# Technical Appendix 1.5: Eskdalemuir Seismic Impact Study

# M74 West Wind Farm, Eskdalemuir Seismic Array Considerations

## Updated Report on Seismic Budget Requirements, Seismic Impact Limits and Queue Scenarios

Client: Renewco Power

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## Document Summary

The detection capabilities of the Eskdalemuir Seismic Array are protected from seismic noise generated by wind turbines using a cumulative noise budget for all turbines built within 50 km of the array. A Seismic Impact Limit (SIL) for any new wind turbines has been proposed to maximise the installable wind energy capacity of the Southern Uplands while continuing to protect the detection capabilities of the Eskdalemuir seismic array. A SIL between 0.00836nm·MW$^{-0.5}$ and 0.00528nm·MW$^{-0.5.}$ will likely be set for all new wind turbines installing Eskdalemuir Consultation Zone.

An analysis was carried out of the 22 turbines in the proposed M74 West Wind Farm to determine the seismic budget requirement for the site and whether seismic levels exceed those specified by the SIL. For the proposed 6.3 MW turbines at M74 West Wind Farm the permitted power seismic value (PSV) for a machine of this power output is 0.021009 nm for a 1 GW SIL limit, and 0.013278 nm for a 2.5 GW SIL Limit. At the time of writing the candidate turbine for M74 West Wind Farm is not known and as such several turbines have been analysed. The seismic output of the site was modelled using publicly available data, a total of eighteen scenarios were run based on *refined Phase 4 'AIFCL-101-Phase4-Rev-v13.*

The seismic budget requirement for M74 West Wind Farm ranges from 0.017515 nm down to 0.004615nm, depending on which make of turbine is deployed. Were background noise to be removed, the seismic budget requirement would be substantially reduced. To remove background noise, a baseline measurement of noise on the site prior to installation of turbines is recommended, from which accurate data can be provided for later stage calculations of actual seismic budget requirements of the operational site.

Due to the relatively large distance (~43 km) of M74 West Wind Farm from the seismic array, the turbine size and the 6.3 MW rated capacity there is very low risk of breaching the SIL and therefore the turbines would not require mitigation to be installed.

Five queue scenarios with 1.0 GW, 2.0 GW or 2.5 GW SILs were considered. For a SIL of 1.0 GW, the only scenario where M74 West Wind Farm falls within the 0.336 nm budget is Scenario 3 (All wind farms except Faw Side, Scoop Hill and Teviot). For a SIL of 2.0 GW, M74 West Wind Farm falls within the budget for all scenarios except for Scenario 5 (All wind farms included). For a SIL of 2.5 GW, M74 West Wind Farm falls within the budget for all scenarios.

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# Contents

# 1. Introduction

The Eskdalemuir Seismic Array (EKA) is operated by the Ministry of Defence (MoD) and is used to detect ground vibration (seismic waves) caused by nuclear weapons tests. Wind turbines in the Eskdalemuir region also create seismic waves which reduce EKA's detection capabilities. To protect the detection capabilities of EKA, a 50 km consultation zone has been placed around the array and the cumulative impact of all wind turbines built within the zone must not exceed a seismic vibration budget of 0.336 nm.

The Scottish Government seek to maximise the installable wind energy capacity while continuing to protect the detection capability of EKA. Based on the results of the recent draft Onshore Wind Policy Statement consultation, as well as the multi-phased technical work carried out by Xi Engineering Consultants to inform the statement, the Scottish Government are considering the establishment of a *Seismic Impact Limit* (SIL) for new turbines placed in the consultation zone. The SIL is an upper limit to seismic impact on EKA that any one turbine is responsible for relative to its electrical generation capacity. Based on The Scottish Government's analysis provided by Xi, the SIL will likely be set between $0.00836 nm \cdot MW^{-0.5}$ and $0.00528 nm \cdot MW^{-0.5}$. Additional wind turbines will need to demonstrate that for their given capacity they do not breach the SIL.

This report assumes a working understanding of considerations within the EKA. For further details, please see the publicly available documents listed in reference section 9.

Renewco Power wish to develop the M74 West Wind Farm site within the Eskdalemuir Consultation Zone. This environmental impact study assesses the vibration impact of the proposed M74 West Wind Farm on the MoD's Eskdalemuir Seismic Array. The M74 West site represents 22 wind turbines with a proposed rotor diameter of 175 m and 200 m tip height (see Table 2)

This report examines;

1. The seismic budget requirements for M74 West Wind Farm
2. If any/all are close enough to the EKA that they breach the SIL and would require seismic mitigation. In this case, determining what degree of mitigation would be required to reduce their impact below the SIL.
3. Five queue scenarios with 1.0 GW, 2.0 GW or 2.5 GW SILs

# 2. Background to Eskdalemuir

The Eskdalemuir Seismic Array is a seismological monitoring station in Dumfries and Galloway which forms part of the UK's obligations under the Comprehensive Test Ban Treaty. The array's operation can be compromised by excessive seismic noise in the vicinity, which can be produced by wind turbines operating around the array. A brief explanatory video about the global network of seismic sensors operated by the Comprehensive Test Ban Treaty Organisation (CTBTO) can be found at;

Video on Seismic Measurement by CTBTO

In May 2005, Scottish Ministers and the Ministry of Defence (MoD) issued a technical site direction with a safeguarding map to relevant planning authorities in England and Scotland as well as Scottish Ministers. This direction advised that any sites within 50km of the array would require consultation with MoD before determination. This 50km radius is often referred to as the 'consultation zone'. Within the consultation zone there is an existing hard no-build area at a radius of 10km from the array – any applications for windfarms within 10km will be objected to by MoD due to the unacceptable impact they would have on the array.

In 2005, a report by Styles recommended a threshold (commonly referred to as the "noise budget") of 0.336 nm of seismic noise disturbance would prevent the array's operation being comprised. Exceeding the 0.336 nm threshold would compromise the array's detection capabilities.

This was followed by the 2014 work undertaken by Xi Engineering Consultants on behalf of the Eskdalemuir Working Group, which developed a purposefully conservative algorithm and associated spreadsheet tool enabling the MoD to manage this seismic ground vibration threshold and thereby safeguard the detection capabilities of the array. The adoption of this 2014 Xi Algorithm allowed in excess of 1.1GW onshore wind development to proceed.

The 0.336nm budget was issued on a first come, first served basis and no project has been allocated budget since January 2018. The MoD's position is that, at present, the threshold of 0.336nm has been reached when using the 2014 Xi Engineering Consultants conservative spreadsheet to calculate the cumulative impact of Wind Turbines on the Eskdalemuir seismic array. As this is the only tool the MoD has available it is objecting to all applications to preserve the array's detection capabilities. Any additional applications received subsequent to January 2018 were added to a 'waiting list' for future MoD approval. The current waiting list based on publicly available data corresponds to approximately 2.5GW of potential onshore wind turbine development. These potential developments would have a significant impact on the 12GW targeted by The Scottish Government by 2030.



## 2.1. 2019-2022 Scottish Government Commissioned Xi Engineering Studies

Between 2019 and 2022 the Scottish Government commissioned Xi Engineering Consultants to deliver a series of technical evaluations and studies. These studies followed a phased approach (Phase 1 through Phase 5) to investigate the potential additional capacity that may be made available were the 2014 algorithm to be revised. These studies confirmed that the algorithm currently used by the MoD to calculate the budget takes a conservative approach and, by design, over-estimates the seismic contribution of each wind turbine.

