoS has felt the need to propose new wording in [draft NPS] EN-3 to address wake effects expressly for the first time*". The Ørsted IPs note that it is the spurious interpretation of NPS EN-3 put forward by waking projects in recent DCO examinations that has necessitated the Secretary of State stepping in with clarifications.

APPENDIX 1

FINANCIAL IMPACT ASSESSMENT

Dogger Bank South

Wake Loss Financial Impact Assessment on behalf of the Ørsted IPs

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Executive Summary

This Financial Impact Assessment has been prepared in relation to the Examination of the Dogger Bank South Offshore Wind Farms (**Dogger Bank South**) and estimates the financial impacts based on the recent addendum to the wake impact assessment published by RWE Renewables UK South (West) Limited & RWE Renewables UK South (East) Limited (the **Applicants**) on the Ørsted IPs' assets (being Hornsea 1 Limited, along with Breesea Limited, Sonningmay Wind Limited, Soundmark Wind Limited and Optimus Wind Limited (together **Hornsea 2**) and Orsted Hornsea Project Three (UK) Limited) as a result of the construction and operation of Dogger Bank South, as submitted into the Examination **[AS-179]** (the **Dogger Bank South Report**).

This financial assessment has been carried out by Ørsted, on behalf of the Ørsted IPs, using publicly available information and wake loss and production assumptions provided by Dogger Bank South. It shows the financial impact on the concerned projects due to wake effects resulting from Dogger Bank South. The assessment shows the financial impact, as a Net Present Value (NPV), across the 24-year Minimum Lifetime, then across solely the assumed 10-year Lifetime Extension, and then across the combined Minimum Lifetime and Lifetime Extension (the total financial impact[1]).

Asset	Wake Loss due to Dogger Bank South (% AEP)	Negative NPV Impact (£m)[2]		
		Impact during Minimum Lifetime[3]	Additional impact during Lifetime Extension[4]	Total financial impact
Hornsea 1	0.65%	£22m-48m	£5m-£27m	£27m-£75m
Hornsea 2	0.75%	£22m-£60m	£5m-£32m	£27m-£92m
Hornsea 3	0.35%	£26m-£82m	£5m-£45m	£30m-£127m
Total		**£70m-£190m**	**£15m-£104m**	**£84m—£295m**

Table 1: Overview of Wake Loss Financial Impact using Table 2 of the Dogger Bank South Report.

Table 1 above shows that the financial impacts of wake losses resulting from Dogger Bank South are significant across the Ørsted IPs' assets, with a total financial impact of between £84m and £295m (depending on the discount rate applied). This creates a negative NPV impact value of between £70m and £190m across the Minimum Lifetime of the assets, and a reduction during the Lifetime Extension of between £15m and £104m.

The impacts throughout each asset's life are material, both when modelling only using Dogger Bank South's individual wake impact on the assets and worsened in the case of Hornsea 1 and Hornsea 2 when considering the cumulative wake impacts from both the proposed Dogger Bank South and Outer Dowsing offshore wind farms. The impact incurred will influence lifetime extension decisions and lead to a likelihood that Hornsea 1 and/or Hornsea 2 will be decommissioned earlier than would otherwise have been the case and clearly displays the financial challenges impacting the Ørsted IPs from multiple new wind farms in the area.

[1] The total financial impact is based on a 24-year Minimum Lifetime and 10-year Lifetime Extension. Changes to these assumptions could alter the financial impact.
[2] Range shown represents Net Discount Rates discount rates from 0% to 7.5%.
[3] The Minimum Lifetime is assumed as 24 years for Hornsea 1, Hornsea 2 and Hornsea 3.
[4] Lifetime Extension is assumed as an additional 10 years of life immediately following the Minimum Lifetime.

1 Introduction

This assessment uses a simple formula to provide an indicative view of the quantum of the financial consequences of wake loss for each project. It uses a mix of publicly available data and information submitted throughout the Examination process. This assessment does not intend to represent the Ørsted IPs' internal view of the financial impact, which cannot be shared publicly due to its reliance on confidential information.

The formula used to calculate the annual financial impact of wake loss is as follows:

Annual Electricity Production (AEP)[5] X Wake Loss (%) X Forecast Electricity Price[6] (£/MWh)

This is calculated from the predicted operational start date of Dogger Bank South until the earliest potential decommissioning dates for the impacted projects giving the "Minimum Lifetime" values. The Lifetime Extension analysis continues this assessment until the end of an assumed lifetime extension (+10 years).

The NPV is then calculated using the annual financial impact for each year across the lifetime of the assets, considering both Minimum Lifetime and the Lifetime Extension. A range of Net Discount Rates are used that take inflation into account.

2 Results

In this report, the results of the financial impact assessment reflect the wake losses presented in the Dogger Bank South Report and the Applicants' Greenhouse Gas Sensitivity Analysis of Wake Effects **[REP5-034]**. The assessments demonstrate the impact, as an NPV loss, across the Minimum Lifetime of the assets (see assumptions used), then solely across the Lifetime Extension (again, see assumptions used), and then the total impact (comprising the combined impact from the Minimum Lifetime to the end of the Lifetime Extension).

2.1 Financial impact during Minimum Lifetime

Using the figures presented in the Dogger Bank South Report, the Ørsted IPs have assessed the NPV impact of the wake losses introduced by Dogger Bank South across the 24-year Minimum Lifetime of the impacted assets (Table 2 below). Ørsted does not consider that it would be appropriate to select one discount rate and has instead opted to run the NPV calculations using a range of potential Net Discount Rates[7] in this section and in all later sections.

Asset	Wake Loss due to Dogger Bank South (% AEP)	Negative NPV of Wake Losses during Minimum Lifetime (£m)			
		Net Discount Rate of 0.0%	Net Discount Rate of 2.5%	Net Discount Rate of 5.0%	Net Discount Rate of 7.5%
Hornsea 1	0.65%	£48m	£37m	£29m	£22m
Hornsea 2	0.75%	£60m	£40m	£29m	£22m
Hornsea 3	0.35%	£82m	£54m	£37m	£26m
Total		**£190m**	**£131m**	**£95m**	**£70m**

Table 2: Minimum Lifetime Impact using the wake losses presented in the Dogger Bank South Report.

The assessment shows the combined impact on the Ørsted IPs' assets due to wake loss from Dogger Bank South of between £70m and £190m across the Minimum Lifetime for the impacted assets – all levels in this range are considered material for the assets involved.

2.2 Financial impact during assumed Lifetime Extension

The Ørsted IPs anticipate that their assets will be operational beyond the earliest decommissioning date and that an additional 10-years is a reasonable period to use for an impact assessment. There are not currently anticipated to be any technical or consenting barriers to extending the Minimum Lifetime by an additional ten years. Therefore, this analysis also considers a 10-year Lifetime Extension (Table 3 overleaf).

[5] The Ørsted IPs' internal expectations of AEP are confidential and cannot be shared publicly. Instead, the AEP numbers are taken from the Applicants' Greenhouse Gas Sensitivity Analysis of Wake Effects **[REP5-034]** which is referenced in Appendix A.
[6] Forecast Electricity Price is the total price received for each MWh of production.
[7] The Net Discount Rate is an adjusted discount rate taking into account the assumed Inflation Rate.

Asset	Wake Loss due to Dogger Bank South (% AEP)	Negative NPV of Wake Losses during Lifetime Extension (£m)			
		Net Discount Rate of 0.0%	Net Discount Rate of 2.5%	Net Discount Rate of 5.0%	Net Discount Rate of 7.5%
Hornsea 1	0.65%	£27m	£15m	£8m	£5m
Hornsea 2	0.75%	£32m	£18m	£10m	£5m
Hornsea 3	0.35%	£45m	£21m	£10m	£5m
Total		**£104m**	**£54m**	**£28m**	**£15m**

Table 3: Impact during 10-year Lifetime Extension using the wake losses presented in the Dogger Bank South Report.

The reduced NPVs during the Lifetime Extension of the concerned assets are material in their own right.

2.3 Total financial impact assuming 10-year Lifetime Extension

The impact has been shown to be significant both for the Minimum Lifetime and the Lifetime Extension. Combining these shows the overall impact of the wake effect from Dogger Bank South on the Ørsted IPs' assets (Table 4 below).

Asset	Wake Loss due to Dogger Bank South (% AEP)	Negative Total NPV of Wake Losses (£m)			
		Net Discount Rate of 0.0%	Net Discount Rate of 2.5%	Net Discount Rate of 5.0%	Net Discount Rate of 7.5%
Hornsea 1	0.65%	£75m	£52m	£37m	£27m
Hornsea 2	0.75%	£92m	£58m	£39m	£27m
Hornsea 3	0.35%	£127m	£75m	£47m	£30m
Total		**£295m**	**£185m**	**£122m**	**£84m**

Table 4: Total Impact assuming 10-year Lifetime Extension using the wake losses presented in the Dogger Bank South Report.

The assessment shows total impacts across the combined assets' lifetimes ranging between £84m and £295m using a 10-year Lifetime Extension. Given that there are not currently any technical or consenting barriers foreseen which would prevent a 10-year Lifetime Extension of the concerned projects, this is considered a likely range of outcomes for the financial impact on the Ørsted IPs' assets.

2.4 Cumulative Impact

The impact of wakes originating from Dogger Bank South alone have a material impact on the economics of the assets. When the impact of wakes from multiple wind farms are considered, the financial impact grows further, and this combined impact should also be taken into account.

Table 5 overleaf shows the financial impact on two of the Ørsted IPs, Hornsea 1 and Hornsea 2, due to wakes originating from both the Dogger Bank South and Outer Dowsing offshore wind farms. The combined financial impact is significant and even with the highest discount factor exceeding £100m.

Asset	Combined Wake Loss due to Dogger Bank South and Outer Dowsing (% AEP)	Negative NPV Impact (£m)		
		Impact during Minimum Lifetime	Additional impact during Lifetime Extension	Total financial impact
Hornsea 1	1.32%	£49m-£104m	£7m-£38m	£56m-£143m
Hornsea 2	1.43%	£41m-£108m	£8m-£68m	£50m-£176m
Total		**£90m-£212m**	**£15m-£106m**	**£106m—£319m**

Table 5: Overview of financial impact of the combined wake loss originating from the Dogger Bank South and Outer Dowsing offshore wind farms using the Dogger Bank South Report and the equivalent assessment submitted into the Outer Dowsing Examination. Note: The impact on Hornsea 3 is not considered in this table as the objection for that asset was withdrawn from the Outer Dowsing Examination.

2.5 Impact on early decommissioning

Alongside the material loss of value set out in the sections above, the wake loss impacts imposed by Dogger Bank South may challenge the economic viability of Hornsea 1 and Hornsea 2, from the point at which market support for these assets falls away and the assets' revenue streams become fully merchant, i.e. as the financial case for these assets becomes more constrained. The cumulative wake loss incurred as a result of both the Dogger Bank South and Outer Dowsing offshore wind farms of 1.3% and 1.4% for Hornsea 1 and Hornsea 2 respectively will influence lifetime extension decisions and lead to a likelihood of the earlier-than-otherwise decommissioning of the two assets.

3 Conclusion

This Financial Impact Assessment demonstrates that the financial impact of the wake losses introduced by Dogger Bank South are significant across the Ørsted IPs' assets. The revenue losses are material in all scenarios, creating a negative NPV impact ranging from £84m to £295m as the total financial impact when using a 10-year Lifetime Extension.

Additionally, this financial assessment also highlights that when wake losses from multiple wind farms are considered, in this case the Dogger Bank South and Outer Dowsing offshore wind farms, the impact on the revenue stream is more pronounced, ranging from £106m to £319m for Hornsea 1 and Hornsea 2. Revenue impacts of this level are material and will threaten the financial viability of the assets leading to a likelihood that Hornsea 1 and/or Hornsea 2 will be decommissioned earlier than would otherwise have been the case.

4 Appendix – Assumptions Used

In order to produce this high-level analysis, the Ørsted IPs have made several assumptions designed to simplify the modelling and create transparency. These assumptions, based on publicly available data, relate to variable factors such as future energy prices and inflation and have a level of uncertainty. The Ørsted IPs do not wish to suggest these results are the only correct results, but rather they are demonstrative of the magnitude of the impact.

Variable	Source used	Notes	Source link(s)
AEP	AEP provided in Table 4-1 of Applicants' Greenhouse Gas Sensitivity Analysis of Wake Effects **[REP5-034]**	AEP assumed to remain stable throughout the lifetime of the asset. These numbers are used for simplicity and their use should not be interpreted as an acceptance by the Ørsted IPs that they are correct.	**[REP5-034]**
Electricity price	Market Prices: Department for Energy Security and Net Zero energy and emissions projections December 2024	Reference market price forecast has been used for this assessment with inflation applied at 2% per annum following the forecast period.	DESNZ
CFD Prices	LCCC CfD Register	CfD Assets' revenue per MWh is based on the Contract for Difference price per MWh (CFD Price). The current CFD Prices are publicly available on the LCCC website (see link). For this Assessment the current CFD Price is taken and inflation applied throughout the remaining period in which CFD's are applicable.	LCCC – CfD Register
Inflation	The Office for National Statistics CPIH (2024). Bank of England target inflation rate (2025 onwards)	Inflation assumed at BoE target rate of 2%.	BoE
Wake loss (Dogger Bank South)	The results of the Dogger Bank South Report	The wake loss has been assumed as the average of the "TurbOPark + Correction" and "VV 3.4" results presented in Table 2 of the Dogger Bank South Report. The "EV-DAWM" results are not considered as the Applicants state that "it should be noted that while EV DAWM performs reasonably well at shorter ranges, it is known that its performance worsens the further wakes travel". Wake losses are assumed static throughout the lifetime of the asset.	**[AS-179]**
Wake Loss (Combined impact of Dogger Bank South and Outer Dowsing)	The Wood Thilsted Report from the Outer Dowsing Examination (see separate appendix of this submission).	Wake losses are assumed static throughout the lifetime of the asset. Outer Dowsing – Scenario 1B from the Wood Thilsted Report has been used in this financial assessment. Dogger Bank South – The wake loss has been assumed as the average of the "TurbOPark + Correction" and "VV 3.4" results presented in Table 2 of the Dogger Bank South Report.	See separate appendix of this submission.
Dogger Bank South Start Date	Dogger Bank South Website	Dogger Bank South website statement states that the target for first power is 2031 and that it has grid connection for 2031. The Ørsted IPs hence assume their first full year of operation as 2031.	Dogger Bank South website
Minimum Lifetime	24 Years	The Minimum Lifetime of each asset is assumed to be 24 years.	
Lifetime Extension	10 Years	Lifetime Extension of each asset is assumed as a period of 10 years immediately following the Minimum Lifetime.	

APPENDIX 2

WOOD THILSTED REPORT SUBMITTED DURING THE EXAMINATION OF THE OUTER DOWSING EXAMINATION

WOOD THILSTED

Wake Impact Assessment report

Outer Dowsing Wind Farm

P0232-C1751A-CA-REP-001-1.0

OUTER DOWSING OFFSHORE WIND

REVISION HISTORY

Rev	Date	Description	Author	Checker	Approver
1.0	13/03/2025	Final Version for submission	CCO	MCA	NEL

LIST OF ACRONYMS

The following table lists some of the acronyms used in this report.

Abbreviations	Definition
AEP	Annual Energy production
BoP	Balance-of-Plant
CFD	Computational Fluid Dynamics
DCO	Development Consent Order
EPA	Energy Production Assessment
ERA5	ECMWF Reanalysis 5th Generation
ECMWF	European Centre for Medium-Range Weather Forecasts
EPSG	European Petroleum Survey Group Geodetic Parameter Database
FL	Floating Lidar
IEC	International Electrotechnical Commission
MM	Meteorological (Met.) Mast
MERRA	Modern-ERA Retrospective analysis for Research and Applications
MoMM	Mean of Monthly Means
CAPEX	Capital Expenditure
EIA	Environment Impact Assessment
O&M	Operation and Maintenance
P50	Exceedance probability: The probability of exceeding the reported P50 value for annual energy production is 50%
P90	Exceedance probability: The probability of exceeding the reported P90 value for annual energy production is 90%
PBE	Production Based Estimate
PC	Power Curve
PPA	Power Purchase Agreement
Q&A	Questions and Answers
SPV	Special Purpose Vehicle
SCADA	Supervisory Control and Data Acquisition
TI	Turbulence Intensity
TSA	Turbine Supply Agreement
WAsP	Wind Atlas Analysis and Application Program
WF	Wind Farm
WRF	Weather Research and Forecasting
WSBE	Wind Speed Based Estimate
WSM	Wind Sector Management
WTG	Wind Turbine Generator
WT	Wood Thilsted

EXECUTIVE SUMMARY

Outer Dowsing Offshore Wind Farm (the "Client") has retained Wood Thilsted Partners Ltd (WT) to develop an independent wake impact assessment, arising from their proposed Outer Dowsing Offshore Wind farm (the "Project" or "ODOW") on neighbouring and future projects. The Outer Dowsing project is situated in the UK region of the Southern North Sea, to the south of Dogger Bank.

The Project and the neighbouring projects are all located in an increasingly busy part of the Southern North Sea and there is potential to impact the operational neighbouring wind farms, along with other proposed future wind farms.

The operational wind farms under consideration are Triton Knoll, Westermost Rough, Lincs, Race Bank, Inner Dowsing, Lynn, Dudgeon, Hornsea 1, Hornsea 2, Humber Gateway and Sheringham Shoal. The other proposed future wind farms along with the Project are, Hornsea 3, Hornsea 4, Dudgeon Extension and Sheringham Shoal Extension.

To assess the additional wakes arising from the Project in combination with other proposed projects given above, several scenarios have been considered. The considered scenarios are: the sole impact of the Project on existing assets, the cumulative impact of all proposed wind farms along with the Project, the cumulative impact of Hornsea 3 and Hornsea 4 with the Project, and finally the cumulative impact of Sheringham Shoal Extension and Dudgeon Extension with the Project. WT has further assessed the impacts from the Project to each of the future projects, Hornsea 3 and Hornsea 4 proposed future projects only, to the Dudgeon Extension and Sheringham Shoal Extension future projects only and finally to all future projects, in combination.

A range of publicly available datasets has been utilised for the assessment of future wind farm parameters, including the development phase, possible turbine configurations, wind farm boundaries, turbine type and hub height. Sources for this include the 4C Offshore Wind Market Intelligence [1], Map Stand Location Intelligence portal [2], and submissions to the National Infrastructure Planning Portal [3], along with correspondence with the Client [4]. It should be noted that due to the early stage of some of the projects, the information compiled for the future projects are not considered final, therefore the impacts will be subject to change – this report should be considered as being based on the best available information at the time of preparation.

This report provides a summary of the data used, along with the methodologies that have a proven track record for assessing the impact of wakes between wind farms. The primary objective of the study is to estimate the comparative loss in energy arising due to wakes caused by the addition of new wind farms including the Project and not estimating the absolute values for energy production and wakes. A short description of wind farm wakes, their effects and methodologies for their modelling is also included in Section 1.2.

WT has assessed the effects of future wind farms by utilising different scenarios. Table 1 below summarises the main scenarios considered and Table 2 summarises the magnitude of additional losses.

