Xi Engineering Consultants

# Millmoor Rig Wind Farm, Eskdalemuir Seismic Array Considerations

## Mathematical Analysis and Report on Seismic Budget

## Client: ESB Asset Development UK Limited

18/11/2022
Document number: Technical Appendix 13.1

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# Document Summary

ESB Asset Development UK Limited (ESB) wishes to develop the Millmoor Rig Wind Farm scheme within the Eskdalemuir Consultation Zone. This desktop study assesses the vibration impact of the proposed Millmoor Rig Wind Farm on the MoD's Eskdalemuir Seismic Array (EKA).

The Millmoor Rig Wind Farm site represents 13 wind turbines with a proposed rotor diameter of 163 m with tip heights ranging between 180 m and 230 m dependent on turbine location within the site (see Table 1). Using these turbine dimensions, this report uses the most up to date information available on the subject matter to assess the likely budget requirement for Millmoor Rig Wind Farm for several different model scenarios.

Based on the data available in the Phase 3 (9.1) and Phase 4 reports (9.4) the budget requirement for the various scenarios is reported.

As the Millmoor Rig Wind Farm has an average distance of 35.6 km away from EKA it will have a relatively low seismic budgetary impact. Based on this mathematical analysis the average value for measured data from Phase 4 work predicts that Millmoor Rig wind Farm would only require a seismic budget in the region of ~0.012189 nm. This result and its distance to the EKA shows Millmoor Rig Wind Farm is an efficient use of any available seismic budget.

Based on current developments surrounding the policy regarding Eskdalemuir, the Millmoor Rig Wind Farm scheme should be able to be built out for the Scottish Government Onshore Wind Policy Refresh proposed options 1, 2 and 3, as it represents a valid and efficient use of seismic budget. The Millmoor Rig Wind Farm scheme would not be subject to any Seismic Impact Limit (SIL) Regulations as described in the Phase 5 report (9.5) and currently under assessment by the Scottish Government.

| Action | Name | Date | Version | Amendment |
|---|---|---|---|---|
| Originator | Dr M P Buckingham | 14/11/2022 | v1 | Issue |
| Review | G. Cowie | 15/11/2022 | v2 | Review |
| Review | Dr M P Buckingham | 15/11/2022 | V3 | Review |
| Review | R. Horton | 16/11/2022 | V4 | Review |
| Review | Dr M P Buckingham | 16/11/2022 | V5 | Issue |
| Comments | ESB | 16/11/2022 | V6 | Client Comments |
| Review | Dr M P Buckingham & R. Horton | 17/11/2022 | V7&8 | Incorporation of client comments |

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# Contents

# 1. Introduction

ESB requires a desktop study to inform the seismic impact of various turbines on their development of the proposed Millmoor Rig Wind Farm in the Eskdalemuir Consultation Zone. This desktop study assesses the vibration impact of the proposed Millmoor Rig Wind Farm on the MoD's Eskdalemuir Seismic Array (EKA).

To better understand the results presented below, an understanding of the Eskdalemuir Consultation Zone is necessary. The first section of this report provides both a summary history of the Eskdalemuir Consultation Zone along with brief updates on further work recently undertaken which will inform the Scottish Government Wind Policy (currently under review and, if changed, may affect this development).

The parameters, assumptions and scenarios are discussed in the Summary, Scope and Methodology Sections. Multiple approaches were used in the analysis of the proposed turbine dimensions and site layout, including Different Scenarios, and the removal of Background Noise.

An in-depth explanation of each of these different approaches is laid out. Results are presented in table summary form in Section 6.

Considerations and risks associated with Background Noise, Potential Policy Changes and recommended approaches are presented in the Discussion at Section 7. Finally, the report is concluded with statements showing that there are several viable approaches for ESB to build out the proposed Millmoor Rig Wind Farm.