The Scottish Government has engaged with MoD to seek the MoD's approval of data collected and are seeking agreement that the MoD will adopt this evidence-based approach and adjust the calculation for budget utilisation.

Unlocking potential capacity whilst safeguarding the array has become the task of the reformed Eskdalemuir Working Group (EWG) with the Scottish Government taking role of secretariat and recognises that:

- Safeguarding of the array lies within the MoD policy remit.
- Maximisation of renewable energy deployment lies within the Scottish Government policy remit.

## 2.2. Eskdalemuir Working Group (EWG) scope of works for 2023 to deliver additional capacity for the region.

A draft scope of works has been issued for the Eskdalemuir Working Group (EWG) to produce guidance and is targeting 2023 for delivery. *

The following is a direct excerpt from the Draft Scope of works.

*Given current demands on resource for Scottish Government and Ministry of Defence, we suggest a preliminary timeframe of Q4 2023 for finalisation of this guidance.*

*The document reiterates the MoD refenced section from the ONWPS (2.51.2)*

*Unlocking potential capacity whilst safeguarding the array will require decisive and meaningful action from the Scottish Government and UK Government. To do so, we must recognise:*

- *Safeguarding of the array lies within the MoD policy remit.*
- *Maximisation of renewable energy deployment lies within the Scottish Government policy remit.*

*The Draft scope of works for the Eskdalemuir working Group puts forward Proposed Approach(es) specifically.*

*Following these conversations and reflecting on the results of the recent draft Onshore Wind Policy Statement consultation, as well as the multi-phased technical work, the Scottish Government are minded pursuing the following approaches:*

1. ***Establishing a Seismic Impact Limit for Eskdalemuir Seismic Array and the consultation zone***

*In order to secure a minimum additional capacity of 1 GW within this zone and encourage the use of turbines with the lowest seismic impact, the Scottish Government would require that any proposal yet to be determined must limit the seismic impact of each individual turbine within the consultation zone to 0.00836 nm.MW$^{-0.5}$* and ensuring the 0.336nm threshold is not exceeded.*

**This limit is based on calculations undertaken by Xi Engineering on behalf of the Scottish Government and may be subject to slight variation during formal signoff process by MoD.*

***2. Deployment Maximisation Zone at the Eskdalemuir Seismic Array***

*To aid in protection of the array, in addition to maximising potential for onshore wind deployment in areas with lesser impact on the array, we would replace the existing 10km exclusion zone with a 15 km exclusion zone. This means that no turbine could be constructed within a 15 km radius of the Eskdalemuir Seismic Array.*

**The revised dates are currently under consideration by the Eskdalemuir Working Group (EWG) – July 2024*

### 2.3. Incorporation of MoD Technical Experts Feedback

Following the MoD subject matter expert's review of the Phase 4 and Phase 5 work packages released in 2022 refinements to the mathematical analysis used to confirm the 'headroom' within the 0.336nm budget were undertaken. As there was a minor change in the headroom and the Seismic Impact Limit (SIL) is calculated based on the available headroom, Phase 5 was also recalculated based on the refined revisions. For details of the refinement and revision please see section 9.



# 3. Definitions

In this report, the following nomenclature in Table 1 is employed for clarity:

| Acronym | Definition | Notes |
|---|---|---|
| SIL | Seismic Impact Limit | Constant 0.00836 nm.MW$^{-0.5}$ for 1 GW capacity. |
| PSV | Power Seismic Value | The permitted seismic impact of a turbine based on its power output. (Equation 1) |
| TMR | Turbine Mitigation Ratio | Ratio defining if mitigation is required for a turbine. TMR < 1 requires mitigation. (Equation 2). Turbine with TMR ≥1 require no mitigation and have TMR listed as "not applicable" (N/A). |

Table 1 Summary of acronyms used in this report relating to Seismic Impact Limit.

# 4. Technical Background

### 4.1. Relationship between distance and seismic impact

The amplitude of a seismic wave decreases rapidly with distance. This means that turbines built close to the EKA have a far greater impact on the seismic array and consume considerably more seismic budget. A single turbine placed on the border of the 10 km exclusion zone would have the equivalent seismic budget requirement equivalent to approximately 2,000 of the same turbines placed at a distance of 50 km (this calculation is model specific and may vary due to the make and model of the turbine). The installable capacity within the consultation zone can be maximised by avoiding placing turbines close to the EKA. To this end, an upper limit SIL, has been proposed to determine the impact that any single turbine has on the EKA. Given the impact reduces rapidly with distance, the SIL will only affect wind turbines close to the EKA (e.g. within ~20 km).

### 4.2. Derivation of the Seismic Impact Limit (SIL)

To quantify an appropriate value for the SIL it is necessary to determine the amount of the 0.336 nm seismic budget that remains in the consultation zone and to have a minimum target of installable wind energy capacity to which the remaining budget will be converted. The Phase 5 study for the Scottish Government and the EWG calculates the remaining Eskdalemuir Consultation Zone budget, where sites that are operating adopt an 'as measured' seismic vibration level. For all sites up to and including Scotston Bank, the cumulative seismic impact of all wind farms in the queue is 0.20756 nm. This is significantly below the budget threshold of 0.336 nm. Given that the impact of farms adds in quadrature, the head-room within the budget is 0.26422nm:

$$\sqrt{0.336^2 - 0.20756^2} = 0.26422$$

The Scottish Government required a SIL level be derived that would result in the consumption of this 0.22560 nm and would produce no less that an additional 1 GW of wind turbine capacity. Definition of the SIL as documented in the Phase 5 report: *A Seismic Impact Limit 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).* The SIL level for a minimum installable capacity 1 GW was found to be 0.00836 nm.MW$^{-0.5}$.

In summary, SIL assumes that the seismic power produced by wind turbines has a close to linear relationship with their output power.

To take account of this near linear relationship to the physical size of a turbine, the Seismic Impact Limit is specific to a turbine's maximum power output.

Definition of the SIL is documented in the Phase 5 report: *A Seismic Impact Limit 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).*

### 4.3. Power Seismic Value for a Given Turbine

The seismic impact that any one turbine is permitted to produce is referred to as the turbine's Power Seismic Value (PSV), which scales for its rated power according to equation 1:

$$PSV = SIL \cdot \sqrt{Power} \qquad (1)$$

where SIL is 0.00836 nm.MW$^{-0.5}$ and Power is the turbine's rated power in MW.

### 4.4. Turbine Mitigation Ratio for a Given Turbine

If the seismic impact of a turbine exceeds it PSV, then it would require some form of mitigation. The level of mitigation required to ensure a turbine is compliant is given by the Turbine Mitigation Ratio (TMR):

$$TMR = \frac{PSV}{Turbine\ Amplitude\ at\ EKA} \qquad (2)$$

For Turbine Mitigation Ratios greater than 1, no mitigation is required while numbers below 1 require mitigation consistent with the ratio.



# 5. Methodology

### 5.1. Candidate Machine

At this stage of development, the specific candidate machine is not fixed.

### 5.2. Wind farm specifications

M74 West Wind Farm is proposed to consist of 22 turbines each proposed to be 6.3 MW, providing a maximum capacity of 138.6 MW (see Table 2). As the current layout of the proposed M74 West Wind Farm is between 41.1 km and 44.6 m from the Eskdalemuir Seismic Array (EKA) it is likely to be subject to a Seismic Impact Limit, if adopted. Based on the proposed 6.3 MW turbines to be deployed at M74 West Wind Farm, the Power Seismic Value (PSV) of each turbine was calculated using equation 1. As all turbines at M74 West Wind Farm are proposed to have the same 6.3 MW power output, the PSV for each turbine is between 0.021009 nm for a 1GW SIL limit, and 0.013278 nm for a 2.5 GW SIL Limit.