Table 1 External Wakes Scenarios

Scenario	Included Wind Farms	Comments / Assumptions
Baseline (Scenario 0a)	Existing Operational Wind Farms [1.]	Existing operational conditions
Baseline + **ODOW** (Scenario 0b)	Baseline + **ODOW** [2]	Sole impact of 1500 MW ODOW project on the operational wind farms, which are expected to be operational in 2030.
Scenario 1a	Baseline + Sheringham Shoal Extension, Dudgeon Extension, Hornsea 3 and Hornsea 4 [2]	Baseline scenario for 1b below, cumulative effect of all future wind farms
Scenario 1b	Baseline + Sheringham Shoal Extension, Dudgeon Extension, Hornsea 3 and Hornsea 4 [2] with **ODOW** [2]	Impact of ODOW along with all future development. Sheringham Shoal Extension (345 MW) and Dudgeon Extension (450 MW) will be operational by 2030. Hornsea 3 (3000 MW) will be operational by 2027. Hornsea 4 (2400 MW) will be operational by 2030.
Scenario 1c	Baseline + Sheringham Shoal Extension, Dudgeon Extension, Hornsea 3 and Hornsea 4 [2] with **ODOW** [2]	Technically same scenario with 1b above, but here the effect of ODOW on Sheringham Shoal Extension, Dudgeon Extension, Hornsea 3 and Hornsea 4 were investigated.
Scenario 2a	Baseline + Hornsea 3 and Hornsea 4 [2]	Baseline scenario for 2b below
Scenario 2b	Baseline + Hornsea 3 and Hornsea 4 [2] with **ODOW** [2]	Impact of ODOW along with Hornsea 3 and Hornsea 4. Hornsea 3 (3000 MW) will be operational by 2027. Hornsea 4 (2400 MW) will be operational by 2030.
Scenario 2c	Baseline + Hornsea 3 and Hornsea 4 [2] with **ODOW** [2]	Technically same scenario with 2b above, but here the effect of ODOW on Hornsea 3 and Hornsea 4 were investigated.
Scenario 3a	Baseline + Sheringham Shoal Extension, Dudgeon Extension [2]	Baseline scenario for 3b below
Scenario 3b	Baseline + Sheringham Shoal Extension, Dudgeon Extension [2], with **ODOW** [2]	Impact of ODOW along with Sheringham Shoal Extension and Dudgeon Extension. Sheringham Shoal Extension (345 MW) and Dudgeon Extension (450 MW) expected to be operational by 2030.
Scenario 3c	Baseline + Sheringham Shoal Extension, Dudgeon Extension [2], with **ODOW** [2]	Technically same scenario with 3b above, but here the effect of ODOW on Sheringham Shoal Extension and Dudgeon Extension were investigated.

[1] Triton Knoll, Westermost Rough, Lincs, Race Bank, Inner dowsing, Lynn, Dudgeon, Hornsea 1, Hornsea 2, Humber Gateway and Sheringham Shoal

[2.] Based on discussions held with the Client a 15 MW turbine with 236 m rotor diameter and 158m rotor height were assumed to be used for all future wind farms including ODOW. This assumption for the future wind farms is considered to provide a conservative position impact assessment as part of the DCO application

Based on these scenarios a conservative assessment of the additional wake loss arising from ODOW on the existing operational wind farms is calculated up to a maximum of **-0.88 %** (primarily the effect of ODOW on the Dudgeon Wind Farm).

The average effect of ODOW on all the existing wind farms, with or without the future wind farms varies between **-0.58 %** (the sole effect of ODOW on existing projects) and **-0.50 %** (the effect of ODOW on existing projects, in combination with all future wind farms). The effect of ODOW on individual operational wind farms varies between **-0.03%** and **-0.88%**.

WT has also investigated the effect of ODOW on future developments, including the impact of ODOW on all future development at once, the impact of ODOW on Hornsea 3 and Hornsea 4 and the impact of ODOW on Sheringham Shoal Extension and Dudgeon Extension. For Hornsea 3 and Hornsea 4, highest effect is observed as -**0.07%** on Hornsea 4 and for Dudgeon Extension and Sheringham Shoal Extension, the highest effect is observed as **-1.05%** on Dudgeon Extension. The individual results are also provided.

The results summarised above are shown in Table 2 for the effects on operational wind farms and Table 3 for the effects on future wind farms, below. Summary of all the results are normalized to the baseline can be seen in Table 4 below.

Considering the engineering wake model approaches used and distances between the Client assets and proposed neighbouring wind farms, WT considers the assessed additional wake loss numbers to be commensurate with WT's expectations. WT also finds the above results comparable with recent studies conducted by DNV and RWE [8] about cluster wakes and their effects on wind farm annual energy production.

Table 2 Comparison of Scenario 1b and 1a, Scenario 2b and 2a and Scenario 3b and 3a for operational wind farms

Scenario	Additional wake loss on each operational wind farm (%)										
	Triton Knoll	Westermost Rough	Lincs	Race Bank	Inner Dowsing	Lynn	Dudgeon	Hornsea 1	Hornsea 2	Humber Gateway	Sheringham Shoal	Total additional wake loss on all operational wind farms
Scenario 0b vs 0a	-0.79%	-0.08%	-0.18%	-0.53%	-0.05%	-0.03%	-0.88%	-0.70%	-0.75%	-0.23%	-0.76%	-0.58%
Scenario 1b vs 1a	-0.77%	-0.08%	-0.17%	-0.52%	-0.05%	-0.03%	-0.54%	-0.67%	-0.68%	-0.23%	-0.39%	-0.50%
Scenario 2b vs 2a	-0.77%	-0.08%	-0.17%	-0.52%	-0.05%	-0.03%	-0.84%	-0.70%	-0.75%	-0.23%	-0.74%	-0.57%
Scenario 3b vs 3a	-0.79%	-0.08%	-0.18%	-0.53%	-0.05%	-0.03%	-0.56%	-0.67%	-0.68%	-0.23%	-0.39%	-0.50%

Table 3 Summary of the results of future wind farm scenarios

Scenarios basis	Scenario Name	Additional wake loss on each future wind farm arising from Outer Dowsing (%)			
		Hornsea 3	Hornsea 4	Sheringham Shoal Extension	Dudgeon Extension[1]
Impact of ODOW on all future wind farms	**Scenario 1c vs Scenario 1a**	-0.01%	-0.06%	-0.26%	-1.02%
Impact of ODOW on Hornsea 3&4	**Scenario 2c vs Scenario 2a**	-0.01%	-0.07%	-	-
Impact of ODOW on Sheringham & Dudgeon Extensions	**Scenario 3c vs Scenario 3a**	-	-	-0.28%	-1.05%

1. It should be noted that the results regarding the Dudgeon Extension are considered highly conservative, because of the missing of an exclusion zone. This is explained in Section 2.2.2.

Table 4 Summary of the results of all scenarios, normalized to the baseline

Scenarios basis	Scenario Name	Additional wake loss on each operational wind farm (%)										
		Triton Knoll	Westermost Rough	Lincs	Race Bank	Inner Dowsing	Lynn	Dudgeon	Hornsea 1	Hornsea 2	Humber Gateway	Sheringham Shoal
Impact of ODOW on existing farms	Scenario 0a	0	0	0	0	0	0	0	0	0	0	0
	Scenario 0b	-0.79%	-0.08%	-0.18%	-0.53%	-0.05%	-0.03%	-0.88%	-0.70%	-0.75%	-0.23%	-0.76%
Impact of all future developments on existing farms	Scenario 1a	-0.65%	-0.18%	-0.28%	-0.50%	-0.13%	-0.18%	-3.16%	-1.09%	-1.45%	-0.10%	-2.35%
	Scenario 1b	-1.43%	-0.26%	-0.46%	-1.02%	-0.18%	-0.21%	-3.71%	-1.76%	-2.14%	-0.34%	-2.74%
Impact of ODOW and Hornsea 3&4 on existing farms	Scenario 2a	-0.22%	-0.17%	-0.01%	-0.02%	0.00%	0.00%	-0.09%	-0.99%	-1.37%	-0.09%	-0.03%
	Scenario 2b	-0.99%	-0.25%	-0.18%	-0.54%	-0.05%	-0.03%	-0.93%	-1.69%	-2.11%	-0.32%	-0.77%
Impact of ODOW and Sheringham & Dudgeon Extensions on existing farms	Scenario 3a	-0.44%	-0.01%	-0.27%	-0.47%	-0.13%	-0.18%	-3.10%	-0.09%	-0.09%	-0.02%	-2.35%
	Scenario 3b	-1.22%	-0.09%	-0.45%	-1.00%	-0.18%	-0.21%	-3.67%	-0.77%	-0.77%	-0.25%	-2.74%

1. INTRODUCTION

1.1. Background to the study

The Client has retained Wood Thilsted Partners Ltd (WT) to develop an independent wake impact assessment, arising from their proposed Outer Dowsing Offshore Wind Farm Project (the "Project" or "ODOW") to the neighbouring projects. The Project and the neighbouring projects, which may potentially be affected are all located in the Southern North Sea.

The neighbouring projects under consideration in the Southern North Sea are:

- Triton Knoll (857 MW, commissioned in 2022)
- Westermost Rough (210 MW, commissioned in 2015)
- Lincs (270 MW, commissioned in 2013)
- Race Bank (573 MW, commissioned in 2017)
- Inner Dowsing (97.2 MW, commissioned in 2008)
- Lynn (97.2 MW, commissioned in 2008)
- Dudgeon (402 MW, commissioned in 2017)
- Hornsea 1 (1218 MW, commissioned in 2020)
- Hornsea 2 (1320 MW, commissioned in 2022)
- Humber Gateway (219 MW, commissioned in 2015)
- Sheringham Shoal (317 MW, commissioned in 2011)

The Client is interested in the potential differences in annual energy production on the operational and future wind farms noted above, driven by the wake effects from the Project in conjunction with the other proposed future wind farms, Hornsea 3, Hornsea 4, Dudgeon Extension and Sheringham Shoal Extension. These proposed future projects have already received Consent.

In order to assess the additional wakes arising from the Project in combination with other proposed projects given above, a range of scenarios have been considered. The chosen scenarios are;

- the sole impact of the Project on existing assets,
- the cumulative impact of all proposed wind farms along with the Project,
- the cumulative impact of Hornsea 3 and Hornsea 4 with the Project,

- the cumulative impact of Sheringham Shoal Extension, Dudgeon Extension with the Project,
- the impact of Project on the proposed projects Hornsea 3 and Hornsea 4, and
- the impact of Project on the proposed projects Sheringham Shoal Extension and Dudgeon Extension.

It should be noted that due to the physical complexity of wind turbine wake phenomena (as explained in Section 1.2), the cumulative assessments will not be as high as the sum of the impact of each individual wind farm added together. This is to be expected, considering the complexity of flow and interaction & recovery processes of wakes downstream of a wind turbine. Therefore, in order to have a fairer view of the wake impacts, it is considered appropriate to assess their effects on both an individual and cumulative basis.

The project area has a range of proposed and operational wind farms as shown in Figure 1-1.

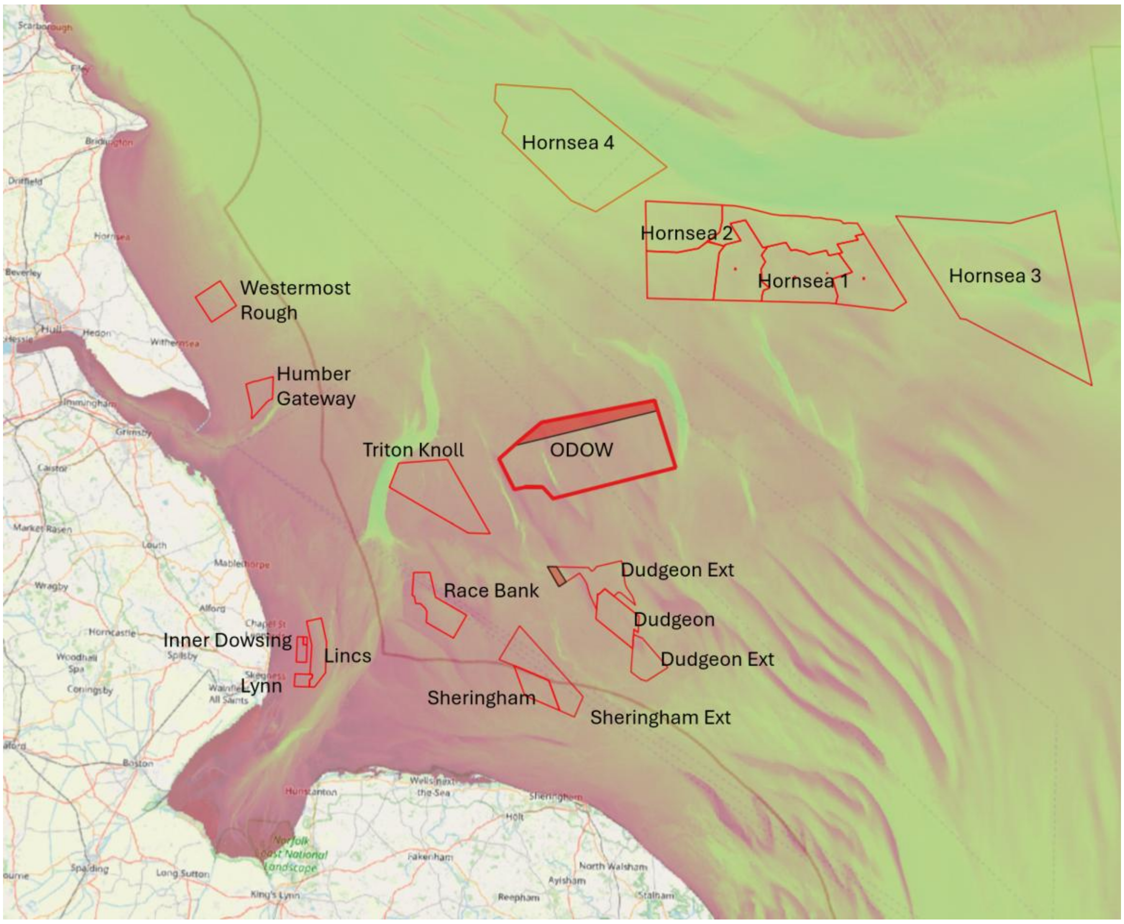

Figure 1-1 Location of the Client's proposed ODOW (shown highlighted in red) in the context of this part of the Southern North Sea.

By way of introduction, WT finds it appropriate to briefly explain the issue of wind farm wakes and industry methodologies to model them.

1.2. Wind Farm Wakes

Wind turbines generate electricity by extracting the useful kinetic energy within the wind. This energy conversion process leaves a slower-moving and highly chaotic, therefore less-useful wind downstream of the wind turbine. This downstream region is characterized by lower wind speeds and higher turbulence and is referred as the wind turbine wake. The turbulence in the wake is driven by tip vortices generated at the turbine blade tips and turbulent eddies just behind the turbine, which is a region with intense swirling motions of air. Wakes both affect the performance of the downstream turbines with respect to energy yield and altered mechanical stress on the structure.

As the flow propagates downstream, the highly chaotic state of the wake recovers gradually to the original airflow state, by mixing of the slower, turbulent air within the wake with the undisturbed air in the surroundings. This recovery is affected by factors such as the atmospheric turbulence, which is the natural turbulence of the background atmosphere; wind shear, which describes the change in wind speed with height; and the atmospheric stability, which is the resistivity of the atmosphere to the disturbances. The full recovery behind a single turbine usually requires distances such as 10-12 turbine rotor diameters.

As a general rule of thumb, modelling the effects associated with internal wakes and designing the wind farm turbine layouts in such a way to minimize these internal wake effects are essential in the realisation of wind farms. Industry best practices often apply constraints of 4-6 rotor diameters between the turbines in non-significant wind directions and 7-8 rotor diameters between the turbines in prevailing wind directions. However, it should be noted that this report is rather about investigation of long distance wakes across the wind farm clusters.

There are several methodologies in the industry for modelling the wakes, ranging from simple analytical / empirical models to more advanced CFD based models, which have trade-offs in terms of accuracy and computational cost. As covered in Section 5, WT's typical best practice is to use the WindFarmer: Analyst Eddy Viscosity with large wind farm correction model to estimate offshore wake and turbine interaction effects. This model has been validated by DNV in 2019, and results in lower errors across a number of operational offshore wind farms compared to other wake models [9], [10].

2. DESCRIPTION OF THE ASSESSED PROJECTS

2.1. Location of the client assets & data

The Outer Dowsing project is situated in the Southern North Sea, off the East coast of the UK.

A map showing the available wind climate locations at Outer Dowsing FL, Race Bank MM, Dogger Bank West MM and boundaries of all neighbouring, all future projects as well as the ODOW project are presented in Figure 2-1. Further information related to the wind climate files can be found in Section 3.

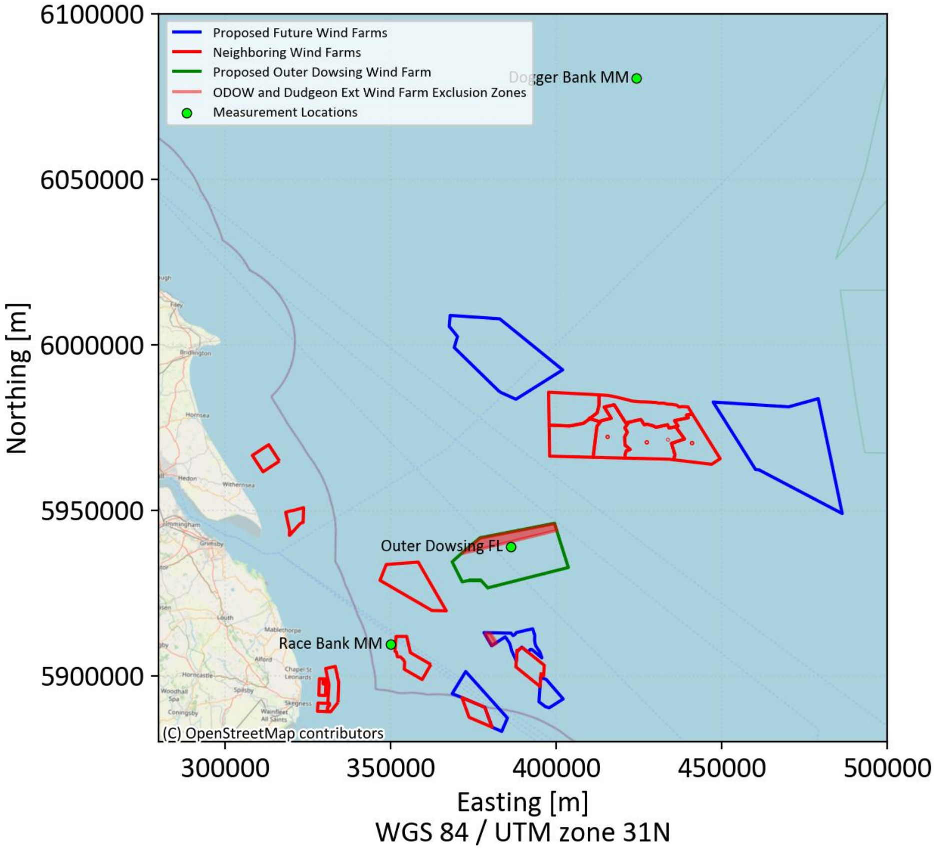

Figure 2-1 Map of the existing projects along with the available measured wind data locations used to derive wind climates. Existing neighbouring farms are shown in red, proposed future farms in blue and ODOW in green. Exclusion zones from the DCO process are shown in red shading.