# 2. Background to Eskdalemuir

The Eskdalemuir Seismological Recording Station is located in the Scottish Borders and is a monitoring facility where seismological, magnetic and other environmental parameters are monitored.

The seismometer array at Eskdalemuir (EKA) has two arms, each of ten seismometers, and became operational on 19 May 1962. EKA is operated by AWE Blacknest (AWE) and is part of the seismic network of the organisation set up to help verify compliance with the Comprehensive Test Ban Treaty (CTBT) which bans nuclear explosions.

Concerns were raised that vibrations from wind turbines might affect the ability of EKA to operate properly, and the Ministry of Defence (MoD) were advised to set a maximum permissible background vibration budget within a 50 km radius of EKA in order to safeguard its effectiveness in accordance with the CTBT. Beyond 50 km it was determined that the vibration contribution from a wind turbine is negligible and is not included in the vibration budget. This 50 km statutory safeguarding zone is referred to as the Eskdalemuir Consultation Zone. The maximum vibration budget that was deemed to be acceptable from all wind turbines that might be built within the Consultation Zone was set at a threshold amplitude of 0.336 nm. This budget was subsequently agreed by the Comprehensive Test Ban Treaty Organisation (CTBTO) in Vienna.

The 0.336 nm budget became 'used up' in 2012, preventing further deployment within the Eskdalemuir Consultation Zone. Xi Engineering Consultants (Xi) were commissioned by the Eskdalemuir Working Group (EWG) in 2013 to develop a robust physics-based approach to estimating the worst-case ground vibration produced by wind turbines to overcome the problem of the budget having been exhausted. Xi developed such an algorithm, which is currently used by the MoD to calculate the worst-case cumulative effect of all wind turbines on EKA; see the 2014 Report (9.1). It is this experience that makes Xi uniquely qualified to assess and deliver a solution to mitigate the seismic vibration risk from wind turbines within the Consultation Zone. The Xi algorithm requires the distance to EKA, turbine diameter and the tip height to estimate the seismic vibration.

Due to the limited public data available on seismic emissions from wind turbines at the time, a conservative 'worst-case' approach was adopted. This '2014 turbine algorithm', currently used by the MoD to allocate budget, is effectively two turbines combined to provide a significant safety factor. The budget algorithm is designed with safety factors such that it over-predicts the output of any single turbine.

Xi's 2014 work (9.1) was reviewed by the Ministry of Defence Subject Matter Expert (Dr D Bowers, and was ultimately accepted by the MoD as a means to protect the EKA. By Adopting the Release 2.0 of Substantial Research Project algorithm this opened up over 1GW of

additional onshore wind power deployment within the Consultation Zone compared to the MoD's earlier approach based on the original Styles' algorithm.

## 2.1. Current Developments

The 2014 turbine algorithm currently used by the MoD to calculate the budget (at the time of writing) takes a highly conservative approach. By design, the algorithm used includes factors of safety appropriate to the data sample size available at the time, ensuring that the algorithm over-estimates the cumulative seismic vibrations produced by wind turbines and does not compromise the EKA.

The Eskdalemuir Working Group (EWG) was reformed in 2018, as once again the budget of 0.336 nm had been used up. The EWG commissioned a review of the Consultation Zone's vibration budget considering current installed developments and improvements in Wind Turbine Generator Technologies.

Since 2018 Xi have been engaged by both the Scottish Government and the EWG to audit the turbines within the region to obtain actual seismic measurement data from the wind farms within the Consultation Zone. Through a series of phased work packages (Phases 1 through 5) which culminated in a measurement campaign of several sites within the region and the delivery of the Phase 4 report (9.4) in February 2022 and the Phase 5 Report (9.5) to confirm a maximum turbine seismic level to deploy a minimum of 1GW new onshore wind turbines, in October 2022.

Directly measuring the seismic output of a greater number of turbines in the Consultation Zone, as carried out in the Phase 4 work, allows the reduction of the safety factor previously applied in the 2014 turbine algorithm. This reduction potentially allows further wind capacity to be deployed within the region without breaching the 0.336 nm absolute seismic budget within the Consultation Zone.