### 5.3. Site details

The proposed M74 West Wind Farm consists of 22 Turbines with a tip height of 200 m. The nearest turbine is 41.1 km from the Eskdalemuir Seismic Array. Specific Turbine locations and dimensions are shown in Table 2.

| Turbine ID | Eastings | Northings | Range (km) | Hub Height (m) | Rotor diameter (m) | Power (MW) |
|---|---|---|---|---|---|---|
| 1 | 289226 | 628279 | 43.97 | 112.5 | 175.0 | 6.3 |
| 2 | 289653 | 628010 | 43.46 | 112.5 | 175.0 | 6.3 |
| 3 | 289983 | 627700 | 43.02 | 112.5 | 175.0 | 6.3 |
| 4 | 288602 | 627840 | 44.27 | 112.5 | 175.0 | 6.3 |
| 5 | 289004 | 627578 | 43.79 | 112.5 | 175.0 | 6.3 |
| 6 | 289398 | 627296 | 43.30 | 112.5 | 175.0 | 6.3 |
| 7 | 289907 | 627124 | 42.78 | 112.5 | 175.0 | 6.3 |
| 8 | 290496 | 626904 | 42.16 | 112.5 | 175.0 | 6.3 |
| 9 | 291024 | 626883 | 41.70 | 112.5 | 175.0 | 6.3 |
| 10 | 287981 | 627375 | 44.56 | 112.5 | 175.0 | 6.3 |
| 11 | 288776 | 626791 | 43.58 | 112.5 | 175.0 | 6.3 |
| 12 | 289303 | 626583 | 43.02 | 112.5 | 175.0 | 6.3 |
| 13 | 289747 | 626380 | 42.54 | 112.5 | 175.0 | 6.3 |
| 14 | 290183 | 626235 | 42.09 | 112.5 | 175.0 | 6.3 |
| 15 | 290787 | 626292 | 41.60 | 112.5 | 175.0 | 6.3 |
| 16 | 291256 | 626117 | 41.10 | 112.5 | 175.0 | 6.3 |
| 17 | 287557 | 626728 | 44.61 | 112.5 | 175.0 | 6.3 |
| 18 | 287965 | 626424 | 44.11 | 112.5 | 175.0 | 6.3 |
| 19 | 288535 | 626071 | 43.44 | 112.5 | 175.0 | 6.3 |
| 20 | 289421 | 625632 | 42.45 | 112.5 | 175.0 | 6.3 |
| 21 | 290002 | 625678 | 41.97 | 112.5 | 175.0 | 6.3 |
| 22 | 290089 | 625121 | 41.62 | 112.5 | 175.0 | 6.3 |

Table 2 M74 West Wind Farm Turbine Locations in Easting and Northing

## 5.4. Budget and SIL Scenarios Assessed

In order to contextualise the implications and demonstrate potential required budget levels and the impact of the SIL, several scenarios have been assessed for different machines. 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 reports 'SGV 203 Technical report v12.pdf' and refined Phase 4 'AIFCL-101-Phase4-Rev-v13': Field audit of Selected sites within the EKA Consultation Zone to support Government Policy Decisions'.

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. It has been 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. Budget Scenarios 9 – 16 & 18 (see below) have been included in the analysis to demonstrate the effect of performing before and after measurement in order to remove background noise. The Budget scenarios modelled are as follows;

| | |
|---|---|
| 1. Standard EKA algorithm | Using the Current MoD 'worst case' algorithm. |
| 2. Siemens | Using Phase 4 published data |
| 3. Senvion | Using Phase 4 published data |
| 4. Vestas | Using Phase 4 published data |
| 5. GE | Using Phase 4 published data |
| 6. Nordex | Using Phase 4 published data |
| 7. Enercon | Using Phase 4 published data |
| 8. Gamesa | Using Phase 4 published data |
| 9. Standard EKA algorithm background removed | See Background noise removal section |
| 10. Siemens background removed | See Background noise removal section |
| 11. Senvion background removed | See Background noise removal section |
| 12. Vestas background removed | See Background noise removal section |
| 13. GE background removed | See Background noise removal section |
| 14. Nordex background removed | See Background noise removal section |
| 15. Enercon background removed | See Background noise removal section |
| 16. Gamesa background removed | See Background noise removal section |
| 17. Siemens Gamesa 155 | Data from Manufacturer measured by Xi |
| 18. SG155 Background removed | See Background noise removal section |

## 5.5. Background Noise Removal

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 effect 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. The authors note that the approach of removing all background noise from the algorithm is contrary to the precautionary approach used to design the 2014 EKA 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 possible development of a methodology which will not penalise a wind turbine for noise which is not attributable to the wind turbine itself.

### 5.6. Queue Scenarios Assessed

The following queue scenarios were assessed for their impact on budget for M74 West Wind Farm:

1. Scenario 1 - All wind farms included except Faw Side
2. Scenario 2 - All wind farms included except Faw Side and Scoop Hill
3. Scenario 3 - All wind farms included except Faw Side, Scoop Hill and Teviot
4. Scenario 4 – All wind farms included except Faw Side and those in Scoping
5. Scenario 5 – All wind farms included (this is in keeping with the Phase 4 work)

For M74 West Wind Farm, the manufacturer and model of the Turbines are unknown and so the worst-case model was used to assess queue scenarios. In this case the worst-case model utilised was the Vestas model.



# 6. Results

### 6.1. The seismic budget requirements for M74 West Wind Farm

The following tables (Table 3 & Table 4) show the seismic budget levels of the Wind Farm as a whole site using the various potential turbine options, with and without background noise, respectively. The seismic budget levels for individual turbines are listed in Table 5 and Table 6 show the seismic budget levels for each individual turbine at the Wind Farm using the various potential turbine options, with and without background noise, respectively. Table 7 shows the TMR against a Scottish Government minimum 1 GW deployment for various turbine types. Table 8 shows the TMR against a Scottish Government maximum 2.5 GW deployment for various turbine types.

| Standard EKA Algorithm (nm) | Siemens (nm) | Senvion (nm) | Vestas (nm) | GE (nm) | Nordex (nm) | Enercon (nm) | Gamesa (nm) | SG155 (nm) |
|---|---|---|---|---|---|---|---|---|
| 0.017515 | 0.011460 | 0.007878 | 0.012654 | 0.012140 | 0.009223 | 0.008269 | 0.017074 | 0.004615 |

Table 3 Seismic results of 8 scenarios modelled using Phase 4 data plus SG155 (all results are in nm).

| Standard EKA Algorithm No Background (nm) | Siemens No Background (nm) | Senvion No Background (nm) | Vestas No Background (nm) | GE No Background (nm) | Nordex No Background (nm) | Enercon No Background (nm) | Gamesa No Background (nm) | SG155 No Background (nm) |
|---|---|---|---|---|---|---|---|---|
| 0.016085 | 0.009292 | 0.004574 | 0.008733 | 0.010243 | 0.006097 | 0.004526 | 0.011496 | 0.002549 |

Table 4 Seismic results of 8 scenarios modelled using Phase 4 data without background noise plus SG155 (all results are in nm).