2.2. Turbine Layouts and Configurations

2.2.1. Power Curves

Turbine configurations for ODOW, operational and other future wind farms, including the turbine model, rated power, hub height, peak power coefficient, number of turbines and total installed capacity, are provided in Table 2-1. The information related to ODOW, and operational wind farms were provided by the Client [4]. For other proposed wind farms, WT has made reasonable assumptions including designing layouts with a set of constraints as described in Section 2.2.2.

It should be noted that for the other proposed wind farms, it has been assumed that the turbine model will be the same as for ODOW, which is a 15.0MW 236m diameter design. Further details regarding this assumption is provided in Section 5.

The general characteristics of all the turbine models under consideration are summarised in Table 2-1. It should be noted that the characteristics and performance data of the operational wind farms are redacted for confidentiality reasons, however it is noted that detailed power curve information has been used in this assessment.

WT has obtained historical pressure and temperature records from eleven nearby meteorological stations within a maximum radial distance of 300 km and maximum elevation difference of 300 m from the site. Using standard lapse rate assumptions, WT has derived air density values between 1.221 kg/m^3 and 1.225 kg/m^3 at an elevation of 158 mMSL. Based on these data, WT has estimated the long-term air density at the site to be 1.224 kg/m^3 at an average elevation of 158 mMSL for all the wind farms.

The supplied power curves used in this analysis have been adjusted to the predicted site air density, in accordance with the recommendations of IEC [11]. This has been undertaken on an individual turbine basis.

2.2.2. Layouts

The layouts related to ODOW, and existing operational wind farms were provided by the Client [4]. For the other future proposed wind farms, WT has designed preliminary wind turbine layouts based on guidelines and constraints described in the project submissions available in the Planning Inspectorate Portal [3], and Development Consent Order (DCO) documents for Hornsea 3 [5], Hornsea 4 [6] Dudgeon Extension and Sheringham Shoal [7], along with general industry practice.

Due to the preliminary nature of the future wind farms, WT did not consider additional constraints while designing the layouts. However, it should be noted that WT has undertaken a high-level review of seabed properties including sea depth, using Emodnet bathymetry data [12] and avoided turbine locations exceeding approximately 50 m, assuming that the project would prefer "shallow" foundation approaches. This has affected Hornsea 3 project in which the northwestern part of the site boundary given in Figure 1-1 remains free of turbines. WT would expect that final layout designed by the respective developer or additional layout considerations would ultimately alter the results, however these are likely to be small in the overall assessment of impact.

As such, WT has designed one layout for each of Hornsea 3, Hornsea 4, Dudgeon Extension and Sheringham Shoal Extension Wind Farms considering the 15.0MW 236m diameter wind turbine, which is the same wind turbine considered for ODOW.

It should be noted that, an exclusion zone in the northwestern part of the northern site of Dudgeon Extension Wind Farm, has not been considered in the present layout design of this study. Consequently, three turbines are placed in that exclusion zone. It is considered however that, the results regarding the combined effect on the Dudgeon Extension is likely to be more conservative, as more turbines are located in closer proximity to other farms including ODOW.

The allowable number of turbines for each of the Hornsea 3, Hornsea 4, Dudgeon Extension and Sheringham Shoal Extension Wind Farm sites has been obtained from the available information on proposed farm size from the DCO submissions, using the assumption of the 15.0MW 236m turbines.

Based on the derived wind climate from ODOW FL (see Section 4), WT has estimated the prevailing wind direction at each site in order to define acceptable minimum turbine separation distances in the prevailing and non-prevailing wind directions, and to align the layout grid such that the wake impacts from a row of turbines on the rows behind them are minimised. Typical offshore wind farms currently under development maintain an average inter-turbine spacing of approximately 7-8 rotor diameters in prevailing wind directions, and 4-6 rotor diameters in non-prevailing wind directions.

Given the wind regimes at the wind climate locations, which can be seen in Appendix C-3, WT considers that inter-turbine spacings of 8 rotor diameters in the prevailing wind directions and 6 rotor diameters in the non-prevailing wind directions can be accommodated for the Hornsea 3, Hornsea 4, Dudgeon Extension and Sheringham Shoal Extension Wind Farm sites.

The grid coordinates of the optimised turbine layouts for the Hornsea 3, Hornsea 4, Dudgeon Extension and Sheringham Shoal Extension wind farms are given in the figures in Appendix A.

Table 2-1 Turbine model parameters and turbine configurations for the neighbouring wind farms.

Wind farm	Associated turbine model	Rated power (MW)	Hub height (mMSL)	Number of turbines	Installed Capacity
Triton Knoll	Vestas V164-9.5MW	9500	110	90	857
Westermost Rough	Siemens Gamesa SG-6.0-154	6000	110	35	210
Lincs	Siemens Gamesa SWT-3.6-120	3600	85	75	270
Race Bank	Siemens Gamesa SG-6.0-154	6000	110	91	573
Inner dowsing	Siemens Gamesa SWT-3.6-107	3600	80	27	97.2
Lynn	Siemens Gamesa SWT-3.6-107	3600	80	27	97.2
Dudgeon	Siemens Gamesa SG-6.0-154	6000	110	67	402
Hornsea 1	Siemens Gamesa SG-7.0-154	7000	116	174	1218
Hornsea 2	Siemens Gamesa SG DD-8.0-167	8000	116	165	1320
Humber Gateway	Vestas V112-3.0MW	3000	80	73	219
Sheringham Shoal	Siemens Gamesa SWT-3.6-107	3600	80	88	317

Table 2-2 Turbine model parameters and turbine configurations for the proposed future wind farms.

Wind farm	Associated turbine model	Rated power (MW)	Hub height (mMSL)	Number of turbines	Assumed Installed Capacity
ODOW	Future 15.0MW 236m diameter Turbine	15000	158	100	1500
Hornsea 3	Future 15.0MW 236m diameter Turbine	15000	158	200	3000
Hornsea 4	Future 15.0MW 236m diameter Turbine	15000	158	160	2400
Sheringham Shoal Extension	Future 15.0MW 236m diameter Turbine	15000	158	23	345
Dudgeon Extension	Future 15.0MW 236m diameter Turbine	15000	158	30	450

3. DESCRIPTION OF THE AVAILABLE WIND DATA

3.1. Wind Climate Files

The Client has provided the long-term corrected time series at the hub heights of all the projects, 80.0 m, 85.0 m, 110.0 m, 116.0 m and 158.0 m from the Outer Dowsing FL [4], which is used as the main source of data in the wind flow / wake modelling.

Additionally, to assess TI, WT has obtained cleaned & processed wind measurements from publicly available Race Bank Met. Mast and Dogger Bank West Met. Mast from Marine Data Exchange portal [13].

The input wind time series data are summarised in Table 3-1 below. The locations are shown in Figure 2-1.

Table 3-1 Wind climates summary.

Device	Provided long term time series heights		Period of time series	Location[1]	
	Wind speed (m)	Wind direction (m)		Easting	Northing
Outer Dowsing FL	80.0, 85.0, 110.0, 116.0, 158.0	80.0, 85.0, 110.0, 116.0, 158.0	01/08/2001–31/07/2023	386319.0	5938966.0
Race Bank MM	90.2[2], 89.3[3], 80.0[3], 70.0[3], 60.0[4], 30.0[4]	89.3, 88.1	08/06/2006–17/12/2008	349933.2	5909531.0
Dogger Bank West MM	110.0[5], 104.5[6], 98.4[7], 83.7[6], 68.6[7], 53.5[5], 38.3[5]	104.5, 78.4, 63,4	24/07/2013–19/11/2014	424230.0	6080569.0

1- Coordinate system: WGS 84 / UTM zone 31N (EPSG:32631)
2- Stub mounted anemometer
3- Anemometers orientated to 225 degrees on Race Bank MM.
4- Anemometers orientated to 45 degrees on Race Bank MM.
5- Parallel measurements available orientated to 320 and 140 degrees on Dogger Bank West MM.
6- Anemometers orientated to 320 degrees on Dogger Bank West MM.
7- Anemometers orientated to 140 degrees on Dogger Bank West MM.

Further details of the individual wind climate files provided by the Client, including monthly data statistics at selected heights, can be found in Appendix B. The Outer Dowsing FL is located within the ODOW project boundary.

The Race Bank MM is in the North Sea, approximately 30 km east of Skegness, UK and approximately 1.5- 2 km west of Race Bank Wind Farm project area. WT has obtained cleaned mean wind speed and standard deviation data from 90.2 m (stub mounted), 89.3 m, 80.0, 70.0 m (orientated to 225 degrees), 60.0 m and 30.0 m (orientated to 45 degrees) from the Marine Data Exchange Portal [13], for the 2.3 year period between 08/06/2006– 17/12/2008. Additional checks have been conducted for the handling of stub mounted anemometer data at 90.2 m and consequently WT has decided to extrapolate the TI data calculated from 89.3 m orientated to 225 degrees to the site locations. Additional information from the checks undertaken can be found in Section 4.4. Though WT has not independently verified the steps undertaken for the processing of the data, through comparison with available reference data sets and other measurements, WT considers that this data is of good quality and appropriate for use in deriving a representative TI profile.

The Dogger Bank West Met. Mast is also located in the North Sea, approximately 200 km east of Sunderland and approximately 100 km north of Hornsea 1 and 2 projects. WT has obtained cleaned mean wind speed and standard deviation data from 110.0 m (parallel measurement), 104.5 m (orientated to 320 degrees), 98.4 m (orientated to 140 degrees), 83.7 m (orientated to 320 degrees), 68.6 m (orientated to 140 degrees), 53.5 m and 38.3 m (both parallel measurement), from Marine Data Exchange Portal [13], for the 1.1 year period between 24/07/2013– 19/11/2014. Although, the wind measurements are available at slightly higher measurement level (110 m vs 90.2 m for Race Bank MM), since the location of the Dogger Bank data is further away from the project sites, WT has not incorporated this data in the assessment of TI profile and used only for additional comparison / validation purposes.

It should be noted that the Client has provided the wind climates in the form of long-term corrected hub height time series from the Outer Dowsing FL for the hub heights of 80.0 m, 85.0 m, 110.0 m, 116.0 m and 158.0 m, which are used as the main source of data in this flow / wake modelling study. WT has discussed the process followed by the Client while producing the wind climate file from Outer Dowsing FL and conducted quality checks of this data, including comparisons of WT's assessment of publicly available data from the Race Bank Met. Mast and the Dogger Bank West Met. Mast, as well as Vortex reference data and have deemed this wind climate data acceptable as input for the flow modelling / wake assessment. Further details can be found in Section 4.

3.2. Reference Data

3.2.1. Global Wind Atlas (GWA) and New European Wind Atlas (NEWA)

WT has utilised reference data in the form of wind speed maps for the derivation of horizontal wind speeds across the turbine locations. These include the New European Wind Atlas (NEWA) [14], Global Wind Atlas (GWA) [15] and Vortex proprietary data. Vortex data has been provided by the Client [4] and publicly available data including NEWA and GWA, have been obtained by WT. Further information regarding NEWA and GWA can be found in Appendix D-4.1 and Appendix D-4.2. The resulting wind maps can be found in Figure 3-1 and Figure 3-2 along with the site boundaries.

WT has undertaken checks regarding the variation of wind speeds on those wind speed maps and compared the cross predictions of the wind climate files summarised in Section 3.1. Based on these checks WT has developed an approach for the prediction of the wind conditions at the turbine locations. More detail on the approach can be found in Section 4.3.1.

It should be noted that the Client has provided time series data from Vortex (Vortex SERIES) [4]. WT has compared the frequency distributions predicted by the wind climate files and Vortex SERIES data, to have a better understanding of the wind climate conditions within the site and as further validation tool of the wind climate files.

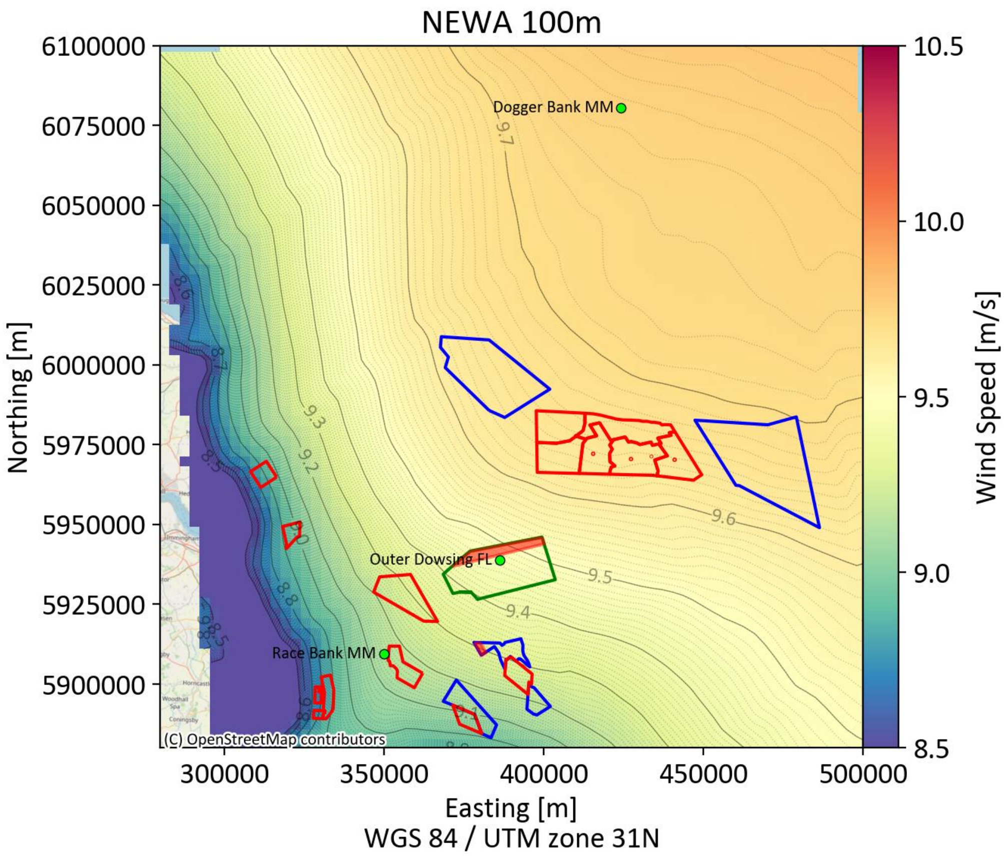

Figure 3-1 New European Wind Atlas (NEWA) 100 m wind map for the site area.

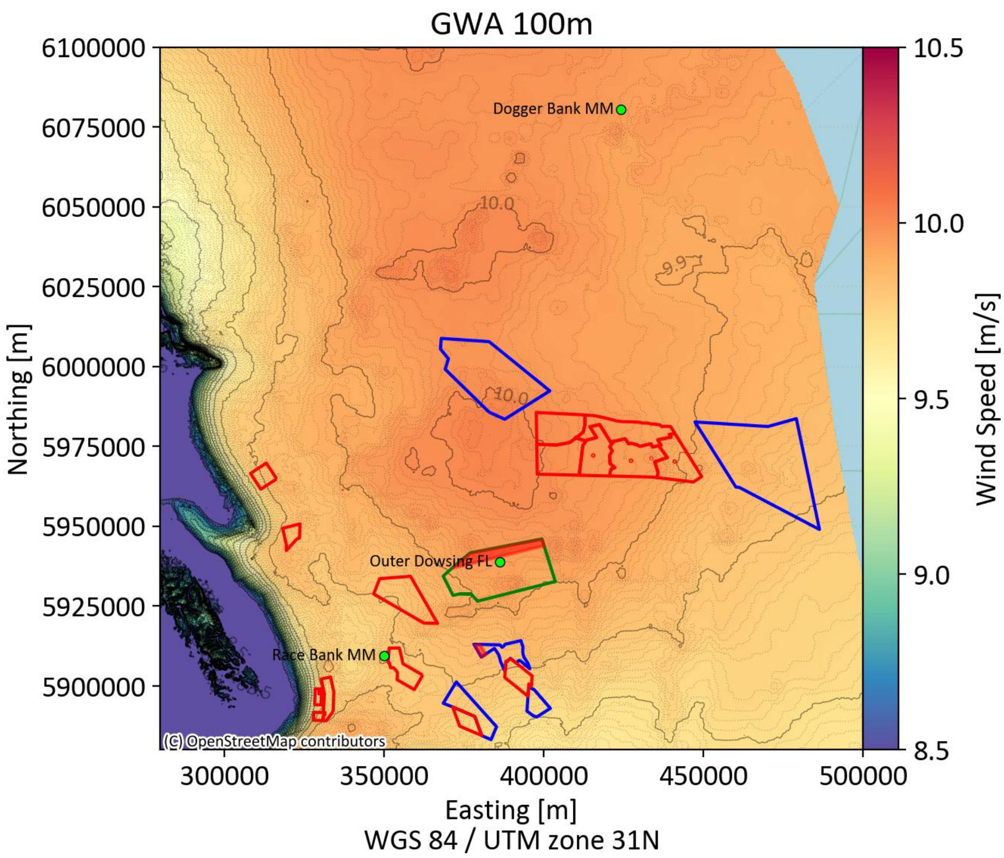

Figure 3-2 Global Wind Atlas (GWA) 100 m wind map for the site area.

3.2.2. Vortex MAP Data

To assess the horizontal wind speed variation across the sites, WT has considered the Vortex MAP product, provided by the Client [4] from Vortex [16]. This has been provided at several heights ranging from 80 m to 160 m and uses the Weather Research and Forecasting (WRF) model forced with ERA5 and downscaled to the site. The wind map at 100 m can be seen in Figure 3-3 along with the site boundaries.

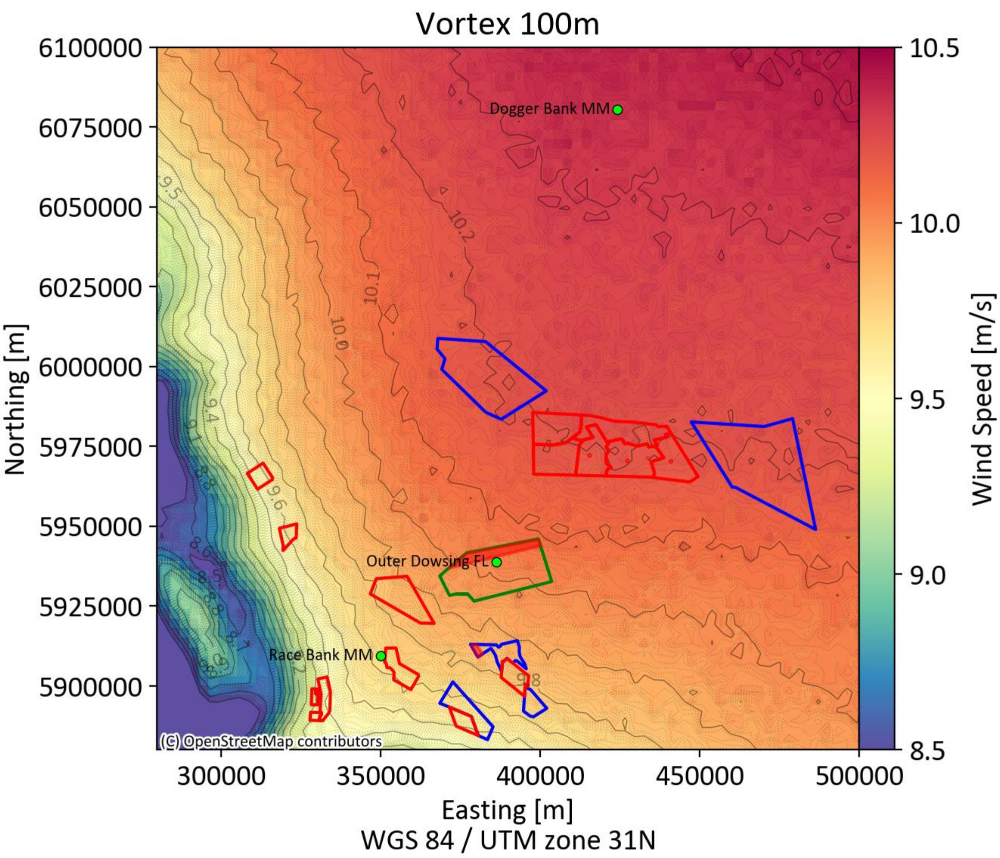

Figure 3-3 Vortex 100 m wind map for the site area.