The further Phase 5 desk-based study was completed for the Scottish Government following on from the Phase 4 report and reflecting on initial findings from the draft Onshore Wind Policy Statement (OnWPS) consultation responses. The main aim of the Phase 5 study is to provide Scottish Government and the EWG with evidence to help quantify and consider how much additional energy capacity could be achieved through future onshore wind turbine developments within the Consultation Zone, with these developments directly contributing to Scottish Government's ambitions for onshore wind, stated in the draft OnWPS to be between 8-12 GW of additional installed onshore wind capacity across Scotland.

The Phase 5 study commissioned by Scottish Government investigated and presented what Seismic Impact Limits (SIL) could be established to achieve a released additional capacity range between a at least a 1.0-2.5 GW within the Consultation Zone.

A SIL for any given turbine is the arrival amplitude at EKA of the groundwave generated by the given turbine (in nanometres) relative to output power (in megawatts).

Effectively it is the maximum seismic level a turbine could contribute to the budget for a given maximum power output. The adoption of such a limit by the Scottish Government would ensure that turbines deployed closer to the EKA have a minimal seismic emission.

The outputs from the 2022 Phase 4 and Phase 5 work will feed into the Scottish Government Policy review which is underway at the time of writing. It is envisaged that this revised policy, and on-going EWG activities, will lead to a minimum additional 1 GW of further development within the Consultation Zone, and likely, substantially more from wind farm schemes at greater distance to the EKA such as Millmoor Rig Wind Farm. Should all those wind farms with allocated noise budget be developed, Millmoor Rig Wind Farm would require budget from the potential Phase 4/5 increased budget to be built out.

## 2.2. Scottish Onshore Wind Policy

The Scottish Government are currently undertaking an Onshore Wind Policy Statement Refresh (9.6). A consultation, which closed in January 2022, specifically references Eskdalemuir and the approach the Scottish Government were taking to explore methods for overcoming the current policy, planning and commercial barriers to development within the Consultation Zone.

The OnWPS Refresh Consultation Draft (9.6) included the following four potential policy options which could be adopted:

1. Option 1: There shall be no onshore wind developments constructed within Scotland which lie within 15 km of the Eskdalemuir Seismic Array. (Noting that without the final report from Phase 4 measurements, we cannot confirm that 15 km is the most appropriate distance to set this at).
2. Option 2: Any onshore wind development within Scotland which lies between 10 km and 20 km of the Eskdalemuir Seismic Array will be required to demonstrate, to the satisfaction of the Ministry of Defence, that they can sufficiently mitigate the impact their development would have of the array to an acceptable level.
3. Option 3: Combination of the two options above. A hard, no build area and an additional buffer zone where mitigation is required.

4. Option 4: Make no changes. The no build limit remains at 10 km and no additional measures are put in place.

While the outcome of the Scottish Government's consultation on the Onshore Wind Policy Statement Refresh is not yet known, with the current Climate Crisis, the Scottish Government are seeking to maximise the available capacity within the Consultation Zone. As distance plays the most significant role in the amount of budget required by any given onshore wind turbine, wind farm schemes further away from the EKA allow significantly more deployment within the Consultation Zone than those closer in. One turbine at 10 km from the EKA would be equivalent to approximately 2,000 similar turbines at a 50 km distance. As Millmoor Rig Wind Farm has an average turbine distance of 35.6 km from EKA this would have significantly less impact than those closer in, and would not be subject to any SIL that could be imposed by the Scottish Government.

To counter this distance-dependent seismic requirement, and make efficient use of the available seismic budget, or to optimise the potential deployment in the Consultation Zone, extending the 10 km Exclusion Zone would offer the most significant increase in potential new onshore wind energy capacity.