| Turbine No | Standard EKA Algorithm (nm) | Siemens (nm) | Senvion (nm) | Vestas (nm) | GE (nm) | Nordex (nm) | Enercon (nm) | Gamesa (nm) | SG155 (nm) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.003381 | 0.002225 | 0.001528 | 0.002464 | 0.002345 | 0.001794 | 0.001601 | 0.003324 | 0.000890 |
| 2 | 0.003538 | 0.002323 | 0.001595 | 0.002568 | 0.002453 | 0.001871 | 0.001673 | 0.003466 | 0.000932 |
| 3 | 0.003682 | 0.002412 | 0.001658 | 0.002665 | 0.002553 | 0.001942 | 0.001739 | 0.003596 | 0.000970 |
| 4 | 0.003291 | 0.002169 | 0.001489 | 0.002403 | 0.002283 | 0.001750 | 0.001560 | 0.003243 | 0.000867 |
| 5 | 0.003435 | 0.002259 | 0.001551 | 0.002500 | 0.002382 | 0.001821 | 0.001626 | 0.003373 | 0.000905 |
| 6 | 0.003588 | 0.002354 | 0.001617 | 0.002602 | 0.002488 | 0.001896 | 0.001696 | 0.003511 | 0.000945 |
| 7 | 0.003762 | 0.002462 | 0.001692 | 0.002718 | 0.002608 | 0.001981 | 0.001776 | 0.003667 | 0.000991 |
| 8 | 0.003980 | 0.002596 | 0.001786 | 0.002862 | 0.002758 | 0.002087 | 0.001876 | 0.003862 | 0.001049 |
| 9 | 0.004151 | 0.002702 | 0.001860 | 0.002976 | 0.002875 | 0.002171 | 0.001954 | 0.004016 | 0.001094 |
| 10 | 0.003205 | 0.002116 | 0.001451 | 0.002346 | 0.002223 | 0.001707 | 0.001521 | 0.003165 | 0.000844 |
| 11 | 0.003499 | 0.002298 | 0.001579 | 0.002542 | 0.002426 | 0.001852 | 0.001655 | 0.003430 | 0.000921 |
| 12 | 0.003680 | 0.002411 | 0.001657 | 0.002663 | 0.002551 | 0.001941 | 0.001738 | 0.003594 | 0.000969 |
| 13 | 0.003846 | 0.002513 | 0.001728 | 0.002774 | 0.002666 | 0.002022 | 0.001814 | 0.003743 | 0.001013 |
| 14 | 0.004007 | 0.002613 | 0.001798 | 0.002880 | 0.002776 | 0.002100 | 0.001888 | 0.003887 | 0.001056 |
| 15 | 0.004191 | 0.002726 | 0.001877 | 0.003002 | 0.002903 | 0.002190 | 0.001972 | 0.004051 | 0.001105 |
| 16 | 0.004386 | 0.002846 | 0.001960 | 0.003131 | 0.003036 | 0.002284 | 0.002062 | 0.004224 | 0.001157 |
| 17 | 0.003191 | 0.002107 | 0.001445 | 0.002336 | 0.002214 | 0.001701 | 0.001514 | 0.003152 | 0.000841 |
| 18 | 0.003338 | 0.002199 | 0.001509 | 0.002435 | 0.002315 | 0.001773 | 0.001582 | 0.003285 | 0.000879 |
| 19 | 0.003545 | 0.002327 | 0.001599 | 0.002573 | 0.002458 | 0.001875 | 0.001677 | 0.003472 | 0.000933 |
| 20 | 0.003877 | 0.002532 | 0.001742 | 0.002794 | 0.002687 | 0.002037 | 0.001828 | 0.003770 | 0.001021 |
| 21 | 0.004052 | 0.002640 | 0.001817 | 0.002910 | 0.002807 | 0.002122 | 0.001909 | 0.003927 | 0.001068 |
| 22 | 0.004183 | 0.002721 | 0.001873 | 0.002997 | 0.002897 | 0.002186 | 0.001969 | 0.004044 | 0.001103 |

Table 5 Individual seismic Budget calculations for M74 West Wind Farm



| Turbine No | Standard EKA Algorithm No Background (nm) | Siemens No Background (nm) | Senvion No Background (nm) | Vestas No Background (nm) | GE No Background (nm) | Nordex No Background (nm) | Enercon No Background (nm) | Gamesa No Background (nm) | SG155 No Background (nm) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.003102 | 0.001805 | 0.000886 | 0.001707 | 0.001975 | 0.001190 | 0.000873 | 0.002248 | 0.000486 |
| 2 | 0.003247 | 0.001884 | 0.000926 | 0.001777 | 0.002068 | 0.001240 | 0.000914 | 0.002339 | 0.000511 |
| 3 | 0.003381 | 0.001956 | 0.000962 | 0.001841 | 0.002153 | 0.001285 | 0.000951 | 0.002423 | 0.000534 |
| 4 | 0.003019 | 0.001760 | 0.000864 | 0.001667 | 0.001922 | 0.001162 | 0.000850 | 0.002195 | 0.000472 |
| 5 | 0.003152 | 0.001833 | 0.000900 | 0.001731 | 0.002007 | 0.001207 | 0.000887 | 0.002280 | 0.000494 |
| 6 | 0.003294 | 0.001909 | 0.000939 | 0.001799 | 0.002098 | 0.001255 | 0.000927 | 0.002368 | 0.000519 |
| 7 | 0.003455 | 0.001996 | 0.000983 | 0.001876 | 0.002201 | 0.001310 | 0.000972 | 0.002469 | 0.000547 |
| 8 | 0.003657 | 0.002104 | 0.001037 | 0.001971 | 0.002329 | 0.001377 | 0.001029 | 0.002594 | 0.000583 |
| 9 | 0.003816 | 0.002189 | 0.001080 | 0.002046 | 0.002430 | 0.001430 | 0.001073 | 0.002692 | 0.000611 |
| 10 | 0.002939 | 0.001717 | 0.000842 | 0.001629 | 0.001871 | 0.001135 | 0.000828 | 0.002145 | 0.000458 |
| 11 | 0.003211 | 0.001864 | 0.000916 | 0.001760 | 0.002045 | 0.001227 | 0.000904 | 0.002317 | 0.000504 |
| 12 | 0.003379 | 0.001955 | 0.000962 | 0.001840 | 0.002152 | 0.001284 | 0.000951 | 0.002422 | 0.000534 |
| 13 | 0.003533 | 0.002038 | 0.001004 | 0.001913 | 0.002250 | 0.001336 | 0.000994 | 0.002518 | 0.000561 |
| 14 | 0.003682 | 0.002118 | 0.001044 | 0.001983 | 0.002345 | 0.001385 | 0.001036 | 0.002610 | 0.000587 |
| 15 | 0.003853 | 0.002209 | 0.001090 | 0.002063 | 0.002453 | 0.001442 | 0.001084 | 0.002715 | 0.000618 |
| 16 | 0.004033 | 0.002305 | 0.001138 | 0.002148 | 0.002567 | 0.001502 | 0.001135 | 0.002825 | 0.000651 |
| 17 | 0.002926 | 0.001710 | 0.000838 | 0.001623 | 0.001863 | 0.001131 | 0.000824 | 0.002137 | 0.000456 |
| 18 | 0.003062 | 0.001784 | 0.000876 | 0.001688 | 0.001950 | 0.001177 | 0.000862 | 0.002223 | 0.000479 |
| 19 | 0.003254 | 0.001887 | 0.000928 | 0.001780 | 0.002072 | 0.001242 | 0.000916 | 0.002344 | 0.000512 |
| 20 | 0.003561 | 0.002053 | 0.001011 | 0.001926 | 0.002268 | 0.001345 | 0.001002 | 0.002535 | 0.000566 |
| 21 | 0.003723 | 0.002140 | 0.001055 | 0.002002 | 0.002371 | 0.001399 | 0.001047 | 0.002636 | 0.000595 |
| 22 | 0.003845 | 0.002205 | 0.001088 | 0.002060 | 0.002448 | 0.001440 | 0.001082 | 0.002710 | 0.000617 |

Table 6 Individual seismic Budget requirements without background noise for M74 West Wind Farm.