3.2.3. Vortex SERIES Data

The Client has supplied a 22.6-year dataset from January 2001 to August 2023, derived within ODOW project area, at multiple heights ranging from 100 m to 160 m. This data is from the Vortex SERIES product where the model boundary conditions have come from the ERA5 reanalysis data (will be denoted as “Vortex ERA5 data” throughout the report). The Vortex ERA5 data comes from a WRF-downscaled model with a horizontal resolution of 3 km.

WT has used this data to compare the frequency distributions predicted by the wind climate files to have an improved understanding of the wind climate conditions within the site and as further validation of the wind climate files.

4. LONG-TERM WIND REGIME AT THE SITE

4.1. Validation of wind climate files, specification of the route in predicting turbine location wind speeds

The Outer Dowsing FL data was used as the main source of data in this wake modelling study, along with the wind maps summarised in Section 3.2.

WT has undertaken some further checks using the Race Bank and Dogger Bank West mast data, and developed an approach in predicting the long term mean wind speeds at the turbine locations, that are detailed in the following sections.

4.1.1. Validation of wind climate files

According to the discussions held with the Client [4], the cleaned Outer Dowsing FL data have been generated using a MCP, which WT opines that the methodology is acceptable and follows the industry best practices.

WT has evaluated the provided long-term wind climate data from the Outer Dowsing FL, by visually comparing the frequency distribution created using this data with the frequency distribution from Vortex ERA5 data. WT has also compared the Outer Dowsing frequency distributions with the Race Bank MM and Dogger Bank West MM. The results of the comparisons can be seen in Appendix C-3. According to the comparison between the Vortex ERA5 and Outer Dowsing FL the wind roses fit each other quite well, confirming Client's MCP methodology from Vortex ERA5 data.

WT observed that there is generally acceptable agreement among the wind climates at the Race Bank MM and Dogger Bank West MM with some differences in some non-significant wind direction sectors, which can also be seen in Appendix C-3. The Outer Dowsing wind rose, and Race Bank / Dogger Bank wind roses are also similar in terms of significant wind directions. Considering that the differences in measurement height, location, period and measurement principles of LiDARs and meteorological masts, WT opines that these differences can be within expectations.

4.1.2. Method for predicting the turbine location wind speeds

To spatially extrapolate the wind speeds from the Outer Dowsing FL location to the turbine locations, Vortex MAP product, Global Wind Atlas and New European Wind Atlas data were considered. WT has made consistency checks with these data. Based on these checks, as explained in Section 4.3, WT has used the average predictions from New European Wind Atlas and Vortex MAP product.

In order to do the consistency checks of wind maps explained above, WT has also made high-level long-term correlations in the Dogger Bank West MM and Race Bank MM data, using monthly correlations with Vortex ERA5 data. Further information can be found in Section 4.2.1.

4.2. Long term hub height wind regime at the site

4.2.1. Derivation of long-term wind speed at the Race Bank MM and Dogger Bank MM

As discussed in Section 3, the Outer Dowsing FL wind climate data contain wind time series already adjusted to the long-term wind speed and extrapolated to the hub heights.

To bring the Race Bank MM and Dogger Bank West MM to the same long-term context with Outer Dowsing FL and make meaningful comparisons, WT has made high level monthly correlation analysis using each of the met. mast data and Vortex SERIES data. The methodology is explained in Appendix D-2.1 and Appendix D-2.2.

The results from each Met. Mast is shown in Appendix C-1, which presents the correlations of monthly mean wind speeds at Race Bank MM at 89.3 mMSL and Dogger Bank West MM at 110 mMSL primary measurement heights and the Vortex ERA5 at 160 mMSL. The correlations are of excellent quality, each with a coefficient of determination, R^2, of 0.99 and 0.98 respectively for Race Bank MM and Dogger Bank West MM.

The long-term wind speeds for Race Bank MM and Dogger Bank MM are as given in Table 5 2:

Table 4-1 Long-term wind speed for Race Bank MM and Dogger Bank MM.

Met. Mast	Height [mMSL]	Valid Measurement period [years]	Measured Mean Wind Speed [m/s]	Long-term reference period [years]	Long-term wind speed adjustment [%]	Long-term wind speed at measurement height [m/s]
Race Bank MM	89.3	2.3	9.9	22.6	-3.5	9.5
Dogger Bank West MM	110.0	1.1	10.7	22.6	-3.6	10.3

4.2.2. Vertical wind speed interpolation

The variations in wind speed with height at the wind climate locations have been defined using the power law shear exponents according to the expression given in Appendix D-3.1. The variations are calculated for each wind climate file and have been used to predict the wind resource at the proposed hub heights.

The shear exponents at the wind climate locations have been derived. WT notes that the estimated wind shear exponents are in line with WT's expectations for such offshore locations.

4.2.3. Derivation of the long-term hub height wind speed and direction frequency distribution

As indicated in Section 4.1, the primary measurement device, which is the main source of data in flow / wake modelling is the Outer Dowsing FL data, for the prediction of long-term wind speeds at the turbine locations.

The long term corrected hub height time series for Outer Dowsing FL, provided by the Client [4] has been used to define the wind speed and direction frequency distributions.

For Race Bank MM and Dogger Bank West MM, which are used only in validation of wind maps and the derivation of TI profile, the hub height time series, which are the vertically extrapolated measurement time series, have been used to define the long-term wind speed and direction frequency distributions.

The following procedure was used, to avoid the introduction of bias into the annual mean wind regime prediction from seasonally uneven data coverage:

- The mean wind speed and direction frequency distribution for each month was determined from the valid data recorded in that month over the period. The frequency distribution for each month considered to be representative of the long term for that month thereby assuming the valid data are representative of any missing data.
- The frequency distributions for each of the twelve months were averaged, weighted by the number of days in each month, to determine the long-term annual frequency distribution.

The resulting hub height wind rose and frequency distributions at the wind climate locations at 100 m height can be seen in Appendix C-2, where the wind rose shapes are considered as representative for the sites under consideration.

4.3. Wind regime across the site

4.3.1. Wind flow modelling

To assess the horizontal wind speed variation across the turbine locations at the sites, as explained in Section 3.2, WT has considered use of the Vortex MAP product, New European Wind Atlas and Global Wind Atlas, at 100 m height for reference.

Wind model validation

Given that wind climate files are available at three different locations across the wind farms, WT has undertaken a performance check utilizing all three-wind maps to understand the agreement. The results of this check are given in Table 4-2 below, including the percentage differences with the predicted long term hub height wind speeds. It should be noted that the lighter colours indicate high performance and darker reds / blues shows poor performance.

Table 4-2 Comparison of wind map wind speeds and long-term wind speeds at 100 m height (colouring shows relative performance of map approaches).

Wind Climate File	Wind speed derived on Vortex wind map [%]	Wind speed derived on GWA [%]	Wind speed derived on NEWA [%]
Outer Dowsing FL	4.80%	3.72%	-1.24%
Race Bank MM	0.47%	1.55%	-5.29%
Dogger Bank West MM	1.50%	-2.29%	-4.26%

Whilst WT considers this exercise beneficial to inform the relative performance and agreement of wind maps and measurements, it is acknowledged that there are limitations and elevated uncertainty in performing this validation, because of the nature of measurement devices, as one is floating LiDAR and other two are meteorological masts, in which the measurements may be affected by lattice structure of the mast at certain wind sectors. It should be noted that the difference in measurement periods, differences in data processing approaches (as Outer Dowsing FL data have been processed by the Client), and also modelling inputs & methodology used in generation of the wind maps can play a role in these error margins, which are up to 4.8%, given in Table 4-2.

Notwithstanding the uncertainties discussed above, it is considered that uncertainties in the wind regime across the site have a lower impact on the analysis conducted in Section 5 due to it being a delta on wake impact, which is not as sensitive to wind speed errors as a traditional energy yield analysis.

WT also conducted a cross-prediction check across the measurement devices using the speedups derived from each of the wind speed maps and evaluated the consistency of the wind climate files and performance of wind speed maps. The results are given in Table 4-3, Table 4-4 and Table 4-5.

Table 4-3 Wind speed cross-predictions at 100 m height for Vortex.

Predicted from wind climate file	Predicted from Vortex MAPS at 100 m [%]		
	Outer Dowsing FL	Race Bank MM	Dogger Bank West MM
Outer Dowsing FL	-	4.31%	3.25%
Race Bank MM	-4.13%	-	-1.02%
Dogger Bank West MM	-3.15%	1.03%	-

Table 4-4 Wind speed cross predictions at 100 m height for GWA.

Predicted from wind climate file	Predicted from GWA at 100 m [%]		
	Outer Dowsing FL	**Race Bank MM**	**Dogger Bank West MM**
Outer Dowsing FL	-	2.14%	6.16%
Race Bank MM	-2.10%	-	3.93%
Dogger Bank West MM	-5.80%	-3.78%	-

Table 4-5 Wind speed cross predictions at 100 m height for NEWA.

Predicted from wind climate file	Predicted from NEWA at 100 m [%]		
	Outer Dowsing FL	**Race Bank MM**	**Dogger Bank West MM**
Outer Dowsing FL	-	4.28%	3.16%
Race Bank MM	-4.10%	-	-1.08%
Dogger Bank West MM	-3.06%	1.09%	-

Regarding the selection of wind speed map, considering the inherent uncertainties in the checks made, as explained above, the results did not easily allow WT to select a wind map, and thus it is considered that the wind flow modelling has additional challenges. It is noted that NEWA and Vortex seem promising according to the cross prediction checks when Dogger Bank MM and Race Bank MM were considered, with cross prediction errors around 1.0% - 1.1%.

WT has decided to further consider two averaging options across different wind speed maps, namely average of three wind speed maps and average of Vortex and NEWA. The results of this check are given in Table 4-6, Table 4-7 and Table 4-8 below.

Table 4-6 Comparison of wind map wind speeds and long-term wind speeds at 100 m height.

Wind Climate File	Wind speed derived using average of all three wind maps [%]	Wind speed derived using average of Vortex and NEWA wind maps [%]
Outer Dowsing FL	2.43%	1.78%
Race Bank MM	-1.09%	-2.41%
Dogger Bank West MM	-1.68%	-1.38%

Table 4-7 Wind speed cross-predictions at 100 m height using average of all three wind maps

Predicted from wind climate file	Predicted from average of all the maps at 100 m [%]		
	Outer Dowsing FL	Race Bank MM	Dogger Bank West MM
Outer Dowsing FL	-	3.56%	4.18%
Race Bank MM	-3.44%	-	0.60%
Dogger Bank West MM	-4.01%	-0.60%	-

Table 4-8 Wind speed cross predictions at 100 m height using average of Vortex and NEWA wind maps

Predicted from wind climate file	Predicted from average of NEWA and Vortex at 100 m [%]		
	Outer Dowsing FL	Race Bank MM	Dogger Bank West MM
Outer Dowsing FL	-	4.30%	3.20%
Race Bank MM	-4.12%	-	-1.05%
Dogger Bank West MM	-3.11%	1.06%	-

Looking at these results, averaging across three maps brings the error margin to the order of around 2.5% and cross prediction errors between Race Bank and Dogger Bank West MM around 0.6%, which is considered as favourable for the use of averaging. WT has further calculated the turbine location wind speeds using these maps and the variation in turbine wind speeds in three wind maps is given in Appendix C-4. Looking the plot given in Appendix C-4, WT considered that the turbine location predictions of GWA is inconsistent with NEWA and Vortex, therefore decided to use the average of NEWA and Vortex in the prediction of turbine location wind speeds.

Wind speed variation across the sites

As noted, the Outer Dowsing FL is the primary sources of data for the analysis and therefore have been used to initiate the wind flow model from which the wind speeds at the proposed turbine locations have been predicted, using the average of NEWA and Vortex wind maps, as explained above.

4.4. Turbulence Intensity

It is widely accepted in the wind industry that turbulence intensity measurements from Lidar devices (volume measurements) are not directly comparable to turbulence intensity measurements from meteorological masts using cup anemometers (point measurements), which is currently what the wind industry standards are based on.

In addition to the difference in turbulence intensity measurements from Lidars due to the volume to point measurement issue, floating Lidar systems have the added complication of motion impacting the measurements, which artificially increases the measured turbulence intensity.

Due to these reasons, WT found that Dogger Bank MM and Race Bank MM are good candidates for the sites under consideration, to calculate the turbulence intensity. Therefore, WT has adjusted the turbulence profile measured at the Dogger Bank MM and Race Bank MM to be representative of the expected long-term hub height wind speeds at the Outer Dowsing FL. As standard deviation is assumed constant, the turbulence intensity can be scaled from the met mast location to the turbine locations using the ratio in long-term wind speed between the met mast and the long-term wind speed of the site in question.

Figure 4-1 and Figure 4-2 show the assumed turbulence intensity profile at the Outer Dowsing FL, from Race Bank MM and Dogger Bank MM, respectively, derived at the turbine hub height of 158 m, along with profiles for IEC turbulence subclasses A, B and C [11]. Considering its distance to the site is much closer than Dogger Bank, therefore expected to have more similar conditions to the turbine locations, and having more measured data of 2.3 years than Dogger Bank West, which is 1.1 years, WT deems Race Bank MM is a better candidate than Dogger Bank MM in predicting the ambient TI for the turbine locations at each hub height. WT has considered Dogger Bank MM just for additional comparison / validation purposes.

It should be noted that, as discussed in Section 3.1, the top anemometer installed at 90.2 m is noted as stub mounted in the Race Bank MM documentation, which is possibly installed to a shorter rod compared to a longer boom, which can induce additional flow distortion from the nearby devices and the lattice structure from the mast itself due to the use of shorter rod. WT was unable to confirm the installation, as no picture related to the anemometer at 90.2 m was provided in the documentation. However, WT has made an additional check and compared the TI profiles of 90.2 m and 89.3 m northwest anemometers. This check yielded that the 90.2 m anemometer has a slightly higher TI values, which may possibly confirm the possible additional flow distortion due to the stub mounting. The results of this check can be seen in Appendix C-5. Therefore, WT has decided to use the 89.3 m orientated to 320 degrees anemometer as the primary one, and used the data measured by this device to derive the on-site TI profiles given below.

Table 4-9 shows the tabulated ambient turbulence intensity profiles for the mentioned combinations of sites and hub heights. WT notes that the magnitude of derived turbulence intensity values is in line with WT's experience, considering the expected offshore wind conditions at sites around the UK, with similar hub height.

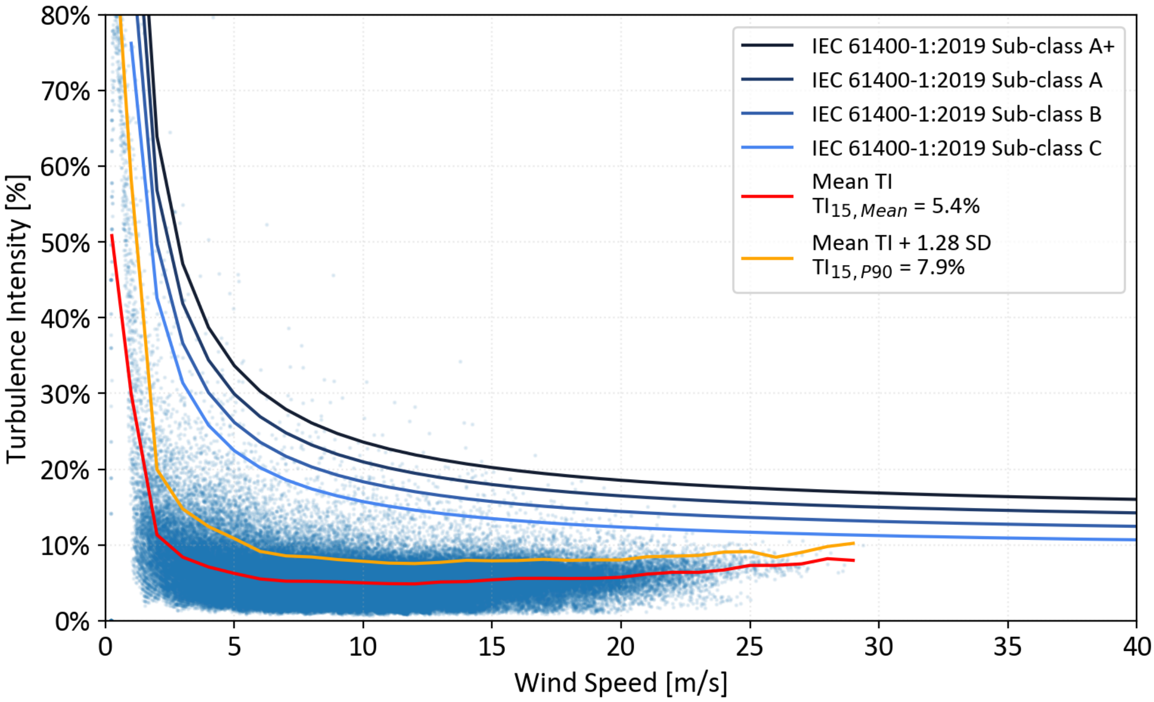

Figure 4-1 Ambient Turbulence Intensity profile assumed at the Outer Dowsing FL location at 158.0 m height, as derived from measurements made at the Race Bank MM.

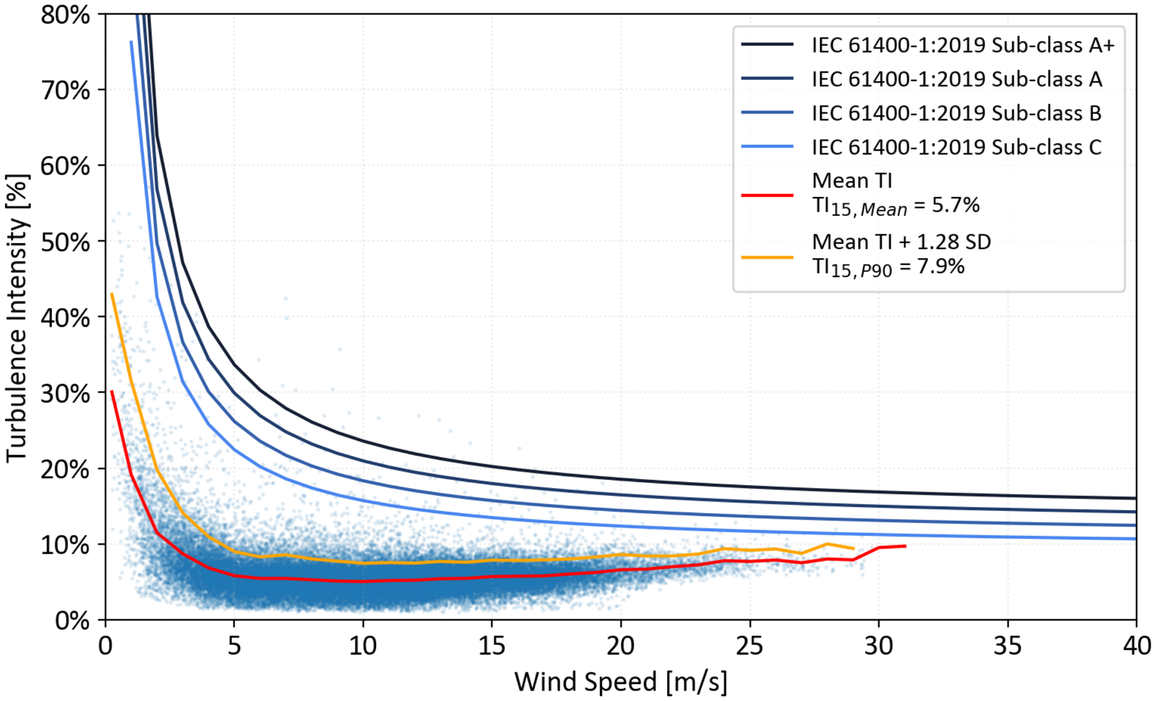

Figure 4-2 Ambient Turbulence Intensity profile assumed at the Outer Dowsing FL location at 158.0 m height, as derived from measurements made at the Dogger Bank MM.