Results of the EWG Phase 2 work (9.2) showed an increase in the 10 km Exclusion Zone would result in higher additional capacity. By increasing the radius of exclusion from 10km to 15 km, as per draft OnWPS Option 1, the additional deployable onshore wind energy capacity increases threefold.

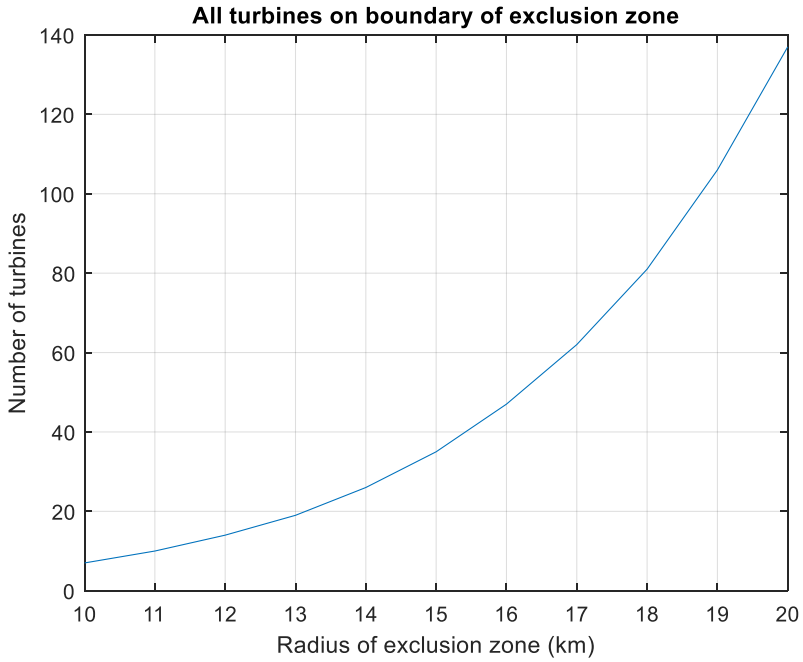


Figure 1: Number of turbines that can be placed on the exclusion zone without breaching the available budget – source: 'SGV_202_Tech_Report_v07' (9.2)

However, even extending the 10 km Exclusion Zone to 15 km, the amount of additional capacity is susceptible to a single large wind farm at the boundary of the exclusion zone, and all available seismic budget could be consumed by a single wind farm. Figure 1 shows that a single site of 35 turbines at an extended 15 km exclusion zone would consume all available budget.

If draft OnWPS Option 2 or 3 were to be adopted at a distance of 20 km this would represent a minimum of 137 turbines that could be built on the boundary of a 20 km exclusion zone. If sites were constructed further out this figure would grow exponentially.

This information would suggest that a SIL should be adopted to ensure maximum deployment within the Consultation Zone. The Phase 5 work output provides the Scottish Government with SIL which will prevent a single wind farm close to the EKA from consuming all the available budget. This SIL would require turbines in closer proximity to the EKA to be specifically seismically quieter as they have greater impact on the seismic budget. Depending on the level of guaranteed onshore wind energy capacity the Scottish Government finally adopts in the OnWPS Refresh from the potential 1.0-2.5 GW additional output, this will likely incorporate an approach which includes a SIL.

The current schedule of the Onshore Wind Policy Statement is for adoption in winter 2022.

## 2.3. Queue System

It was found that the adopted ‘first come first served’ queuing system approach used by the MoD was deemed to be unlawful in a recent Judicial Review. This system treated applications made under Section 36 of the Electricity Act 1989 differently to applications made under the Town and Country Planning Acts (TCPA). Section 36 schemes got a position in the queue at scoping stage as opposed to T CPA schemes at application stage. A revised, yet unknown, system is needed.

# 3. Millmoor Rig Wind Farm Summary

ESB wishes to develop the proposed Millmoor Rig Wind Farm at a site within the Eskdalemuir Consultation Zone. As seismic budget is required to allow this development to progress, understanding the impact the development would have on the EKA is critical.