6.2.Seismic Impact Limit Turbine Mitigation Ratio Results

| | | With Background Noise | | | | | | | | | Without Background Noise | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WTG No | PSV (nm) | Standard EKA TMR | Siemens TMR | Senvion TMR | Vestas TMR | GE TMR | Nordex TMR | Enercon TMR | Gamesa TMR | SG155 TMR | Standard EKA TMR | Siemens TMR | Senvion TMR | Vestas TMR | GE TMR | Nordex TMR | Enercon TMR | Gamesa TMR | SG155 TMR |
| 1 | 0.021009 | 6.214 | 9.441 | 13.752 | 8.527 | 8.959 | 11.710 | 13.119 | 6.320 | 23.597 | 6.773 | 11.637 | 23.702 | 12.305 | 10.636 | 17.648 | 24.056 | 9.346 | 43.253 |
| 2 | 0.021009 | 5.939 | 9.045 | 13.168 | 8.180 | 8.564 | 11.228 | 12.556 | 6.062 | 22.552 | 6.470 | 11.152 | 22.687 | 11.824 | 10.159 | 16.949 | 22.988 | 8.980 | 41.138 |
| 3 | 0.021009 | 5.705 | 8.709 | 12.672 | 7.884 | 8.229 | 10.818 | 12.078 | 5.842 | 21.663 | 6.213 | 10.740 | 21.828 | 11.414 | 9.756 | 16.353 | 22.082 | 8.669 | 39.341 |
| 4 | 0.021009 | 6.384 | 9.685 | 14.112 | 8.741 | 9.203 | 12.007 | 13.467 | 6.479 | 24.241 | 6.960 | 11.936 | 24.328 | 12.601 | 10.932 | 18.079 | 24.715 | 9.570 | 44.557 |
| 5 | 0.021009 | 6.116 | 9.300 | 13.544 | 8.404 | 8.818 | 11.538 | 12.919 | 6.228 | 23.225 | 6.665 | 11.464 | 23.340 | 12.134 | 10.466 | 17.399 | 23.675 | 9.215 | 42.499 |
| 6 | 0.021009 | 5.856 | 8.926 | 12.992 | 8.075 | 8.445 | 11.083 | 12.386 | 5.984 | 22.236 | 6.379 | 11.005 | 22.382 | 11.678 | 10.016 | 16.737 | 22.666 | 8.870 | 40.499 |
| 7 | 0.021009 | 5.584 | 8.534 | 12.415 | 7.730 | 8.055 | 10.605 | 11.829 | 5.728 | 21.202 | 6.080 | 10.525 | 21.382 | 11.200 | 9.547 | 16.043 | 21.612 | 8.508 | 38.409 |
| 8 | 0.021009 | 5.279 | 8.093 | 11.764 | 7.340 | 7.618 | 10.066 | 11.201 | 5.439 | 20.034 | 5.745 | 9.984 | 20.257 | 10.658 | 9.021 | 15.258 | 20.424 | 8.098 | 36.053 |
| 9 | 0.021009 | 5.061 | 7.776 | 11.298 | 7.060 | 7.306 | 9.679 | 10.750 | 5.232 | 19.196 | 5.506 | 9.596 | 19.453 | 10.269 | 8.646 | 14.693 | 19.573 | 7.803 | 34.368 |
| 10 | 0.021009 | 6.556 | 9.930 | 14.475 | 8.956 | 9.450 | 12.305 | 13.816 | 6.639 | 24.889 | 7.149 | 12.237 | 24.959 | 12.898 | 11.230 | 18.511 | 25.378 | 9.796 | 45.869 |
| 11 | 0.021009 | 6.005 | 9.140 | 13.308 | 8.263 | 8.659 | 11.344 | 12.691 | 6.124 | 22.803 | 6.542 | 11.268 | 22.931 | 11.940 | 10.273 | 17.117 | 23.245 | 9.068 | 41.645 |
| 12 | 0.021009 | 5.709 | 8.714 | 12.680 | 7.888 | 8.234 | 10.825 | 12.085 | 5.846 | 21.677 | 6.217 | 10.746 | 21.841 | 11.420 | 9.762 | 16.362 | 22.096 | 8.674 | 39.368 |
| 13 | 0.021009 | 5.462 | 8.359 | 12.155 | 7.575 | 7.881 | 10.391 | 11.579 | 5.613 | 20.737 | 5.947 | 10.310 | 20.934 | 10.985 | 9.337 | 15.731 | 21.139 | 8.345 | 37.471 |
| 14 | 0.021009 | 5.243 | 8.041 | 11.687 | 7.294 | 7.567 | 10.003 | 11.127 | 5.405 | 19.896 | 5.706 | 9.920 | 20.125 | 10.595 | 8.960 | 15.165 | 20.284 | 8.049 | 35.777 |
| 15 | 0.021009 | 5.012 | 7.706 | 11.195 | 6.998 | 7.237 | 9.593 | 10.651 | 5.186 | 19.011 | 5.453 | 9.510 | 19.275 | 10.182 | 8.564 | 14.568 | 19.385 | 7.738 | 33.996 |
| 16 | 0.021009 | 4.790 | 7.382 | 10.719 | 6.711 | 6.919 | 9.197 | 10.191 | 4.974 | 18.155 | 5.210 | 9.113 | 18.455 | 9.782 | 8.183 | 13.990 | 18.518 | 7.436 | 32.278 |
| 17 | 0.021009 | 6.584 | 9.970 | 14.534 | 8.991 | 9.490 | 12.353 | 13.873 | 6.665 | 24.994 | 7.179 | 12.286 | 25.062 | 12.946 | 11.279 | 18.582 | 25.486 | 9.832 | 46.083 |
| 18 | 0.021009 | 6.294 | 9.555 | 13.921 | 8.628 | 9.074 | 11.849 | 13.282 | 6.395 | 23.899 | 6.860 | 11.777 | 23.995 | 12.444 | 10.775 | 17.850 | 24.365 | 9.451 | 43.864 |
| 19 | 0.021009 | 5.926 | 9.028 | 13.142 | 8.164 | 8.546 | 11.207 | 12.531 | 6.051 | 22.506 | 6.456 | 11.131 | 22.643 | 11.803 | 10.138 | 16.918 | 22.941 | 8.964 | 41.044 |
| 20 | 0.021009 | 5.419 | 8.296 | 12.063 | 7.519 | 7.819 | 10.315 | 11.490 | 5.572 | 20.572 | 5.899 | 10.233 | 20.775 | 10.908 | 9.263 | 15.620 | 20.971 | 8.287 | 37.138 |
| 21 | 0.021009 | 5.185 | 7.957 | 11.564 | 7.220 | 7.484 | 9.900 | 11.007 | 5.350 | 19.674 | 5.643 | 9.817 | 19.912 | 10.491 | 8.860 | 15.016 | 20.059 | 7.971 | 35.330 |
| 22 | 0.021009 | 5.022 | 7.720 | 11.215 | 7.010 | 7.251 | 9.611 | 10.671 | 5.195 | 19.048 | 5.464 | 9.527 | 19.311 | 10.200 | 8.580 | 14.594 | 19.423 | 7.751 | 34.071 |