Table 4-9 Ambient Turbulence Intensity profile assumed at Outer Dowsing FL at each hub height.

Wind speed bin centre (m/s)	Mean TI at Outer Dowsing FL at 80 mMSL hub height (%)	Mean TI at Outer Dowsing FL at 85 mMSL hub height (%)	Mean TI at Outer Dowsing FL at 110 mMSL hub height (%)	Mean TI at Outer Dowsing FL at 116 mMSL hub height (%)	Mean TI at Outer Dowsing FL at 158 mMSL hub height (%)
0	57.86%	57.41%	54.34%	54.22%	50.83%
1	27.40%	27.40%	28.51%	28.45%	29.94%
2	11.66%	11.68%	11.55%	11.55%	11.34%
3	8.59%	8.54%	8.45%	8.43%	8.40%
4	7.36%	7.34%	7.21%	7.21%	7.10%
5	6.39%	6.36%	6.33%	6.32%	6.25%
6	5.79%	5.77%	5.65%	5.64%	5.52%
7	5.59%	5.56%	5.41%	5.40%	5.23%
8	5.58%	5.55%	5.37%	5.36%	5.21%
9	5.46%	5.42%	5.30%	5.29%	5.13%
10	5.31%	5.28%	5.15%	5.14%	5.00%
11	5.23%	5.19%	5.05%	5.04%	4.90%
12	5.52%	5.46%	5.16%	5.14%	4.86%
13	5.59%	5.53%	5.37%	5.35%	5.12%
14	5.87%	5.78%	5.47%	5.44%	5.17%
15	6.05%	6.01%	5.76%	5.74%	5.41%
16	5.99%	5.95%	5.76%	5.77%	5.59%
17	6.07%	6.02%	5.84%	5.81%	5.60%
18	6.08%	6.03%	5.77%	5.76%	5.58%
19	6.48%	6.33%	5.92%	5.89%	5.60%
20	6.80%	6.71%	6.31%	6.30%	5.74%
21	6.94%	6.84%	6.57%	6.53%	6.16%
22	7.01%	6.89%	6.69%	6.68%	6.39%
23	7.86%	7.68%	6.93%	6.84%	6.38%
24	7.93%	7.84%	7.46%	7.50%	6.71%
25	8.06%	7.95%	7.65%	7.59%	7.31%
26	8.56%	9.08%	7.80%	7.81%	7.31%
27	9.36%	8.11%	8.51%	8.49%	7.51%
28	-	-	8.28%	8.26%	8.19%
29	-	-	-	-	7.97%

5. METHODOLOGY & RESULTS OF THE WAKE ASSESSMENT

The Energy Yield and the subsequent impact of the wakes produced by the individual wind farms have been calculated using WindFarmer: Analyst software. Of concern in any Energy Yield study is the effect of wake and turbine interaction losses (including blockage effect) from inside the farm and from adjacent farm sites. WT's typical best practice is to use the WindFarmer: Analyst Eddy Viscosity with large wind farm correction model to estimate offshore wake and turbine interaction effects, as validated by DNV in 2019, which results in lower errors across a number of operational offshore wind farms compared to other wake models [9], [10].

As noted in Appendix D-4.1a, the blockage effects have also been calculated using the Blockage Effect Estimator Tool (BEET) implemented within WindFarmer: Analyst software, which is based on a validation study incorporating more than 50 CFD simulations. The wind farm blockage is defined as the slowing-down effect caused by the wind farm itself, as it presents an obstacle to the incoming wind flow. This effect is usually not estimated in many standard industry wake models. According to WT's estimates, the wind farm blockage based on the BEET is found to be around 0.9% for all the scenarios considered and this figure is also inherent in the wake effect estimations given in Table 5-3.

No specific sensitivity assessment of the available range of wake models has been undertaken as the intention is to provide an independent assessment, in line with methodologies that have a proven track record.

A series of scenarios have been established to assess the relative impact of the build out of the Outer Dowsing farm to the proposed future sites. Table 5-1 below summarises the scenarios applied in this assessment.

The Baseline scenario represents the current situation of the project area, such that all existing operational wind farms, as listed in Table 5-2.

Baseline + ODOW scenario assumes the sole impact of ODOW on the existing operational wind farms.

Then, the effect of ODOW along with all the additional future wind farms, Sheringham Shoal, Dudgeon Extension, Hornsea 3 and Hornsea 4 was considered in Scenarios 1a and 1b. The effect of ODOW along with Hornsea 3 and Hornsea 4 only, was considered in Scenarios 2a and 2b and finally the effect of ODOW along with Sheringham Shoal Extension and Dudgeon Extension was considered in Scenarios 3a and 3b.

WT has further investigated the effect of ODOW in the future development, such that impact of ODOW in Hornsea 3 and Hornsea 4 was considered in Scenario 2c and the impact of ODOW in Sheringham Shoal Extension and Dudgeon Extension was considered in Scenario 3c.

For the future wind farms, Sheringham Shoal, Dudgeon Extension, Hornsea 3 and Hornsea 4, it is assumed that the same 15 MW wind turbine as for ODOW, which is a 15.0MW 236m rotor diameter at a hub height of 158 m. This assumption is considered reasonable, given that the project timelines are similar as well as considering current sector trends.

It should be noted that the information compiled for the future projects are not certain at this stage, and the impacts will be subject to change; therefore, this report should be considered as being based on the best available information at the time of preparation.

No changes to the existing wind farms e.g. repowering/ extended maintenance or non-operational turbines were assumed.

The projected decrease in potential energy production due to additional wake and turbine interaction losses from each scenario on each of the Client assets are shown in Table 5-3, Table 5-4 and Table 5-5.

The results of the turbine basis analysis are presented in Appendix C. A definition of turbine interaction loss factors applied to all scenarios is included in Appendix D-4.

Table 5-1 External Wake Main Scenarios

Scenario	Included Wind Farms	Comments / Assumptions
Baseline (Scenario 0a)	Existing Operational Wind Farms [1]	Existing operational conditions
Baseline + **ODOW** (Scenario 0b)	Baseline + **ODOW** [2]	Sole impact of 1500 MW ODOW project on the operational wind farms, which are expected to be operational in 2030.
Scenario 1a	Baseline + Sheringham Shoal Extension, Dudgeon Extension, Hornsea 3 and Hornsea 4 [2]	Baseline scenario for 1b below, cumulative effect of all future wind farms
Scenario 1b	Baseline + Sheringham Shoal Extension, Dudgeon Extension, Hornsea 3 and Hornsea 4 [2] with **ODOW** [2]	Impact of ODOW along with all future development. Sheringham Shoal Extension (345 MW) and Dudgeon Extension (450 MW) will be operational by 2030. Hornsea 3 (3000 MW) will be operational by 2027. Hornsea 4 (2400 MW) will be operational by 2030.
Scenario 1c	Baseline + Sheringham Shoal Extension, Dudgeon Extension, Hornsea 3 and Hornsea 4 [2] with **ODOW** [2]	Technically same scenario with 1b above, but here the effect of ODOW on Sheringham Shoal Extension, Dudgeon Extension, Hornsea 3 and Hornsea 4 were investigated.
Scenario 2a	Baseline + Hornsea 3 and Hornsea 4 [2]	Baseline scenario for 2b below
Scenario 2b	Baseline + Hornsea 3 and Hornsea 4 [2] with **ODOW** [2]	Impact of ODOW along with Hornsea 3 and Hornsea 4. Hornsea 3 (3000 MW) will be operational by 2027. Hornsea 4 (2400 MW) will be operational by 2030.
Scenario 2c	Baseline + Hornsea 3 and Hornsea 4 [2] with **ODOW** [2]	Technically same scenario with 2b above, but here the effect of ODOW on Hornsea 3 and Hornsea 4 were investigated.
Scenario 3a	Baseline + Sheringham Shoal Extension, Dudgeon Extension [2]	Baseline scenario for 3b below
Scenario 3b	Baseline + Sheringham Shoal Extension, Dudgeon Extension [2], with **ODOW** [2]	Impact of ODOW along with Sheringham Shoal Extension and Dudgeon Extension. Sheringham Shoal Extension (345 MW) and Dudgeon Extension (450 MW) expected to be operational by 2030.
Scenario 3c	Baseline + Sheringham Shoal Extension, Dudgeon Extension [2], with **ODOW** [2]	Technically same scenario with 3b above, but here the effect of ODOW on Sheringham Shoal Extension and Dudgeon Extension were investigated.

[1] Triton Knoll, Westermost Rough, Lincs, Race Bank, Inner dowsing, Lynn, Dudgeon, Hornsea 1, Hornsea 2, Humber Gateway and Sheringham Shoal

[2] Based on discussions held with the Client a 15 MW turbine with 236 m rotor diameter and 158m rotor height were assumed to be used for all future wind farms including ODOW. This assumption for the future wind farms is considered to provide a conservative position impact assessment as part of the DCO application

Table 5-2 Baseline scenario wind farms included.

Project Name	Ownership details [1]	Turbine	Farm Capacity
Triton Knoll	RWE (59%) J-Power (24%) Kansai Electric Power (16%)	Vestas V164-9.5MW (164 m rotor diameter)	857 MW
Westermost Rough	Ørsted (50%) Green Investment Group (GIG) Equitix Limited	Siemens Gamesa SG-6.0-154 (154 m rotor diameter)	210 MW
Lincs	Ørsted Green Investment Bank Offshore Wind Fund Octopus Renewables Infrastructure Trust plc Equitix Limited	Siemens Gamesa SWT-3.6-120 (120 m rotor diameter)	270 MW
Race Bank	Ørsted Macquarie Capital Group Limited Norges Bank Investment Management	Siemens Gamesa SG-6.0-154 (154 m rotor diameter)	573 MW
Inner dowsing	Green Investment Group (GIG) Equitix Limited	Siemens Gamesa SWT-3.6-107 (107 m rotor diameter)	97.2 MW
Lynn	Green Investment Group (GIG) Equitix Limited	Siemens Gamesa SWT-3.6-107 (107 m rotor diameter)	97.2 MW
Dudgeon	Equinor Masdar Chine Resources Company Limited	Siemens Gamesa SG-6.0-154 (154 m rotor diameter)	402 MW
Hornsea 1	Ørsted Global Infrastructure Partners LLP The Renewables Infrastructure Group Limited (TRIG) Greencoat UK Wind Octopus Energy Generatuin Daiwa Energy & Infrastructure Brookfield Infrastructure Partners	Siemens Gamesa SG-7.0-154 (154 m rotor diameter)	1218 MW

Hornsea 2	Ørsted AXA IM Alts Credit Agricole Assurances Brookfield Infrastructure Partners	Siemens Gamesa SG DD-8.0-167 (167 m rotor diameter)	1320 MW
Humber Gateway	RWE AG Greencoat UK Wind	Vestas V112-3.0MW (112 m rotor diameter)	219 MW
Sheringham Shoal	Equinor Green Investment Group (GIG) Equitix Limited The Renewables Infrastructure Group Limited (TRIG)	Siemens Gamesa SWT-3.6-107 (107 m rotor diameter)	317 MW

1- Publically available datasets were used [1] and [2] for the ownership details.

It should be noted that the scope of work presented in this report has been focused on the potential difference in annual energy production due to wake impacts of each future wind farm scenario. As this is not a complete EPA study, WT did not undertake a comprehensive technical loss assessment, which is typically required in order to estimate a realistic annual energy production for any wind farm, and as such Table 5-3 presents the results of additional effect of addition of ODOW project to the development of all future projects (Scenario 1b vs Scenario 1a), addition of ODOW to the development of Hornsea 3 and Hornsea 4 only (Scenario 2b vs Scenario 2a) and addition of ODOW to the development of Sheringham Shoal Extension and Dudgeon Extension only (Scenario 3b vs Scenario 3a)

Table 5-4. presents the effect of ODOW in the future development, only, such that impact of ODOW in Hornsea 3 and Hornsea 4 and the impact of ODOW in Sheringham Shoal Extension and Dudgeon Extension.

Table 5-5 presents the results as a percentage difference normalised to the baseline.

Table 5-3 Comparison of Scenario 1b and 1a, Scenario 2b and 2a and Scenario 3b and 3a for operational wind farms

Scenario	Additional wake loss on each operational wind farm (%)											
	Triton Knoll	Westermost Rough	Lincs	Race Bank	Inner Dowsing	Lynn	Dudgeon	Hornsea 1	Hornsea 2	Humber Gateway	Sheringham Shoal	Total additional wake loss on all operational wind farms
Scenario 0b vs 0a	-0.79%	-0.08%	-0.18%	-0.53%	-0.05%	-0.03%	-0.88%	-0.70%	-0.75%	-0.23%	-0.76%	-0.58%
Scenario 1b vs 1a	-0.77%	-0.08%	-0.17%	-0.52%	-0.05%	-0.03%	-0.54%	-0.67%	-0.68%	-0.23%	-0.39%	-0.50%
Scenario 2b vs 2a	-0.77%	-0.08%	-0.17%	-0.52%	-0.05%	-0.03%	-0.84%	-0.70%	-0.75%	-0.23%	-0.74%	-0.57%
Scenario 3b vs 3a	-0.79%	-0.08%	-0.18%	-0.53%	-0.05%	-0.03%	-0.56%	-0.67%	-0.68%	-0.23%	-0.39%	-0.50%

Table 5-4 Summary of the results of the future wind farm scenarios

Scenarios basis	Scenario Name	Additional wake loss on each future wind farm arising from Outer Dowsing (%)			
		Hornsea 3	Hornsea 4	Sheringham Shoal Extension	Dudgeon Extension[1]
Impact of ODOW on all future wind farms	**Scenario 1c vs Scenario 1a**	-0.01%	-0.06%	-0.26%	-1.02%
Impact of ODOW on Hornsea 3&4	**Scenario 2c vs Scenario 2a**	-0.01%	-0.07%	-	-
Impact of ODOW on Sheringham & Dudgeon Extensions	**Scenario 3c vs Scenario 3a**	-	-	-0.28%	-1.05%

1. It should be noted that the results regarding the Dudgeon Extension is considered conservative, because of the missing of an exclusion zone. This is explained in Section 2.2.2.

Table 5-5 Summary of the results of the scenarios for the impact on existing farm assets, normalized to the baseline

Scenarios basis	Scenario Name	Additional wake loss on each operational wind farm (%)										
		Triton Knoll	Westermost Rough	Lincs	Race Bank	Inner Dowsing	Lynn	Dudgeon	Hornsea 1	Hornsea 2	Humber Gateway	Sheringham Shoal
Impact of ODOW on existing farms	Scenario 0a	0	0	0	0	0	0	0	0	0	0	0
	Scenario 0b	-0.79%	-0.08%	-0.18%	-0.53%	-0.05%	-0.03%	-0.88%	-0.70%	-0.75%	-0.23%	-0.76%
Impact of all future developments on existing farms	Scenario 1a	-0.65%	-0.18%	-0.28%	-0.50%	-0.13%	-0.18%	-3.16%	-1.09%	-1.45%	-0.10%	-2.35%
	Scenario 1b	-1.43%	-0.26%	-0.46%	-1.02%	-0.18%	-0.21%	-3.71%	-1.76%	-2.14%	-0.34%	-2.74%
Impact of ODOW and Hornsea 3&4 on existing farms	Scenario 2a	-0.22%	-0.17%	-0.01%	-0.02%	0.00%	0.00%	-0.09%	-0.99%	-1.37%	-0.09%	-0.03%
	Scenario 2b	-0.99%	-0.25%	-0.18%	-0.54%	-0.05%	-0.03%	-0.93%	-1.69%	-2.11%	-0.32%	-0.77%
Impact of ODOW and Sheringham & Dudgeon Extensions on existing farms	Scenario 3a	-0.44%	-0.01%	-0.27%	-0.47%	-0.13%	-0.18%	-3.10%	-0.09%	-0.09%	-0.02%	-2.35%
	Scenario 3b	-1.22%	-0.09%	-0.45%	-1.00%	-0.18%	-0.21%	-3.67%	-0.77%	-0.77%	-0.25%	-2.74%

6. CONCLUSIONS

A differential energy yield assessment approach has been undertaken using the WindFarmer: Analyst software which has a proven track record, to provide an independent evaluation of the possible external wake losses caused by the Outer Dowsing project.

The following conclusions are noted:

1. Based on the approach detailed in this report, WT has conducted a series of wake model runs according to the selected scenarios given in Table 5-1 and compared the results with a baseline scenario whose details are provided in Table 5-2. Table 5-3 provides the additional wake effect results at all operational neighbouring wind farms for each of the future scenarios. It was assumed that there are no changes to the existing wind farms e.g. repowering/ extended maintenance or non-operational turbines.

2. Based on these scenarios a conservative assessment of the additional wake loss arising from ODOW on the existing operational wind farms is calculated up to a maximum of **-0.88 %** (primarily the effect of ODOW on the Dudgeon Wind Farm).

3. The average effect of ODOW on all the existing wind farms, with or without the future wind farms varies between **-0.58 %** (the sole effect of ODOW on existing projects) and **-0.50 %** (the effect of ODOW on existing projects, in combination with all future wind farms). The effect of individual operational wind farms varies between **-0.03%** and **-0.88%**.

4. WT has also investigated the effect of ODOW on future developments individually, such as the impact of ODOW on all future development at once, the impact of ODOW on Hornsea 3 and Hornsea 4 and the impact of ODOW on Sheringham Shoal Extension and Dudgeon Extension. As seen on Hornsea 3 and Hornsea 4, the highest effect is observed as -**0.07%** on Hornsea 4 and for Dudgeon Extension and Sheringham Shoal Extension, the highest effect is observed as **-1.05%** on Dudgeon Extension.

5. It should be noted that, an exclusion zone in the northwestern part of the northern site of Dudgeon Extension Wind Farm, has not been considered in the present layout design of this study. Consequently, three turbines are placed in that exclusion zone. It is considered however that, the results regarding the combined effect of ODOW on the Dudgeon Extension are likely to be more conservative, as more turbines are located in closer proximity to other farms.

6. Considering the engineering wake model approaches used and distances between the Client assets and proposed neighbouring wind farms, WT considers the assessed additional wake loss numbers to be commensurate

with WT's expectations. WT also finds the above results comparable with recent studies conducted by DNV and RWE [8] about cluster wakes and their effects on wind farm annual energy production.