The proposed Millmoor Rig Wind Farm development is situated approximately 35.6 km from the EKA, and as such, would likely have a relatively low seismic signature. This desk top study assesses the current proposed turbine dimensions and layout using both the current MoD 2014 turbine algorithm, and a multitude of potential seismic levels previously recorded by Xi. Based on the data available in the Phase 3 report (9.3) the budget requirement for the proposed development is reported.

Following this desktop study, it is likely empirical data will need to be shown to evidence the compliance of the proposed development within its budget allocation.

# 4. Scope

This desk top study assesses the proposed turbine dimensions and layout, using both the current MoD 2014 turbine algorithm, and a multitude of scenarios based on signals previously recorded by Xi. Based on the data available in the Phase 3 (9.3) and Phase 4 reports (9.4) the budget requirement for the various scenarios is reported.

# 5. Methodology

## 5.1. Development Details

The proposed Millmoor Rig Wind Farm consists of 13 turbines with a tip height of ranging between 180 m to 230 m, located approximately 35.6 km from the EKA. Specific Turbine locations are shown in Table 1.

| Turbine No | Eastings | Northings | Distance to Eskdalemuir (km) | Tip Height (m) | Rotor Diameter (m) |
|---|---|---|---|---|---|
| 1 | 363467 | 605540 | 37.0 | 200 | 163 |
| 2 | 363225 | 606000 | 36.7 | 200 | 163 |
| 3 | 363500 | 606716 | 37.0 | 180 | 163 |
| 4 | 362806 | 606357 | 36.3 | 210 | 163 |
| 5 | 362152 | 606085 | 35.7 | 230 | 163 |
| 6 | 362073 | 605489 | 35.6 | 230 | 163 |
| 7 | 362314 | 607067 | 35.9 | 180 | 163 |
| 8 | 361771 | 607162 | 35.3 | 180 | 163 |
| 9 | 360577 | 606834 | 34.1 | 180 | 163 |
| 10 | 360977 | 606405 | 34.5 | 180 | 163 |
| 11 | 360995 | 605828 | 34.5 | 210 | 163 |
| 12 | 361395 | 605389 | 34.9 | 210 | 163 |
| 13 | 361644 | 606198 | 35.2 | 210 | 163 |

Table 1: Proposed Millmoor Rig Wind Farm Turbine Locations in Easting and Northing

### 5.1.1. Scenarios Assessed

With a view to demonstrating potential required budget, several scenarios have been assessed for each candidate machine. The turbine coordinates and turbine options were coded into MatLab, and calculations were performed to determine budget levels in line with the mathematical approaches in the Phase 3 (9.3) and Phase 4 (9.4) Reports.

The scenarios modelled are as follows:

1. Standard EKA 2014 algorithm — Using the Current MoD 'worst case' algorithm
2. Craig — Using a scaled Nordex N80 as representative
3. Middle Muir — Using a scaled Senvion as representative.
4. Clyde — Using a scaled Siemens 2.3 as representative
5. Standard EKA background removed — See Background noise removal section

| | |
|---|---|
| 6. Craig Background removed | See Background noise removal section |
| 7. Middle Muir Background removed | See Background noise removal section |
| 8. Clyde Background removed | See Background noise removal section |
| 9. Nordex | Phase 4 scaled data |
| 10. Siemens | Phase 4 scaled data |
| 11. Senvion | Phase 4 scaled data |
| 12. Vestas | Phase 4 scaled data |
| 13. Gamesa | Phase 4 scaled data |
| 14. GE | Phase 4 scaled data |
| 15. Enercon | Phase 4 scaled data |

### 5.1.2. Background Noise Removal

Seismic measurements of wind turbines include ambient seismic noise. This noise is not attributed to the wind turbines themselves, rather it is produced by a combination of natural and anthropogenic sources. The ambient noise may, however, mask lower amplitude wind turbine seismicity (i.e., there may be some component of wind turbine noise, but it may be just below the background noise level, so it wasn't detected). For this reason, the 2014 turbine algorithm includes a noise floor based on the measurements of Clyde Wind Farm.