Table 7 TMR for Scottish Government 1GW SIL Individual Turbine – Note red denotes the SIL limit is NOT met



Xi

| | | With Background Noise | | | | | | | | | Without Background Noise | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WTG No | PSV (nm) | Standard EKA TMR | Siemens TMR | Senvion TMR | Vestas TMR | GE TMR | Nordex TMR | Enercon TMR | Gamesa TMR | SG155 TMR | Standard EKA TMR | Siemens TMR | Senvion TMR | Vestas TMR | GE TMR | Nordex TMR | Enercon TMR | Gamesa TMR | SG155 TMR |
| 1 | 0.013278 | 3.927 | 5.967 | 8.692 | 5.390 | 5.662 | 7.401 | 8.292 | 3.994 | 14.914 | 4.281 | 7.355 | 14.980 | 7.777 | 6.722 | 11.154 | 15.204 | 5.907 | 27.337 |
| 2 | 0.013278 | 3.753 | 5.717 | 8.322 | 5.170 | 5.412 | 7.096 | 7.936 | 3.831 | 14.253 | 4.089 | 7.048 | 14.339 | 7.473 | 6.421 | 10.712 | 14.529 | 5.676 | 26.000 |
| 3 | 0.013278 | 3.606 | 5.504 | 8.009 | 4.983 | 5.201 | 6.837 | 7.633 | 3.693 | 13.692 | 3.927 | 6.788 | 13.796 | 7.214 | 6.166 | 10.335 | 13.956 | 5.479 | 24.864 |
| 4 | 0.013278 | 4.035 | 6.121 | 8.919 | 5.525 | 5.817 | 7.588 | 8.511 | 4.095 | 15.321 | 4.399 | 7.544 | 15.376 | 7.964 | 6.909 | 11.426 | 15.620 | 6.048 | 28.161 |
| 5 | 0.013278 | 3.865 | 5.878 | 8.560 | 5.311 | 5.573 | 7.292 | 8.165 | 3.936 | 14.678 | 4.212 | 7.246 | 14.751 | 7.669 | 6.615 | 10.997 | 14.963 | 5.824 | 26.860 |
| 6 | 0.013278 | 3.701 | 5.641 | 8.211 | 5.103 | 5.337 | 7.004 | 7.828 | 3.782 | 14.054 | 4.031 | 6.956 | 14.146 | 7.381 | 6.330 | 10.578 | 14.326 | 5.606 | 25.596 |
| 7 | 0.013278 | 3.529 | 5.394 | 7.846 | 4.885 | 5.091 | 6.703 | 7.476 | 3.620 | 13.400 | 3.843 | 6.652 | 13.514 | 7.079 | 6.034 | 10.140 | 13.659 | 5.377 | 24.275 |
| 8 | 0.013278 | 3.336 | 5.115 | 7.435 | 4.639 | 4.815 | 6.362 | 7.079 | 3.438 | 12.662 | 3.631 | 6.310 | 12.803 | 6.736 | 5.702 | 9.643 | 12.908 | 5.118 | 22.786 |
| 9 | 0.013278 | 3.198 | 4.915 | 7.140 | 4.462 | 4.618 | 6.117 | 6.794 | 3.307 | 12.132 | 3.480 | 6.065 | 12.294 | 6.490 | 5.465 | 9.286 | 12.371 | 4.932 | 21.721 |
| 10 | 0.013278 | 4.143 | 6.276 | 9.149 | 5.661 | 5.973 | 7.777 | 8.732 | 4.196 | 15.730 | 4.518 | 7.734 | 15.775 | 8.152 | 7.097 | 11.699 | 16.040 | 6.191 | 28.990 |
| 11 | 0.013278 | 3.795 | 5.777 | 8.411 | 5.223 | 5.472 | 7.170 | 8.021 | 3.871 | 14.412 | 4.135 | 7.122 | 14.493 | 7.546 | 6.493 | 10.818 | 14.691 | 5.731 | 26.321 |
| 12 | 0.013278 | 3.608 | 5.507 | 8.014 | 4.985 | 5.204 | 6.841 | 7.638 | 3.695 | 13.700 | 3.929 | 6.792 | 13.804 | 7.218 | 6.170 | 10.341 | 13.965 | 5.482 | 24.881 |
| 13 | 0.013278 | 3.452 | 5.283 | 7.682 | 4.787 | 4.981 | 6.567 | 7.318 | 3.548 | 13.106 | 3.759 | 6.516 | 13.231 | 6.943 | 5.901 | 9.942 | 13.360 | 5.274 | 23.682 |
| 14 | 0.013278 | 3.314 | 5.082 | 7.387 | 4.610 | 4.783 | 6.322 | 7.032 | 3.416 | 12.575 | 3.606 | 6.270 | 12.720 | 6.696 | 5.663 | 9.585 | 12.820 | 5.087 | 22.612 |
| 15 | 0.013278 | 3.168 | 4.870 | 7.075 | 4.423 | 4.574 | 6.063 | 6.732 | 3.278 | 12.015 | 3.447 | 6.010 | 12.182 | 6.435 | 5.412 | 9.207 | 12.252 | 4.890 | 21.486 |
| 16 | 0.013278 | 3.028 | 4.666 | 6.774 | 4.241 | 4.373 | 5.813 | 6.441 | 3.143 | 11.474 | 3.293 | 5.760 | 11.664 | 6.182 | 5.172 | 8.842 | 11.704 | 4.699 | 20.400 |
| 17 | 0.013278 | 4.161 | 6.301 | 9.186 | 5.683 | 5.998 | 7.808 | 8.768 | 4.212 | 15.797 | 4.538 | 7.765 | 15.840 | 8.182 | 7.128 | 11.744 | 16.108 | 6.214 | 29.125 |
| 18 | 0.013278 | 3.978 | 6.039 | 8.798 | 5.453 | 5.735 | 7.489 | 8.395 | 4.042 | 15.105 | 4.336 | 7.443 | 15.165 | 7.865 | 6.810 | 11.282 | 15.399 | 5.973 | 27.723 |
| 19 | 0.013278 | 3.746 | 5.706 | 8.306 | 5.160 | 5.401 | 7.083 | 7.920 | 3.824 | 14.224 | 4.081 | 7.035 | 14.311 | 7.460 | 6.407 | 10.692 | 14.499 | 5.666 | 25.941 |
| 20 | 0.013278 | 3.425 | 5.243 | 7.624 | 4.752 | 4.942 | 6.519 | 7.262 | 3.522 | 13.002 | 3.729 | 6.468 | 13.130 | 6.894 | 5.854 | 9.872 | 13.254 | 5.237 | 23.472 |
| 21 | 0.013278 | 3.277 | 5.029 | 7.309 | 4.563 | 4.730 | 6.257 | 6.957 | 3.382 | 12.435 | 3.566 | 6.205 | 12.585 | 6.631 | 5.600 | 9.490 | 12.678 | 5.038 | 22.329 |
| 22 | 0.013278 | 3.174 | 4.879 | 7.088 | 4.431 | 4.583 | 6.074 | 6.744 | 3.283 | 12.039 | 3.453 | 6.021 | 12.205 | 6.446 | 5.423 | 9.223 | 12.276 | 4.899 | 21.534 |

Table 8 TMR for Scottish Government 2.5GW SIL Individual Turbine – Note red denotes the SIL limit is NOT met

## 6.1. Mitigation

As can be seen in Table 7 and Table 8 all turbines are above the Turbine Mitigation Ratio, which would indicate that no mitigation would be required should either a 1GW or 2.5GW SIL be adopted.