7. The future wind farms in the vicinity of the operational neighbouring wind farms are at an early stage of development. For the operational wind farms in the vicinity of Client assets, basic turbine and layout parameters are known to WT and summarised in Table 5-2, and as such modelling of these assets contains reduced uncertainty. For the wind farms at an early stage of development, there is currently limited information available about the turbine types, layouts and hub heights. For the prediction of current status of those future wind farms, including the development phase and possible turbine configurations, a range of publicly available datasets has been utilised including the 4C Offshore Wind Market Intelligence [1], Map Stand Location Intelligence portal [2], and submissions to the National Infrastructure Planning Portal [3], along with correspondence with the Client [4]. As such, as some of the information compiled for the future projects is uncertain at this stage, the impacts will be subject to change – this report should be considered as being based on the best available information at the time of preparation.

8. It should also be noted that WT has utilised WindFarmer: Analyst Eddy Viscosity wake model with large wind farm and blockage correction, which is an engineering wake model having a proven track record in wind energy industry.

7. REFERENCES

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3. National Infrastructure Planning Portal , https://infrastructure.planninginspectorate.gov.uk/
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6. Infrastructure Planning, The Hornsea Four Offshore Wind Farm Order 2023, https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010098/EN010098-002330-DCO%20Hornsea%204%20OWF%20signed.pdf
7. Infrastructure Planning, The Sheringham Shoal and Dudgeon Offshore Wind Farm Order 2024, https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010109/EN010109-002390-SADEP%20DCO%20DESNZ%20170424_Redacted.pdf
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13. Marine Data Exchange portal, [redacted]

14. New European Wind Atlas, a free, web-based application developed, owned and operated by the NEWA Consortium. For additional information: [redacted]

15. Global Wind Atlas 3.0. For additional information: [redacted]

16. Vortex MAPS data sets. Purchased on behalf of the client for the area [redacted]

APPENDIX A: WIND FARM SITE INFORMATION

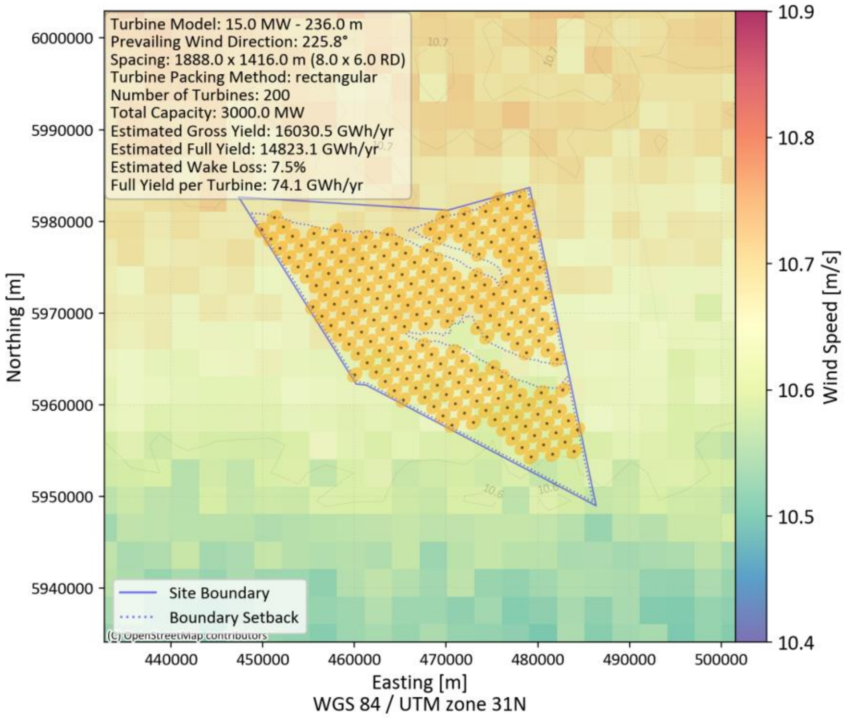


Figure A-1 Optimised turbine layout for Hornsea 3 future wind farm.

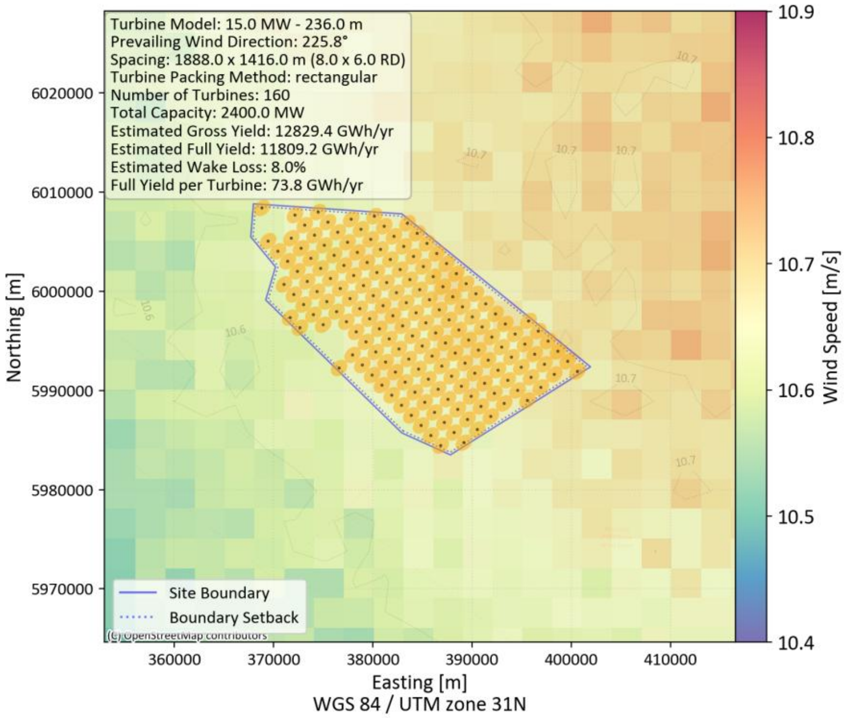


Figure A-2 Optimised turbine layout for Hornsea 4 future wind farm.

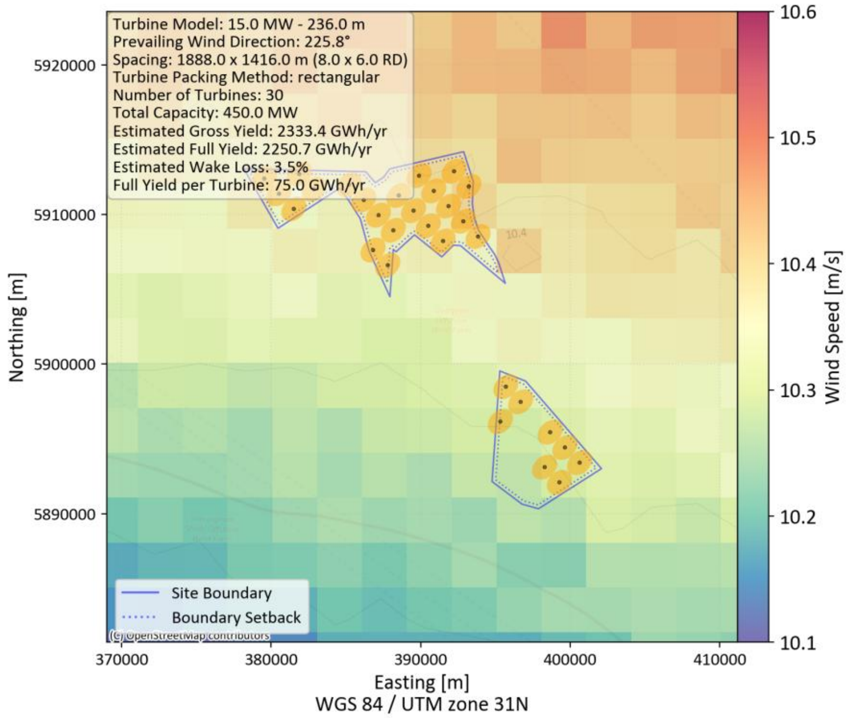


Figure A-3 Optimised turbine layout for Dudgeon Extension future wind farm.

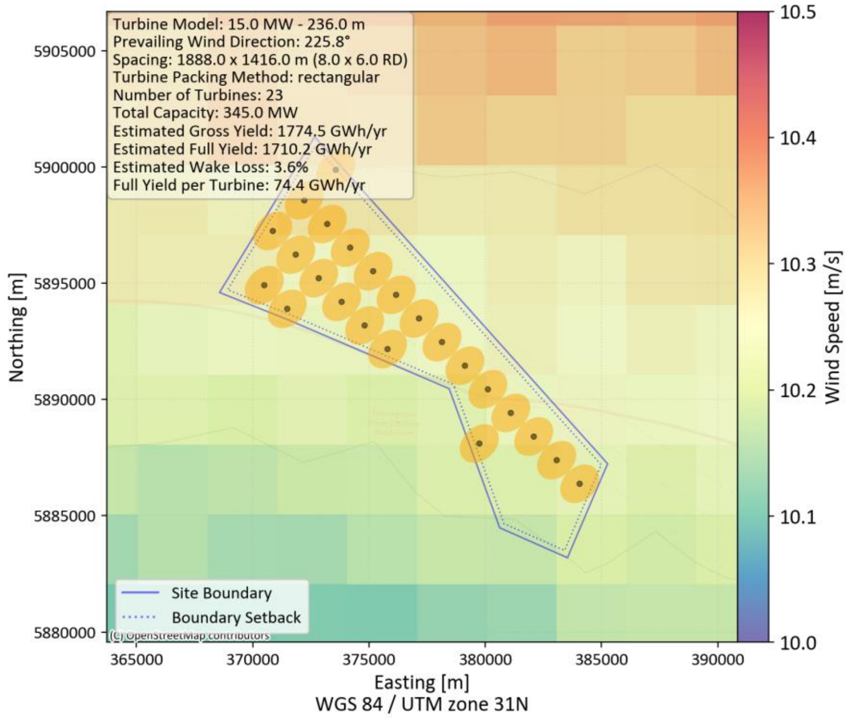


Figure A-4 Optimised turbine layout for Sheringham Shoal future wind farm.

APPENDIX B: WIND DATA

B-1. Outer Dowsing FL

B-2. Race Bank MM

B-3 Dogger Bank West MM

B-1 Outer Dowsing FL

Table C-1 Outer Dowsing FL configuration.

Site name	Outer Dowsing	Elevation (mMSL)	Eastings (m)	Northings (m)	Coordinate system	Datum	Zone
Device name	Outer Dowsing FL	0	386319.0	5938966.0	UTM	WGS 84	31N
Installation date	Unknown*						

* Long term corrected data between 01/08/2001– 31/07/2023 was provided by the Client

B-2 Race Bank MM

Table C-3 Race Bank MM configuration.

Site name	Race Bank	Elevation (mMSL)	Eastings (m)	Northings (m)	Coordinate system	Datum	Zone
Device name	Race Bank MM	0	349933.2	5909531.0	UTM	WGS 84	31N
Installation date	Unknown *						

* Cleaned data between 08/06/2006– 17/12/2008 was utilised by WT

Table C-4 Race Bank MM data summary at selected heights.

Month	Mean wind speed (m/s)					Wind speed data coverage (%)				
	90.2 mMSL¹	89.3 mMSL²	80 mMSL²	70 mMSL²	60 mMSL³	90.2 mMSL¹	89.3 mMSL²	80 mMSL²	70 mMSL²	60 mMSL³
Jun-06	8.0	7.0	7.8	7.6	6.7	74.8	99.5	74.8	74.8	99.5
Jul-06	7.2	7.1	7.1	6.9	6.7	99.9	100.0	99.9	99.9	99.9
Aug-06	8.2	8.3	8.3	8.2	8.0	100.0	100.0	100.0	100.0	100.0
Sep-06	8.8	8.7	8.6	8.4	8.1	100.0	100.0	100.0	100.0	100.0
Oct-06	10.5	10.4	10.3	10.1	9.8	100.0	100.0	100.0	100.0	100.0
Nov-06	12.5	12.4	12.3	12.0	11.4	98.6	98.6	98.6	98.6	98.6
Dec-06	11.5	11.9	11.3	11.0	10.6	99.8	92.5	99.8	99.8	92.4
Jan-07	14.0	13.9	13.7	13.3	12.5	99.7	99.7	99.7	99.7	99.7
Feb-07	9.9	9.9	9.7	9.4	9.1	100.0	100.0	100.0	100.0	100.0
Mar-07	10.9	10.8	10.6	10.4	10.0	100.0	100.0	100.0	100.0	100.0
Apr-07	8.0	8.5	7.7	7.6	8.0	47.3	100.0	48.0	47.3	100.0
May-07	_	8.4	_	_	7.9	0.0	100.0	0.0	0.0	100.0
Jun-07	9.9	7.5	9.5	9.6	7.1	24.3	100.0	25.1	24.3	100.0
Jul-07	8.8	8.7	8.6	8.5	8.1	100.0	100.0	100.0	100.0	100.0
Aug-07	8.4	8.4	8.3	8.2	8.0	100.0	100.0	100.0	100.0	100.0
Sep-07	9.6	9.5	9.4	9.3	9.0	100.0	100.0	100.0	100.0	100.0
Oct-07	7.0	6.9	6.9	6.8	6.6	100.0	100.0	100.0	100.0	100.0
Nov-07	11.1	11.1	11.0	10.9	10.6	99.8	99.8	99.8	99.8	99.8
Dec-07	11.1	11.0	10.8	10.6	10.1	99.2	99.2	99.2	99.2	99.2
Jan-08	13.6	13.4	13.2	12.9	12.2	99.8	99.8	99.8	99.8	99.8
Feb-08	11.3	10.7	11.0	10.7	9.7	90.4	97.3	90.9	90.4	97.3
Mar-08	12.6	12.4	12.3	12.1	11.8	98.7	99.7	98.7	98.7	99.7
Apr-08	9.6	9.2	9.4	9.2	8.6	88.1	98.3	88.2	88.1	98.3
May-08	9.3	9.2	8.9	8.7	8.6	99.4	99.4	99.4	99.4	99.4
Jun-08	7.9	7.8	7.8	7.6	7.3	100.0	100.0	100.0	100.0	100.0
Jul-08	8.8	8.8	8.7	8.5	8.2	97.2	97.2	97.2	97.2	97.2
Aug-08	9.3	9.2	9.1	9.0	8.5	93.9	94.0	93.9	93.9	93.9
Sep-08	8.1	8.0	7.9	7.8	7.6	99.9	99.9	99.9	99.9	99.9
Oct-08	11.1	11.0	10.9	10.7	10.2	99.9	99.9	99.9	99.9	99.9
Nov-08	11.6	11.5	11.3	11.2	10.9	99.7	99.8	99.8	99.8	99.8
Dec-08	10.4	10.4	10.3	10.2	10.0	53.0	53.1	53.0	53.0	53.1

1- Stub mounted anemometer

2- Anemometers orientated to 225 degrees on Race Bank MM.

3- Anemometers orientated to 45 degrees on Race Bank MM.

B-3 Dogger Bank West MM

Table C-4 Dogger Bank West MM configuration.

Site name	Walney	Elevation (mMSL)	Eastings (m)	Northings (m)	Coordinate system	Datum	Zone
Device name	Dogger Bank West MM	0	424230.0	6080569.0	UTM	WGS 84	31N
Installation date	Unknown *						

* Cleaned data between 24/07/2013– 19/11/2014 was utilised by WT

Table C-5 Dogger Bank West MM data summary at selected heights.

Month	Mean wind speed (m/s)					Wind speed data coverage (%)				
	110.0 mMSL[1]	104.5 mMSL[1]	83.7 mMSL[1]	53.5 mMSL[1]	38.3 mMSL[1]	110.0 mMSL[1]	104.5 mMSL[1]	83.7 mMSL[1]	53.5 mMSL[1]	38.3 mMSL[1]
Sep-13	9.5	9.5	10.7	10.3	10.0	14.5	14.9	11.1	11.1	11.1
Oct-13	13.4	13.1	12.8	12.2	11.9	93.5	100.0	87.4	86.9	86.9
Nov-13	10.7	10.6	10.5	10.2	9.9	98.5	100.0	98.9	98.9	98.9
Dec-13	15.3	15.3	14.8	14.1	13.7	100.0	100.0	99.6	99.7	99.7
Jan-14	13.0	12.6	12.3	11.8	11.6	94.8	99.6	86.4	86.7	86.7
Feb-14	15.0	14.9	14.5	13.9	13.5	99.6	100.0	92.1	92.6	92.6
Mar-14	11.7	11.4	11.2	10.6	10.3	84.8	100.0	95.3	96.8	96.8
Apr-14	10.0	9.9	9.6	8.8	8.5	79.8	98.3	91.7	98.3	98.3
May-14	8.4	8.6	8.4	7.8	7.6	89.5	100.0	94.2	100.0	100.0
Jun-14	7.1	7.0	6.9	6.7	6.6	85.3	87.2	81.7	87.1	87.1
Jul-14	7.5	7.5	7.4	7.1	6.9	90.8	100.0	97.9	98.0	98.0
Aug-14	9.8	9.8	9.7	9.3	9.2	98.6	100.0	96.1	96.7	96.7
Sep-14	6.6	6.6	6.5	6.3	6.2	99.8	99.9	98.6	98.6	98.6
Oct-14	12.3	12.1	11.9	11.4	11.2	96.6	99.9	94.0	94.5	94.5
Nov-14	10.9	10.5	10.0	9.6	9.5	55.3	62.0	52.1	51.9	51.9

1- Anemometers orientated to 320 degrees on Dogger Bank West MM.