Through discussions with the MOD's subject matter expert, Xi has proposed that a background noise measurement could be conducted before wind farms are built and then a subsequent measurement be conducted once the farm is operational. The background noise could then be subtracted from the operational noise giving a truer value of the contribution of the wind farm to seismicity. This approach is common in acoustic measurements of wind farms. To illustrate the affect that such a measurement campaign may have, tables have been provided where the noise floor has been removed from the algorithms such that the seismic contribution of the wind turbines only come from blade pass and structural resonances. This is very much a best-case scenario and is provided for illustrative purposes only. Xi notes that the approach of removing all background noise from the algorithm is contrary to the precautionary approach used to design the EKA 2014 algorithm and that it is likely that some turbines generate noise which exists below the noise floor. Working through real world empirical assessments of this will provide further understanding of how close to this best-case scenario results will be. It will also inform the development of a methodology which will not penalise a wind turbine for noise which is not attributable to the wind turbine itself.

# 6. Results

The following tables (Table 2, Table 3, Table 4 and Table 5) show the seismic levels of the proposed Millmoor Rig Wind Farm development using the various potential turbine options.

The required seismic budget ranges from 0.024802 nm using the current MoD 2014 algorithm down to the predicted 0.010081 nm using the Siemens 2.3 machine with the background noise removed.

The budget range based on Phase 4 measurements including background is between 0.023380 nm and 0.014032 nm. Individual turbine calculations can be seen in Tables 4 and 5.

| Standard EKA Algorithm (nm) | Craig (nm) | Middle Muir (nm) | Clyde (nm) | Standard EKA Algorithm Background Removed (nm) | Craig Background Removed (nm) | Middle Muir Background Removed (nm) | Clyde Background Removed (nm) |
|---|---|---|---|---|---|---|---|
| 0.024802 | 0.020493 | 0.018075 | 0.014032 | 0.022800 | 0.018018 | 0.013306 | 0.010081 |

Table 2: Seismic Results of 4 scenarios modelled with and without Background Noise

| Nordex | Siemens | Senvion | Vestas | Gamesa | GE | Enercon |
|---|---|---|---|---|---|---|
| 0.016441 | 0.014032 | 0.018075 | 0.016794 | 0.023380 | 0.015706 | 0.017464 |

Table 3: Seismic Results of 7 Scenarios using Phase 4 data all results are in nm.

| Turbine NO | Standard EKA Algorithm (nm) | Craig (nm) | Middlemuir (nm) | Clyde (nm) | Standard EKA Algorithm Background Removed (nm) | Craig Background Removed (nm) | Middlemuir Background Removed (nm) | Clyde Background Removed (nm) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.005977 | 0.004970 | 0.004400 | 0.003401 | 0.005490 | 0.004372 | 0.003255 | 0.002447 |
| 2 | 0.006112 | 0.005078 | 0.004493 | 0.003476 | 0.005615 | 0.004467 | 0.003321 | 0.002500 |
| 3 | 0.005726 | 0.004763 | 0.004218 | 0.003260 | 0.005259 | 0.004190 | 0.003121 | 0.002345 |
| 4 | 0.006459 | 0.005356 | 0.004734 | 0.003667 | 0.005935 | 0.004711 | 0.003495 | 0.002637 |
| 5 | 0.007082 | 0.005857 | 0.005169 | 0.004010 | 0.006510 | 0.005150 | 0.003808 | 0.002882 |
| 6 | 0.007147 | 0.005908 | 0.005213 | 0.004046 | 0.006570 | 0.005195 | 0.003839 | 0.002907 |
| 7 | 0.006413 | 0.005308 | 0.004687 | 0.003634 | 0.005894 | 0.004668 | 0.003455 | 0.002612 |
| 8 | 0.006760 | 0.005583 | 0.004923 | 0.003823 | 0.006215 | 0.004908 | 0.003622 | 0.002746 |
| 9 | 0.007623 | 0.006266 | 0.005509 | 0.004291 | 0.007012 | 0.005506 | 0.004038 | 0.003078 |
| 10 | 0.007340 | 0.006042 | 0.005317 | 0.004138 | 0.006751 | 0.005311 | 0.003902 | 0.002970 |
| 11 | 0.007731 | 0.006363 | 0.005600 | 0.004358 | 0.007110 | 0.005593 | 0.004110 | 0.003128 |
| 12 | 0.007436 | 0.006130 | 0.005399 | 0.004198 | 0.006838 | 0.005389 | 0.003968 | 0.003014 |
| 13 | 0.007241 | 0.005976 | 0.005267 | 0.004093 | 0.006658 | 0.005254 | 0.003874 | 0.002940 |