## 6.2. Queue Scenario Results

### 6.2.1. Scenario 1 – All wind farms included except Faw Side

| | | | | SIL 1.0 GW | | SIL 2.0 GW | | SIL 2.5 GW | |
|---|---|---|---|---|---|---|---|---|---|
| **Wind Farm** | **Status** | **Manufacturer** | **Synthetic Model** | **Amplitude (nm)** | **Cumulative (nm)** | **Amplitude (nm)** | **Cumulative (nm)** | **Amplitude (nm)** | **Cumulative (nm)** |
| Land SE of Scotston Bank Farm | Operational | unknown | GE | 0.000164 | 0.207559 | 0.000164 | 0.207559 | 0.000164 | 0.207559 |
| Little Hartfell | Approved | Nordex | Nordex | 0.059846 | 0.216014 | 0.042317 | 0.211829 | 0.037850 | 0.210982 |
| Faw Side | In Planning | unknown | Vestas | | 0.216014 | | 0.211829 | | 0.210982 |
| Little Hartfell 2nd Sub | In Planning | Nordex | Nordex | 0.059846 | 0.224151 | 0.042317 | 0.216014 | 0.037850 | 0.214350 |
| Scoop Hill | In Planning | unknown | Vestas | 0.171237 | 0.282074 | 0.121083 | 0.247636 | 0.108300 | 0.240156 |
| Harestanes South | In Planning | unknown | GE | 0.028465 | 0.283507 | 0.028465 | 0.249266 | 0.028465 | 0.241837 |
| Daer | In Planning | unknown | GE | 0.039895 | 0.286300 | 0.039895 | 0.252439 | 0.039895 | 0.245105 |
| Cloich Forest | In Planning | unknown | Vestas | 0.006445 | 0.286373 | 0.006445 | 0.252521 | 0.006445 | 0.245190 |
| Greystone Knowe | In Planning | unknown | Vestas | 0.006266 | 0.286441 | 0.006266 | 0.252599 | 0.006266 | 0.245270 |
| Grayside | In Planning | unknown | GE | 0.027374 | 0.287746 | 0.027374 | 0.254077 | 0.027374 | 0.246793 |
| Callisterhall | In Planning | unknown | Vestas | 0.050983 | 0.292228 | 0.038290 | 0.256946 | 0.034247 | 0.249158 |
| Teviot | In Planning | unknown | Vestas | 0.166147 | 0.336158 | 0.119516 | 0.283382 | 0.106899 | 0.271122 |
| Scawd Law | In Planning | unknown | Vestas | 0.009172 | 0.336283 | 0.009172 | 0.283531 | 0.009172 | 0.271277 |
| Liitle Gala | In Planning | unknown | Vestas | 0.003219 | 0.336298 | 0.003219 | 0.283549 | 0.003219 | 0.271296 |
| Bloch | In Planning | unknown | GE | 0.058260 | 0.341308 | 0.058260 | 0.289472 | 0.057218 | 0.277264 |
| Millmoor Rig | In Planning | unknown | GE | 0.017249 | 0.341743 | 0.017249 | 0.289986 | 0.017249 | 0.277800 |
| Bodinglee | In Planning | unknown | Vestas | 0.012636 | 0.341977 | 0.012636 | 0.290261 | 0.012636 | 0.278087 |
| Rivox Farm | In Planning | unknown | Vestas | 0.073345 | 0.349754 | 0.073345 | 0.299384 | 0.072140 | 0.287292 |
| Westerkirk | S36 planning | unknown | Vestas | 0.091148 | 0.361435 | 0.064451 | 0.306243 | 0.057647 | 0.293019 |
| West Andershaw | S36 planning | unknown | Vestas | 0.006489 | 0.361494 | 0.006489 | 0.306312 | 0.006489 | 0.293091 |
| Brown Rig | S36 planning | unknown | Vestas | 0.091530 | 0.372901 | 0.064722 | 0.313075 | 0.057889 | 0.298753 |
| Oliver Forest | S36 planning | unknown | GE | 0.038533 | 0.374887 | 0.038533 | 0.315437 | 0.038533 | 0.301227 |
| Harestanes West | S36 planning | unknown | GE | 0.022021 | 0.375533 | 0.022021 | 0.316205 | 0.022021 | 0.302031 |
| Liddesdale | S36 planning | unknown | Vestas | 0.059365 | 0.380196 | 0.059365 | 0.321729 | 0.059365 | 0.307810 |
| Hearthstanes | S36 planning | unknown | Vestas | 0.055235 | 0.384188 | 0.040934 | 0.324323 | 0.036612 | 0.309980 |
| **M74 West** | | **unknown** | **Vestas** | **0.012654** | **0.384396** | **0.012654** | **0.324570** | **0.012654** | **0.310238** |

| **Key** | |
|---|---|
| | Site cannot be built within 0.336nm budget |
| | Site can be built within 0.336nm budget |
| | Site omitted from cumulative calculation as assumed unsuccessful in planning |

Table 9 – Results for queue Scenario 1 – All wind farms included except Faw Side.