APPENDIX C: ANALYSIS RESULTS

C-1. Long term correlations for Race Bank and Dogger Bank West MM

C-2. Site long term wind regime

C-3 Long term frequency distribution comparisons

C-4 Plot of turbine predictions of each wind climate file

C-5 Race Bank MM 90.2 mMSL and 89.3 mMSL Ambient Turbulence Intensity Comparisons

C-6 Turbine level wake results

C-1 Long term correlations for Race Bank and Dogger Bank West MM

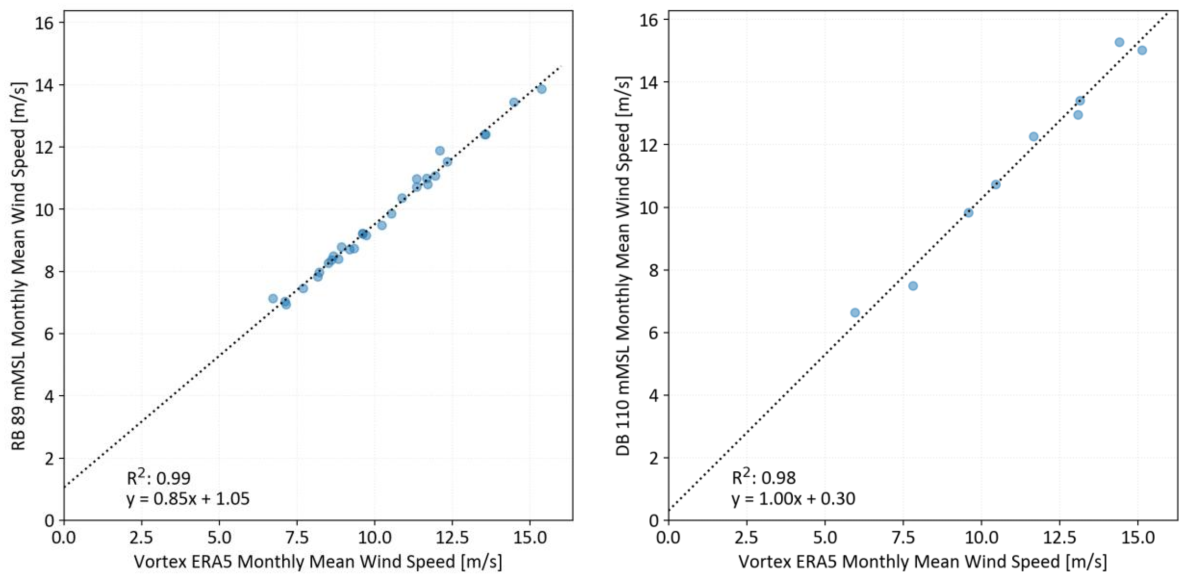
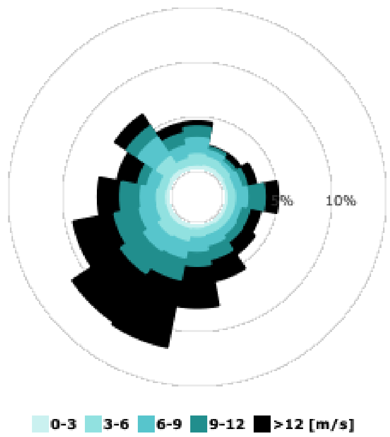


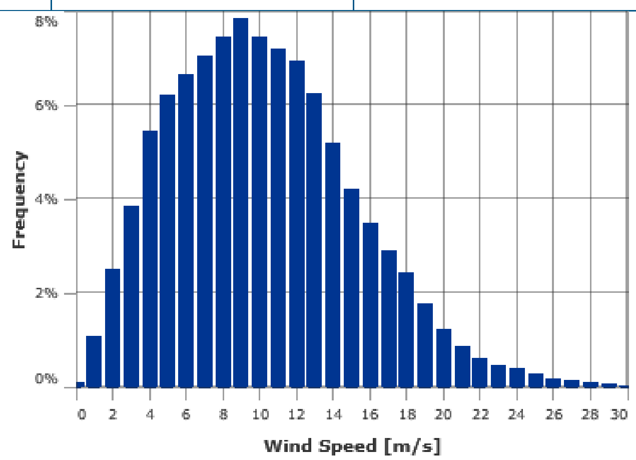
Figure D-1 Long-term correlations – monthly correlations between Race Bank MM - Vortex ERA5 reanalysis data (left) and between Dogger Bank West MM - Vortex ERA5 reanalysis data (right).

C-2 Site long-term wind regimes at 100 m height

Table D-1 Long-term wind regime for Dogger Bank West MM at 100 m

Monthly mean wind speeds			
Month	Wind speed [m/s]	Valid wind speed data [years]	Valid direction data [years]
January	12.2	1.0	1.0
February	14.3	1.0	1.0
March	11.0	1.0	1.0
April	9.6	1.0	1.0
May	8.2	1.0	1.0
June	6.8	0.9	0.9
July	7.2	1.0	1.0
August	9.4	1.0	0.6
September	6.7	1.2	0.5
October	12.1	2.0	2.0
November	10.2	1.6	1.6
December	14.6	1.0	1.0
Annual	10.2		



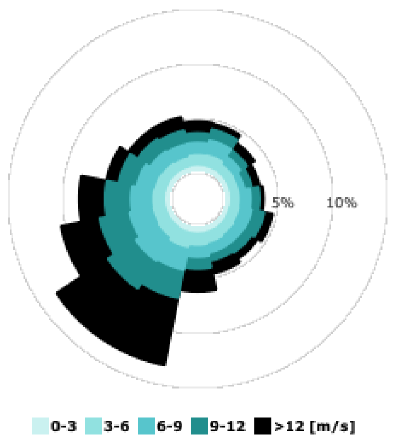


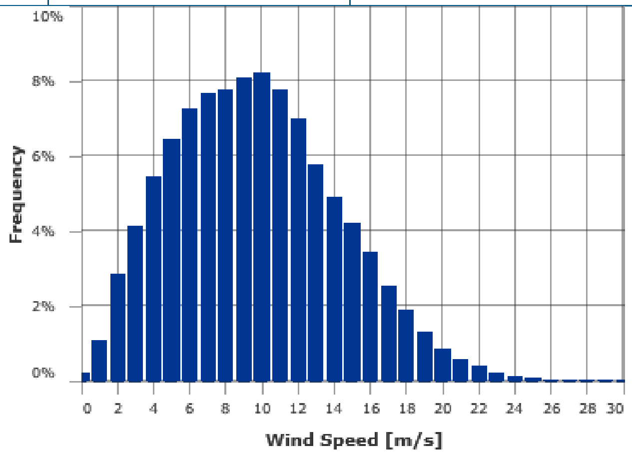
Wind Speed [m/s]	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	No Direc tion	Total [%]
0	+	0.01	0.01	0.01	+	+	+	+	+	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.09
1	0.04	0.05	0.04	0.02	0.04	0.03	0.04	0.03	0.05	0.06	0.07	0.07	0.08	0.06	0.08	0.06	0.23	1.07
2	0.09	0.14	0.14	0.08	0.09	0.09	0.10	0.09	0.12	0.17	0.17	0.15	0.13	0.10	0.17	0.12	0.55	2.50
3	0.22	0.29	0.23	0.15	0.15	0.20	0.25	0.18	0.18	0.20	0.24	0.19	0.19	0.17	0.18	0.20	0.61	3.83
4	0.36	0.24	0.28	0.22	0.25	0.29	0.27	0.27	0.27	0.32	0.40	0.27	0.21	0.24	0.37	0.24	0.93	5.43
5	0.44	0.30	0.25	0.25	0.24	0.25	0.18	0.24	0.28	0.49	0.53	0.32	0.35	0.27	0.71	0.26	0.83	6.19
6	0.48	0.29	0.17	0.24	0.29	0.15	0.17	0.25	0.31	0.56	0.53	0.47	0.45	0.34	0.77	0.33	0.82	6.62
7	0.51	0.22	0.17	0.30	0.32	0.19	0.23	0.30	0.40	0.51	0.60	0.55	0.43	0.40	0.74	0.36	0.85	7.05
8	0.47	0.22	0.12	0.25	0.42	0.22	0.31	0.42	0.53	0.52	0.53	0.53	0.49	0.40	0.72	0.49	0.80	7.43
9	0.51	0.20	0.10	0.23	0.56	0.26	0.25	0.46	0.56	0.61	0.53	0.63	0.66	0.37	0.57	0.47	0.87	7.84
10	0.36	0.14	0.11	0.14	0.60	0.32	0.24	0.46	0.46	0.69	0.77	0.79	0.65	0.27	0.44	0.34	0.67	7.45
11	0.31	0.07	0.12	0.15	0.52	0.30	0.26	0.40	0.41	0.68	1.01	0.87	0.60	0.27	0.36	0.38	0.45	7.17
12	0.25	0.04	0.12	0.26	0.35	0.22	0.33	0.40	0.44	0.77	1.01	0.80	0.60	0.32	0.24	0.41	0.36	6.93
13	0.14	0.03	0.12	0.31	0.37	0.22	0.35	0.36	0.50	0.82	0.76	0.68	0.54	0.40	0.16	0.27	0.22	6.25
14	0.08	0.01	0.11	0.23	0.34	0.30	0.26	0.30	0.43	0.74	0.61	0.64	0.38	0.39	0.12	0.16	0.08	5.19
15	0.03	+	0.11	0.14	0.22	0.22	0.14	0.24	0.37	0.63	0.68	0.61	0.24	0.30	0.13	0.11	0.03	4.21
16	0.02	+	0.08	0.07	0.11	0.10	0.13	0.14	0.38	0.62	0.68	0.52	0.18	0.22	0.12	0.09	0.01	3.47
17	0.01	+	0.04	0.01	0.03	0.05	0.13	0.11	0.40	0.63	0.57	0.39	0.15	0.16	0.12	0.07	+	2.88
18	0.01	+	0.03		0.01	0.02	0.12	0.16	0.42	0.61	0.43	0.25	0.11	0.12	0.09	0.02	+	2.41
19	0.01	0.01	0.01		+	0.01	0.05	0.18	0.30	0.55	0.35	0.10	0.06	0.07	0.07	+		1.77
20	0.02	0.01	+			+	0.02	0.11	0.19	0.46	0.24	0.06	0.03	0.03	0.05	0.01		1.23
21	0.03	+					+	0.07	0.15	0.29	0.16	0.04	0.02	0.02	0.05	0.01		0.84
22	0.02						0.01	0.06	0.13	0.18	0.07	0.05	0.02	0.01	0.05	+		0.61
23	+						+	0.04	0.12	0.13	0.06	0.03	0.01	+	0.04	+		0.44
24	+						+	0.02	0.05	0.14	0.09	0.01	+	+	0.05	+		0.37
25							+	0.02	0.04	0.06	0.09	0.01	+	+	0.05	+		0.29
26							+	0.01	0.03	0.03	0.04	+	+	0.01	0.04			0.16
27								0.01	0.04	0.03	+	+	+	+	0.02			0.11
28								0.01	0.04	0.01	0.01	+	+	+	0.01			0.08
29									0.03	0.01	+	+	+	+				0.04
30									+	0.01	+	0.01		+				0.02
30+																		
Total [%]	4.42	2.28	2.34	3.06	4.91	3.44	3.85	5.35	7.63	11.51	11.24	9.08	6.61	4.99	6.54	4.38	8.34	100.0
Mean Speed	7.95	6.25	7.98	8.90	9.45	9.32	9.84	10.98	12.40	12.74	11.84	11.12	10.00	10.25	9.04	8.90	6.82	10.18

Note: '+' indicates a non-zero frequency <0.005%. Blank cell indicates zero frequency.

Table D-2 Long-term wind regime for Race Bank MM at 100 m

Monthly mean wind speeds			
Month	Wind speed [m/s]	Valid wind speed data [years]	Valid direction data [years]
January	13.4	2.0	2.0
February	10.1	2.0	2.0
March	11.4	2.0	2.0
April	8.7	2.0	2.0
May	8.6	2.0	2.0
June	7.3	3.0	3.0
July	8.0	3.0	3.0
August	8.4	2.9	2.9
September	8.6	3.0	3.0
October	9.2	3.0	3.0
November	11.4	3.0	3.0
December	10.8	2.5	2.4
Annual	9.7		





Wind Speed [m/s]	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5	No Direc tion	Total [%]
0	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.02	+	0.23
1	0.07	0.08	0.07	0.06	0.07	0.05	0.06	0.08	0.07	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.03	1.06
2	0.19	0.18	0.18	0.17	0.15	0.17	0.18	0.20	0.20	0.22	0.16	0.17	0.15	0.15	0.16	0.18	0.04	2.86
3	0.29	0.26	0.23	0.24	0.23	0.18	0.26	0.25	0.30	0.33	0.30	0.24	0.25	0.25	0.25	0.22	0.03	4.12
4	0.36	0.34	0.33	0.29	0.30	0.27	0.29	0.37	0.40	0.44	0.38	0.33	0.36	0.32	0.31	0.32	0.03	5.42
5	0.37	0.43	0.29	0.29	0.31	0.37	0.37	0.40	0.45	0.58	0.48	0.47	0.44	0.43	0.37	0.33	0.06	6.44
6	0.41	0.49	0.30	0.27	0.29	0.48	0.40	0.41	0.49	0.68	0.62	0.61	0.50	0.43	0.44	0.38	0.04	7.26
7	0.37	0.51	0.36	0.22	0.35	0.41	0.40	0.36	0.37	0.70	0.86	0.71	0.62	0.52	0.43	0.41	0.03	7.64
8	0.38	0.43	0.30	0.19	0.41	0.38	0.33	0.28	0.32	0.71	0.94	0.80	0.73	0.65	0.45	0.46	0.02	7.77
9	0.36	0.43	0.23	0.18	0.39	0.41	0.32	0.26	0.34	0.77	0.96	0.86	0.89	0.69	0.50	0.46	0.02	8.08
10	0.31	0.44	0.24	0.18	0.32	0.46	0.32	0.24	0.37	0.85	1.04	0.92	0.92	0.62	0.50	0.46	0.01	8.19
11	0.28	0.29	0.25	0.28	0.24	0.38	0.32	0.25	0.38	0.93	1.05	0.99	0.74	0.52	0.45	0.43	0.01	7.77
12	0.25	0.18	0.25	0.31	0.15	0.30	0.27	0.27	0.37	0.94	0.99	0.94	0.59	0.45	0.34	0.34	0.01	6.97
13	0.20	0.13	0.19	0.23	0.11	0.25	0.18	0.22	0.39	0.91	0.92	0.77	0.46	0.32	0.22	0.26	0.01	5.77
14	0.17	0.10	0.15	0.14	0.10	0.18	0.11	0.19	0.38	0.88	0.93	0.62	0.38	0.17	0.17	0.23	0.01	4.90
15	0.15	0.08	0.15	0.10	0.06	0.09	0.08	0.18	0.31	0.86	0.88	0.52	0.32	0.12	0.13	0.19	+	4.22
16	0.14	0.05	0.10	0.08	0.03	0.05	0.06	0.15	0.23	0.78	0.75	0.42	0.26	0.10	0.10	0.14		3.43
17	0.11	0.03	0.06	0.03	0.01	0.04	0.03	0.11	0.18	0.65	0.56	0.29	0.20	0.06	0.06	0.09		2.53
18	0.08	0.02	0.03	0.01		0.02	0.02	0.08	0.13	0.59	0.42	0.19	0.14	0.03	0.05	0.07		1.88
19	0.06	0.01	0.01	+		+	0.02	0.04	0.10	0.45	0.29	0.11	0.08	0.02	0.04	0.05		1.28
20	0.03	+	+			+	0.02	0.03	0.08	0.28	0.18	0.07	0.05	0.03	0.04	0.03		0.84
21	0.02	+				+	0.01	0.03	0.06	0.20	0.10	0.05	0.04	0.02	0.04	0.02		0.58
22	0.01	+					+	0.02	0.03	0.12	0.08	0.04	0.04	0.01	0.02	0.01		0.38
23	+							0.01	0.01	0.05	0.04	0.03	0.04	0.01	+	+		0.20
24	+							+	+	0.02	0.03	0.02	0.03	0.01	+	+		0.11
25								+	+	0.02	0.01	0.01	0.01	+				0.06
26									+	0.01	0.01	+	+					0.03
27									+	+	+	+	+					0.01
28										+		+						+
29												+						+
30																		
30+																		
Total [%]	**4.61**	**4.50**	**3.74**	**3.29**	**3.53**	**4.49**	**4.09**	**4.46**	**5.99**	**13.02**	**13.03**	**10.25**	**8.34**	**6.03**	**5.14**	**5.14**	**0.35**	**100.0**
Mean Speed	**8.69**	**7.69**	**8.30**	**8.22**	**7.55**	**8.38**	**8.10**	**8.83**	**9.79**	**11.70**	**11.28**	**10.50**	**9.95**	**8.86**	**8.84**	**9.14**	**5.55**	**9.66**

Note: '+' indicates a non-zero frequency <0.005%. Blank cell indicates zero frequency.

C-3 Long-term frequency distribution comparisons

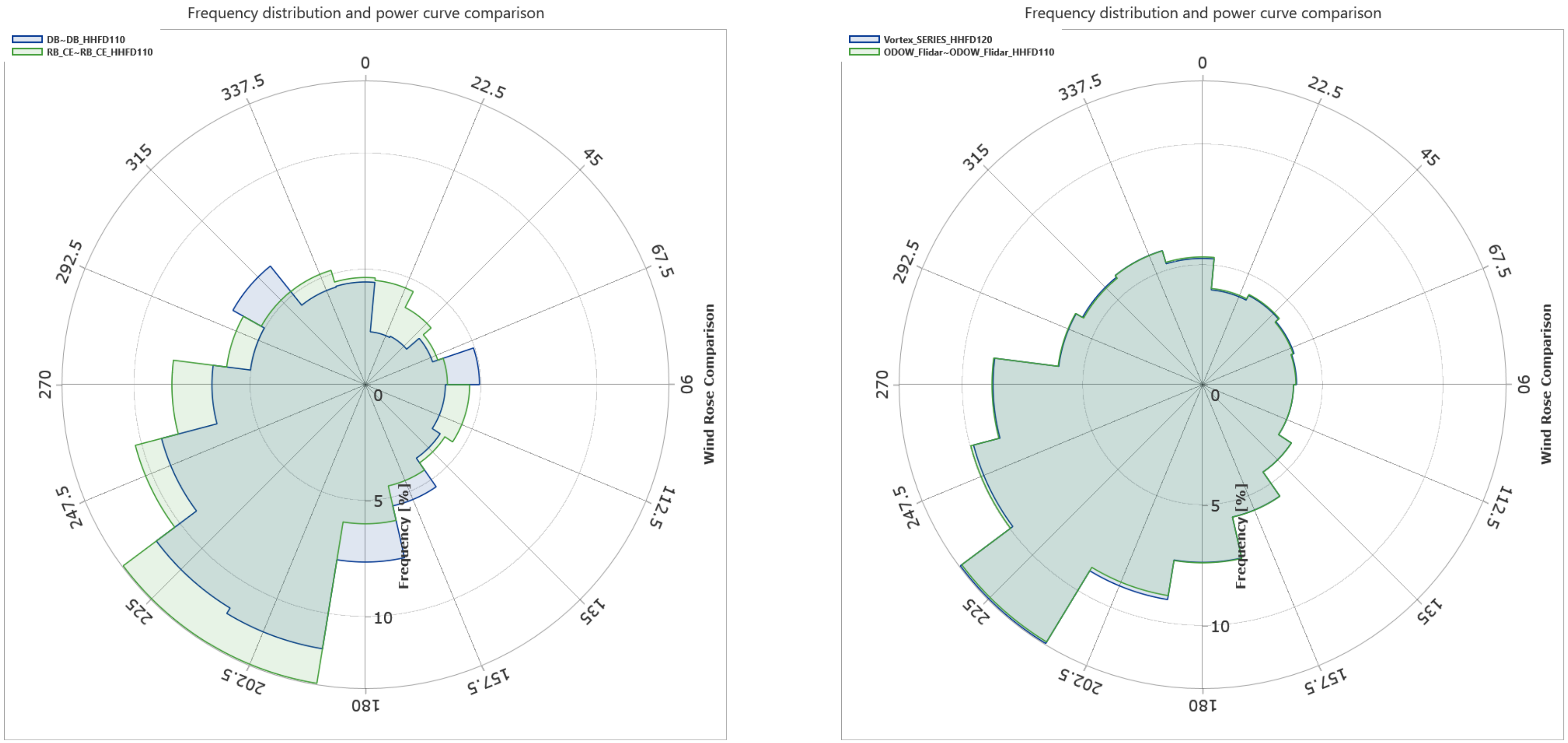


Figure D-2 Comparison of Race Bank MM and Dogger Bank West MM (left) and Race Bank MM and Outer Dowsing FL long-term frequency distributions (right)

C-4 Plot of turbine predictions of reference wind map

Figure D-3 Prediction of turbine wind speeds from each wind climate file using NEWA

C-5 Race Bank MM 90.2 mMSL and 89.3 mMSL Ambient Turbulence Intensity Comparisons

Wind Speed [m/s]	All DirectionTI from 90.2 m [%]	All DirectionTI from 89.3 m [%]
1	31.7	30.1
2	17.4	11.6
3	12	8.6
4	9.7	7.3
5	8.4	6.5
6	7.2	5.8
7	6.7	5.6
8	6.4	5.4
9	6.2	5.4
10	5.9	5.2
11	5.8	5.1
12	5.6	5.1
13	5.6	5.3
14	5.6	5.3
15	5.8	5.5
16	5.9	5.7
17	5.9	5.7
18	5.8	5.7
19	5.8	5.8
20	6	5.9
21	6.3	6.3
22	6.5	6.6
23	6.7	6.4
24+	6.8	7.2

APPENDIX D: ANALYSIS METHODOLOGY

D-1. Wind data analysis process overview

D-2. Hub-height wind speed and direction distributions

D-3. Wind flow modelling

D-4. Gross energy output

D-1 Wind data analysis process overview

The analysis of the wind data involved several steps, which are summarised below:

1. The processed and long-term corrected wind speed data from the wind climate location are processed and evaluated for an estimation of long-term wind speeds extrapolated to hub height using power law wind shear exponent.
2. The on-site mast measurements are correlated with the sources of long-term reference wind data, and the results evaluated, to develop an estimate of reference period wind speeds at measurement height.
3. Long-term hub-height wind speed and direction frequency distribution estimates at each wind climate location are derived from the measured and synthesized data.
4. The wind regime at the turbine locations is assessed using wind flow models and WT experience and judgment.