Table 4: Individual Turbine Seismic Results of Four Scenarios modelled with and without Background Noise

| Turbine NO | Nordex | Siemens | Senvion | Vestas | Gamesa | GE | Enercon |
|---|---|---|---|---|---|---|---|
| 1 | 0.003978 | 0.003401 | 0.004400 | 0.004071 | 0.005716 | 0.003798 | 0.004229 |
| 2 | 0.004065 | 0.003476 | 0.004493 | 0.004159 | 0.005833 | 0.003882 | 0.004322 |
| 3 | 0.003812 | 0.003260 | 0.004218 | 0.003901 | 0.005479 | 0.003639 | 0.004053 |
| 4 | 0.004291 | 0.003667 | 0.004734 | 0.004388 | 0.006139 | 0.004098 | 0.004560 |
| 5 | 0.004697 | 0.004010 | 0.005169 | 0.004799 | 0.006690 | 0.004488 | 0.004990 |
| 6 | 0.004739 | 0.004046 | 0.005213 | 0.004841 | 0.006745 | 0.004528 | 0.005034 |
| 7 | 0.004255 | 0.003634 | 0.004687 | 0.004349 | 0.006070 | 0.004066 | 0.004521 |
| 8 | 0.004479 | 0.003823 | 0.004923 | 0.004575 | 0.006366 | 0.004280 | 0.004758 |
| 9 | 0.005038 | 0.004291 | 0.005509 | 0.005137 | 0.007099 | 0.004813 | 0.005347 |
| 10 | 0.004855 | 0.004138 | 0.005317 | 0.004953 | 0.006859 | 0.004639 | 0.005154 |
| 11 | 0.005113 | 0.004358 | 0.005600 | 0.005217 | 0.007224 | 0.004885 | 0.005428 |
| 12 | 0.004922 | 0.004198 | 0.005399 | 0.005025 | 0.006974 | 0.004703 | 0.005227 |
| 13 | 0.004796 | 0.004093 | 0.005267 | 0.004898 | 0.006808 | 0.004583 | 0.005094 |

Table 5: Individual Turbine Seismic Results of 7 scenarios using Phase 4 data (all results shown in nm)

# 7. Discussion

The mathematical approach used in this document to determine the level of seismic budget required to build out the proposed Millmoor Rig Wind Farm is that of the standard EKA 2014 algorithm currently used by the MoD, and a further 14 scenarios representing scaled measurement data from a range of turbines deployed within the Eskdalemuir Consultation Zone. This work represents the best available science on the subject matter. These scenarios specifically include the Phase 4 results. Due to the distance from the EKA, the proposed development would not be subject to any potential Seismic Impact Limit that is derived from the Phase 5 work.

In order to optimise the proposed development, Xi would recommend candidate turbine pre- and post-construction measurements of the proposed development, which will allow ESB to accurately maximise the output of this site while minimising the effect on the budget. Table 2 shows that upon removing background noise, significant further reductions can be seen on the budget requirement levels.

It should be noted that the mathematical approach to background removal used is a 'best case' scenario. The background noise comes from natural sources or from localised anthropogenic activities. As the wind farm sites measured as part of Scottish Government and EWG work were not measured prior to installation; without pre-installation seismic data, background noise caused by non-turbine sources is not accurately able to be removed. Removing the background seismic energy to calculate the contribution just wind turbines make, would provide an additional increase in the available budget and increase deployment within the Consultation Zone.

Available data show that the seismic energy produced by a wind turbine increases with the cube of the wind speed, as would be expected as the energy content of the wind varies with the cube (the third power) of the average wind speed. However, the background noise increases at a greater rate than the third power which results in background masking the turbine signals at higher wind speeds. Conducting before and after installation measurements of sufficient length would allow quantification of background noise and provide a means of removing this energy from the calculations. Increased understanding of how the background noise scales at onshore wind farm sites would potentially allow future measurements to be simplified and clarify methodology for background noise removal. Removal of background noise would effectively reduce the seismic levels of the turbines and further increase capacity in the Consultation Zone, while continuing to rigorously protect the EKA.

It is highly likely that some form of before and after measurement will be adopted as part of the future approach to managing the EKA noise budget to ensure maximum use of the entire

seismic budget of 0.336 nm for the 50 km Consultation Zone around the Eskdalemuir Seismic Array.

Recent activity with both the EWG and Judicial Review cases focusing on the MoD's queueing system for budget allocation means that the use of the current 2014 turbine algorithm and queuing process is currently subject to review. Xi has engaged with the Scottish Government, EWG and independent developers to further the understanding of the seismic levels produced by turbines and increase the potential development within the Eskdalemuir Consultation Zone. The timescale and output from this work is ultimately subject to decisions by the Scottish Government and the MoD, which are not expected until late 2023, or beyond.

Based on the potential options raised by the Scottish Government in the Consultation Draft of the OnWPS Refresh, ESB's proposed development of Millmoor Rig Wind Farm represents a valid and efficient use of potential seismic budget that may be released. ESB is explicitly aware of the challenges surrounding this topic through their participation in the EWG and have invested in due diligence on the matter, including commissioning this report.

# 8. Conclusion

- As the proposed Millmoor Rig Wind Farm has no MoD allocated budget the proposed development will be reliant on the adoption of Phase 4 and Phase 5 of the Scottish Government's work to release sufficient budget to allow construction. It is expected that this work will provide sufficient budget to allow Millmoor Rig Wind Farm to be developed in full.
- Millmoor Rig Wind Farm has an average distance to the Eskdalemuir Seismic Array of 35.6 km and therefore represents an efficient use of any available Seismic Budget.
- The levels of Seismic Budget have been calculated using the best available science and most up to date data in the public domain.
- The proposed Millmoor Rig Wind Farm development will not be subject to any future potential Scottish Government-imposed Seismic Impact Limit (SIL).
- This data provide ESB the knowledge and understating of the requirements it must meet in order to consent and build the proposed Millmoor Rig Wind Farm.
- ESB would minimise seismic levels through performing candidate turbine, before and after measurements, should a recognised process be available.

# 9. References


9.1. A – ’Seismic Vibration produced by wind turbines in the Eskdalemuir region Release 2.0 of Substantial Research Project‘
9.2. B - ‘SGV_202_Tech_Report_v07’
9.3. C - ‘SGV 203 Technical report v12.pdf’
9.4. D - ‘SGV_204_Tech_Report _v12 Field audit of Selected sites within the EKA Consultation Zone to support Government Policy Decisions’
9.5. E - ‘SGV-205-LimitSet-TechReport-v11 Calculations’
9.6. F - Onshore wind - policy statement refresh 2021: consultative draft