D-2 Data correlation and prediction

The period of data available at the measurement locations can be extended through establishing relationships between two data sets, using correlations to synthesize the missing data at the measurement location. In this procedure, concurrent wind data from a “target” sensor and a “reference” sensor are compared. 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 synthesize data at the “target” location from the “reference” location.

“Monthly synthesis method” and “Mean of monthly means” methods are used in this assessment, to extend the period of record available at a measurement location.

D-2.1 Monthly synthesis method

In the correlation of monthly wind speeds, the concurrent monthly wind speeds are compared to establish a single correlation slope and offset. The slope and offset values are applied to the wind data at the “reference” location, thereby obtaining synthesized monthly wind data for the period of missing data at the “target” location.

The measured and synthesised monthly wind speed time series are combined, with priority given to the measured data. The long-term wind speed is then derived from this combined measured and synthesised monthly time series.

D-2.2 Mean of monthly means

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

- The 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 to determine the annual mean ("mean of means").

D-3 Hub-height wind speed and direction distributions

D-3.1 Shear power law

The boundary layer power law shear exponents at the measurement locations are derived from the available measurement heights. The power law relates the ratio of measured wind speeds, $\boldsymbol{U_1/U_2}$, to the ratio of the measurement heights, $\boldsymbol{z_1/z_2}$, using the wind shear exponent, $\boldsymbol{\alpha}$, as follows:

$$\frac{\overline{U}(z_1)}{\overline{U}(z_2)} = \left(\frac{z_1}{z_2}\right)^{\alpha}$$

where

α is power law wind shear exponent
$\overline{U}$ is the wind speed
z is the height above mean sea level

The boundary-layer power law shear exponent was derived for each measurement location using the ratios of measured concurrent wind speed data recorded at multiple measurement heights.

D-3.2 Directional shear method

The relationship between two or more heights at a measurement location is established for each of twelve 30° direction sectors, using the technique described in Section D-4.1. 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 primary 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 Section D-4.4. The resulting distributions in each direction sector are then scaled to the predicted long-term hub height wind speed(s).

D-3.3 Time series method

The boundary-layer power law shear exponent is derived between two measurement heights for each 10 minutes, 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. The Mean of Monthly Means procedure is used to avoid the introduction of bias into the annual wind regime prediction from seasonally uneven data coverage at each mast as discussed in Section D-4.4.

D-3.4 Annual shear method

The relationship between two, or more, heights at a measurement location is established using the concurrent mean of monthly means technique described in Section D-4.4. 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.

D-4 Wind flow modelling (offshore)

To calculate the variation of mean wind speed over the site, several techniques are considered:

- For offshore projects, any site-specific downscaled mesoscale map obtained for the site will be considered.
- In addition to the above, any publicly available wind maps (global, regional, national) covering the vicinity of the project is considered.

Unless coastal effects are anticipated, speed-up factors between the proposed turbine locations and wind climate locations are derived on an all-directional basis from the different techniques outlined above and compared. Depending on the results of the comparison, and the quality of the validation if multiple measurement locations are available, the most robust technique for predicting the wind speed variation across the site will be identified. This may be an ensemble approach consisting of results from multiple models.

To determine the long-term mean wind speed at any location, the speed-up factor for each location is applied to the long-term wind speed previously derived for the measurement location.

The following sub-sections describe each of the modelling approaches in further detail.

D-4.1 Global Wind Atlas

The Global Wind Atlas is a combined mesoscale and microscale wind flow model which has been run to produce results for the entire global land mass and coastal areas with a focus on the needs of wind resource and energy assessment. Model outputs are available at elevations of 10, 50, 100, 150 and 200 m above ground/sea at a downscaled horizontal grid spacing of 250 m. Further details of the model can be found at [redacted]

D-4.2 New European Wind Atlas

The New European Wind Atlas (NEWA) uses the Weather Research and Forecasting (WRF) model, forced with ERA5 reanalysis data, to generate a regional map of wind speed variation across Europe and Turkey, including offshore.

Data are available at seven heights between 50 m and 500 m. Both mesoscale and microscale modelling has been performed. The mesoscale data is based on a simulation period of 30 years and has a horizontal grid resolution of 3 km. Further details of the model can be found at [redacted]

D-5 Gross energy output / assessment of wakes

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. The Energy Yield and the subsequent impact of the wakes produced by the individual wind farms have been calculated using WindFarmer Analyst computational model. It 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.

Of concern in any Energy Yield study is the effect of wake and turbine interaction losses (including blockage effect) from inside the farm and from adjacent farm sites. WT's typical best practice is to use the WindFarmer: Analyst Eddy Viscosity with large wind farm correction model to estimate offshore wake and turbine interaction effects, as validated by DNV in 2019, which results in lower errors across a number of operational offshore wind farms compared to other wake models.

D-5.1 Turbine interaction effect calculations

Wind turbines extract energy from the wind and downstream from each turbine there is a momentum deficit with respect to free stream conditions, which is equal to the thrust force on the machine, referred to as the wake, where the wind speed is reduced. As the flow proceeds downstream there is a spreading of the wake and the wake recovers towards free stream conditions. Turbulent momentum transfer is important in this process.

The wake effect loss 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. WT uses the WindFarmer: Analyst software – Eddy Viscosity model and implements the Large Wind Farm correction for offshore projects. This software has been developed by DNV and validated using measurements on both full-scale machines and on wind-tunnel models.

The model is employed in a scheme which, taking each wind speed and direction in turn calculates the power production of the wind farm. The important parameters used in this process are:

- array layout
- upstream mean wind speed
- ambient turbulence
- wind turbine thrust characteristic
- wind turbine power characteristic
- rotor speed
- speed-up factors from site wind flow calculations

Any wind speed variations across the site due to coastal or mesoscale effects are accounted for in the model using the speed-up factors calculated by an appropriate wind flow model as described above. The array model is used to calculate the wind speed in the turbine wakes, assuming the terrain is flat, and the wind speed is adjusted by the speed-up factor when the wake reaches a downstream turbine.

D-5.1a Internal wake and blockage effects

This is the effect that the wind turbines within the wind farm being considered have on each other. In addition, the wind farm itself presents an obstacle to the incoming wind flow, which is not accounted for in many standard industry wake models and causes a slow-down effect referred to as wind farm blockage. This effect has also been calculated using the Blockage Effect Estimator Tool (BEET) within WindFarmer:Analyst which is based on more than 50 CFD simulations.

D-5.1b Wake effect external

This is the effect that the wind turbines from neighbouring wind farms (if any) have on the wind farm being considered. These are calculated in the same way as internal wake effects.

D-5.1c Future wake effect

Where future wind farms are to be constructed in the vicinity of the project under consideration, the wake effect of these may be estimated and taken into account if sufficient information is available.

APPENDIX 3

ØRSTED 2019 MARKET UPDATE

Company announcement
No. 28/2019

Ørsted
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Ørsted presents update on its long-term financial targets

At our Capital Markets Day on 28 November 2018, Ørsted presented a number of long-term financial targets. These targets are based on estimates of capital and operational expenses, production forecasts, outcome of offshore auctions, expected long term power prices, interest rates and other factors that are all inherently dynamic and subject to uncertainty. Given the combined impact of an adjustment of our offshore wind production forecasts and certain key positive and negative developments since the Capital Markets Day, as described below, we will give an update on the long-term targets.

On the negative side, three factors have added pressure on our long-term targets. The first factor relates to our offshore production forecasts.

We have been running a comprehensive project, which was finalised and presented to our Board of Directors today, to upgrade the models and processes we use to forecast the energy production from our offshore wind farms based on our access to extensive production data from our asset portfolio. The project has involved advanced analysis of a long list of variables impacting our production, and we have developed new proprietary models to forecast our expected energy production.

The project has led us to conclude that our current production forecasts underestimate the negative impact of two effects across our asset portfolio, i.e. the blockage effect and the wake effect.

The blockage effect arises from the wind slowing down as it approaches the wind turbines. There is an individual blockage effect for every turbine position and a global effect for the whole wind farm, which is larger than the sum of the individual effects. Our new wind simulation models show that we have historically underestimated these blockage effects. This finding is also supported by industry consultant DNV GL's recent report on blockage, which indicates that this effect is more broadly underestimated.

The second effect is the wake within wind farms and between neighbouring wind farms. There is a wake after each wind turbine where the wind slows down. As the wind flow continues, the wake spreads and the wind speed recovers. This effect, with wind turbines shielding and impacting each other, has been subject to extensive modelling by the industry for many years, and it is still a highly complex dynamic to model. Our results point to a higher negative effect on production than earlier models have predicted.

With respect to wake effects between neighbouring wind farms, we are in the process of developing a new model capable of more accurately predicting wake effects over longer distances. We have, among other things, leveraged a first-of-its-kind advanced radar system collecting three-dimensional data on the wind flow. The new model, which is still being refined, suggests a slower wind speed recovery and higher wake effects. At the same time, we have now factored in a more extensive offshore wind build-out in the different basins, which will increase the wake effect from neighbouring wind farms. As the global offshore wind build-out accelerates, the whole industry will see higher wake effects from neighbouring wind farms.

Over the years, we have benchmarked our internal production estimates against third-party views from industry experts. In comparison, most third-party production estimates have been trending towards a more positive view than ours. Therefore, we believe that underestimation of blockage and wake effects is likely to be an industry-wide issue.

While there is still uncertainty involved, it is clear that the production forecast adjustment arising out of our analysis has a negative effect on our financial estimates (see status below).

The higher-than-forecasted blockage and wake effects have also been embedded in our actual historical production numbers, but they have been captured in more broadly defined deviation buckets, such as wind contents, availability, curtailments and effects of ramp-up of new capacity being either behind or ahead of schedule. We have until now not had the data and the advanced analytics models to do a more granular breakdown of the production deviation. The new tools leveraging all our production data, including large new assets built over the past couple of years, have given us more detailed insight into the blockage and wake effects and other underlying production impacts. It is this analysis that has led us to conclude that the blockage and wake effects have been underestimated.

While the production adjustment is negative we are convinced that Ørsted's access to data and advanced analytics will be a driver of our long-term competitive advantage. We will, of course explore how the recent findings may translate into improvements to our design and lay-out of future wind farms.

The second key negative development since the Capital Markets Day is the lower feed-in tariff in Taiwan, where we had to accept a 6% reduction and a cap on full-load hours for our Changhua 1 &2a projects. Thirdly, we have raised the CAPEX estimate for the Deepwater development portfolio in the US, mostly related to the transmission assets.

In terms of positive developments since the Capital Markets Day, we now expect slightly lower capital expenses on some of our construction projects. Secondly, lower interest rates have led to lower return requirements on our offshore transmissions assets in the UK, which leads to lower transmission charges. Thirdly, we have seen higher than budgeted availability on one of our newer wind turbine platforms, which positively impacts some of our assets.

Fourth and finally, in addition to the ongoing optimisation of our projects, we are taking measures to reduce our annual overhead cost base by DKK 500-600 million between 2020 and 2022, recognising that tight cost control remains an imperative in a competitive market environment. Roughly half of the cost reductions will be fall-away costs relating to the simplification of our structure following the divestment of our Danish downstream assets, and half will come from reductions across our staff functions, both internal and external spend.

The combined impact of these key developments since the Capital Markets Day leads to the following status on the long-term financial targets:

- Average growth in site EBITDA: ~20% for 2017-2023. Unchanged
- Average return on capital employed (ROCE): ~10% for the period 2019-2025. Unchanged
- Unlevered lifecycle IRR, capacity-weighted average for seven named offshore wind projects won in competitive tenders (Borssele 1 & 2, Hornsea 2, German Cluster 1, Gode Wind 3 & 4, Greater Changhua 1 & 2a, Greater Changhua 2b & 4 and Revolution Wind). The target is reduced from 7.5-8.5% to 7.0-8.0%
- Share of contracted and regulated EBITDA, average 2019-2025 of ~90%. Unchanged.

Lifetime load factor of 48-50% for a defined European offshore wind portfolio and construction and development projects is reduced to around 48% due to the adjustment of production forecasts.

The CAPEX and OPEX multiples communicated at the Capital Markets Day remain unchanged.

The information provided in this announcement does not change Ørsted's previously announced financial outlook for the 2019 financial year or the expected investment level announced for 2019.

For further information, please contact:

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APPENDIX 4

RWE/DNV REPORT

RESOURCE & TECH

NOVEMBER 14–15 | AUSTIN, TX

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DNV

RWE

Big cluster & far-field wakes - an assessment of multi-fidelity models against North Sea wind farms' SCADA data

BACKGROUND

With the steady build-up of wind farms in the North Sea and US Eastern Seaboard, the impact of cluster wakes on wind farm annual energy production (AEP) increases over time. Wake effects over large distances / clusters is an increasingly emergent risk to LCoE.

The effect of cluster wakes is investigated for the object wind farms of Amrumbank West (ARB) and Triton Knoll (TK), operating in different parts of the North Sea.

OBJECTIVE

- ❑ Better understand (and reduce) uncertainty and bias of turbine interaction losses for tomorrow's wind farms.
- ❑ Assess the suitability of a range of wake models (from fast engineering models for wakes and blockage to higher fidelity CFD) in their ability to capture pattern of production (PoP) seen in SCADA data
- ❑ Focus on wind directions where the object wind farm is partly in the wake of an operating wind farm.

METHODS

- ❑ Carefully process (clean, filter) SCADA data from two wind farms operating in the North Sea.
- ❑ Filter 10 minutes records for high windfarm availability (100% for ARB, 95.6% for TK of the turbines operating)
- ❑ From the filtered time series, derive PoP from the average power of each individual turbine.
- ❑ Compare (with SCADA) the PoP obtained from models such as the EVM + LWF [1], VV [2], and DNV and RWE CFD solutions [3, 4].

RESULTS

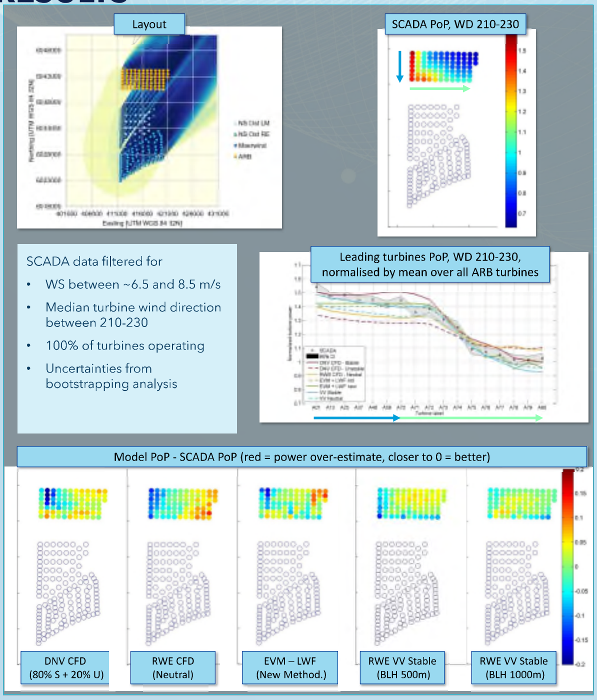

Figure 1: Amrumbank West results

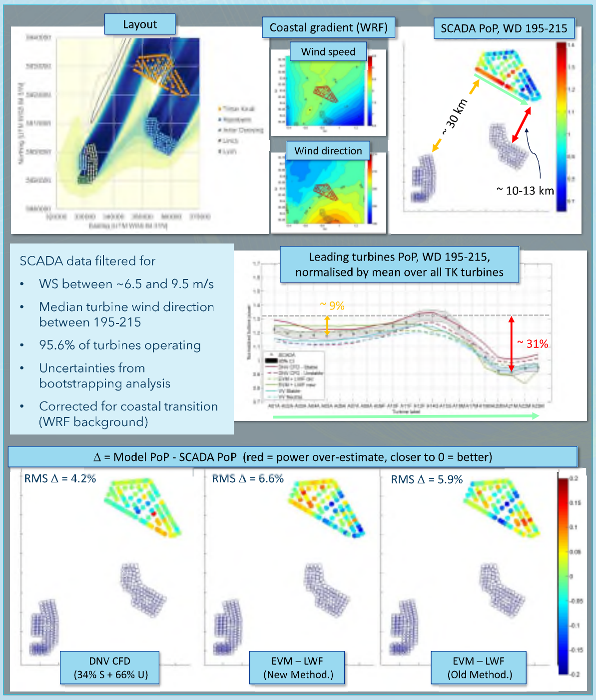

Figure 2: Triton Knoll Results

RMS Δ = root mean square of difference between model and SCADA PoP

CONCLUSIONS

While it was known from previous work that wind farm wakes can persist for distances over 50 km, when atmospheric conditions are stable, the current work demonstrates that cluster wakes can be detected in the SCADA data of offshore wind farms, without limiting the investigation to stable conditions. At TK, on the plateau of the thrust curve, the effect leads to a variation in turbine power of approximately 31% for leading turbines, when the distance between TK and the upstream cluster varies between 10-13 km (65 – 85 rotor diameters) **. For the larger distance of roughly 30 km, the variation in power across the leading turbines is approximately 9%. The magnitude of the effects will be significantly less once aggregated over the site wind speed distribution.

The EVM + LWF model appears to capture the wakes from the neighbours reasonably well for the leading turbines (improved after the methodology change [5]), but despite this, still tends to under-estimate the wake effects deeper in the array. RWE's VV model shows very good agreement with the measured PoP when set up with stable conditions (Obukhov length of 125 m) using a boundary layer (BL) height of 1000 m. The high-fidelity CFD models can capture the PoP with good accuracy for the leading turbines and throughout the array, when driven with appropriate boundary conditions.

Both the CFD and VV also reveal high sensitivity of the results to modelled stability conditions (surface stability, boundary layer height). To feed these high-fidelity models with the required inputs, there is a need to develop/test robust methodologies (either from meso-scale models or new measurement campaigns) to characterise the site stability conditions and boundary layer height.

The validation and the assessment of the effect in AEP terms is ongoing.

** Latest results removing effects in the SCADA data at TK that can be attributed to coastal gradients.

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