### 6.2.2. Scenario 2 – All wind farms included except Faw Side and Scoop Hill

| Wind Farm | Status | Manufacturer | Synthetic Model | SIL 1.0 GW | | SIL 2.0 GW | | SIL 2.5 GW | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Amplitude (nm) | Cumulative (nm) | Amplitude (nm) | Cumulative (nm) | Amplitude (nm) | Cumulative (nm) |
| Land SE of Scotston Bank Farm | Operational | unknown | GE | 0.000164 | 0.207559 | 0.000164 | 0.207559 | 0.000164 | 0.207559 |
| Little Hartfell | Approved | Nordex | Nordex | 0.059846 | 0.216014 | 0.042317 | 0.211829 | 0.037850 | 0.210982 |
| Faw Side | In Planning | unknown | Vestas | | 0.216014 | | 0.211829 | | 0.210982 |
| Little Hartfell 2nd Sub | In Planning | Nordex | Nordex | 0.059846 | 0.224151 | 0.042317 | 0.216014 | 0.037850 | 0.214350 |
| Scoop Hill | In Planning | unknown | Vestas | | 0.224151 | | 0.216014 | | 0.214350 |
| Harestanes South | In Planning | unknown | GE | 0.028465 | 0.225951 | 0.028465 | 0.217882 | 0.028465 | 0.216232 |
| Daer | In Planning | unknown | GE | 0.039895 | 0.229446 | 0.039895 | 0.221504 | 0.039895 | 0.219881 |
| Cloich Forest | In Planning | unknown | Vestas | 0.006445 | 0.229537 | 0.006445 | 0.221598 | 0.006445 | 0.219976 |
| Greystone Knowe | In Planning | unknown | Vestas | 0.006266 | 0.229622 | 0.006266 | 0.221686 | 0.006266 | 0.220065 |
| Grayside | In Planning | unknown | GE | 0.027374 | 0.231248 | 0.027374 | 0.223370 | 0.027374 | 0.221761 |
| Callisterhall | In Planning | unknown | Vestas | 0.050983 | 0.236802 | 0.038290 | 0.226628 | 0.034247 | 0.224390 |
| Teviot | In Planning | unknown | Vestas | 0.166147 | 0.289275 | 0.119516 | 0.256212 | 0.106899 | 0.248552 |
| Scawd Law | In Planning | unknown | Vestas | 0.009172 | 0.289420 | 0.009172 | 0.256376 | 0.009172 | 0.248721 |
| Liitle Gala | In Planning | unknown | Vestas | 0.003219 | 0.289438 | 0.003219 | 0.256396 | 0.003219 | 0.248742 |
| Bloch | In Planning | unknown | GE | 0.058260 | 0.295243 | 0.058260 | 0.262932 | 0.057218 | 0.255238 |
| Millmoor Rig | In Planning | unknown | GE | 0.017249 | 0.295747 | 0.017249 | 0.263497 | 0.017249 | 0.255820 |
| Bodinglee | In Planning | unknown | Vestas | 0.012636 | 0.296017 | 0.012636 | 0.263800 | 0.012636 | 0.256132 |
| Rivox Farm | In Planning | unknown | Vestas | 0.073345 | 0.304968 | 0.073345 | 0.273806 | 0.072140 | 0.266097 |
| Westerkirk | S36 planning | unknown | Vestas | 0.091148 | 0.318297 | 0.064451 | 0.281290 | 0.057647 | 0.272270 |
| West Andershaw | S36 planning | unknown | Vestas | 0.006489 | 0.318364 | 0.006489 | 0.281364 | 0.006489 | 0.272348 |
| Brown Rig | S36 planning | unknown | Vestas | 0.091530 | 0.331260 | 0.064722 | 0.288712 | 0.057889 | 0.278432 |
| Oliver Forest | S36 planning | unknown | GE | 0.038533 | 0.333494 | 0.038533 | 0.291272 | 0.038533 | 0.281085 |
| Harestanes West | S36 planning | unknown | GE | 0.022021 | 0.334220 | 0.022021 | 0.292104 | 0.022021 | 0.281947 |
| Liddesdale | S36 planning | unknown | Vestas | 0.059365 | 0.339451 | 0.059365 | 0.298075 | 0.059365 | 0.288129 |
| Hearthstanes | S36 planning | unknown | Vestas | 0.055235 | 0.343916 | 0.040934 | 0.300872 | 0.036612 | 0.290445 |
| **M74 West** | | **unknown** | **Vestas** | **0.012654** | **0.344148** | **0.012654** | **0.301138** | **0.012654** | **0.290721** |

| Key | |
|---|---|
| | Site cannot be built within 0.336nm budget |
| | Site can be built within 0.336nm budget |
| | Site omitted from cumulative calculation as assumed unsuccessful in planning |

Table 10 – Results for queue Scenario 2 – All wind farms included except Faw Side and Scoop Hill.



### 6.2.3. Scenario 3 – All wind farms except Faw Side, Scoop Hill and Teviot

| Wind Farm | Status | Manufacturer | Synthetic Model | SIL 1.0 GW | | SIL 2.0 GW | | SIL 2.5 GW | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Amplitude (nm) | Cumulative (nm) | Amplitude (nm) | Cumulative (nm) | Amplitude (nm) | Cumulative (nm) |
| Land SE of Scotston Bank Farm | Operational | unknown | GE | 0.000164 | 0.207559 | 0.000164 | 0.207559 | 0.000164 | 0.207559 |
| Little Hartfell | Approved | Nordex | Nordex | 0.059846 | 0.216014 | 0.042317 | 0.211829 | 0.037850 | 0.210982 |
| Faw Side | In Planning | unknown | Vestas | | 0.216014 | | 0.211829 | | 0.210982 |
| Little Hartfell 2nd Sub | In Planning | Nordex | Nordex | 0.059846 | 0.224151 | 0.042317 | 0.216014 | 0.037850 | 0.214350 |
| Scoop Hill | In Planning | unknown | Vestas | | 0.224151 | | 0.216014 | | 0.214350 |
| Harestanes South | In Planning | unknown | GE | 0.028465 | 0.225951 | 0.028465 | 0.217882 | 0.028465 | 0.216232 |
| Daer | In Planning | unknown | GE | 0.039895 | 0.229446 | 0.039895 | 0.221504 | 0.039895 | 0.219881 |
| Cloich Forest | In Planning | unknown | Vestas | 0.006445 | 0.229537 | 0.006445 | 0.221598 | 0.006445 | 0.219976 |
| Greystone Knowe | In Planning | unknown | Vestas | 0.006266 | 0.229622 | 0.006266 | 0.221686 | 0.006266 | 0.220065 |
| Grayside | In Planning | unknown | GE | 0.027374 | 0.231248 | 0.027374 | 0.223370 | 0.027374 | 0.221761 |
| Callisterhall | In Planning | unknown | Vestas | 0.050983 | 0.236802 | 0.038290 | 0.226628 | 0.034247 | 0.224390 |
| Teviot | In Planning | unknown | Vestas | | 0.236802 | | 0.226628 | | 0.224390 |
| Scawd Law | In Planning | unknown | Vestas | 0.009172 | 0.236979 | 0.009172 | 0.226814 | 0.009172 | 0.224577 |
| Liitle Gala | In Planning | unknown | Vestas | 0.003219 | 0.237001 | 0.003219 | 0.226837 | 0.003219 | 0.224600 |
| Bloch | In Planning | unknown | GE | 0.058260 | 0.244057 | 0.058260 | 0.234199 | 0.057218 | 0.231774 |
| Millmoor Rig | In Planning | unknown | GE | 0.017249 | 0.244666 | 0.017249 | 0.234833 | 0.017249 | 0.232415 |
| Bodinglee | In Planning | unknown | Vestas | 0.012636 | 0.244992 | 0.012636 | 0.235173 | 0.012636 | 0.232758 |
| Rivox Farm | In Planning | unknown | Vestas | 0.073345 | 0.255735 | 0.073345 | 0.246345 | 0.072140 | 0.243681 |
| Westerkirk | S36 planning | unknown | Vestas | 0.091148 | 0.271493 | 0.064451 | 0.254636 | 0.057647 | 0.250407 |
| West Andershaw | S36 planning | unknown | Vestas | 0.006489 | 0.271570 | 0.006489 | 0.254719 | 0.006489 | 0.250491 |
| Brown Rig | S36 planning | unknown | Vestas | 0.091530 | 0.286580 | 0.064722 | 0.262813 | 0.057889 | 0.257093 |
| Oliver Forest | S36 planning | unknown | GE | 0.038533 | 0.289159 | 0.038533 | 0.265623 | 0.038533 | 0.259965 |
| Harestanes West | S36 planning | unknown | GE | 0.022021 | 0.289997 | 0.022021 | 0.266534 | 0.022021 | 0.260896 |
| Liddesdale | S36 planning | unknown | Vestas | 0.059365 | 0.296010 | 0.059365 | 0.273065 | 0.059365 | 0.267565 |
| Hearthstanes | S36 planning | unknown | Vestas | 0.055235 | 0.301120 | 0.040934 | 0.276116 | 0.036612 | 0.270058 |
| **M74 West** | | **unknown** | **Vestas** | **0.012654** | **0.301385** | **0.012654** | **0.276406** | **0.012654** | **0.270354** |

| Key | |
|---|---|
| | Site cannot be built within 0.336nm budget |
| | Site can be built within 0.336nm budget |
| | Site omitted from cumulative calculation as assumed unsuccessful in planning |

Table 11 – Results for queue Scenario 3 – All wind farms except Faw Side, Scoop Hill and Teviot.

### 6.2.4. Scenario 4 – All wind farms except Faw Side and those in Scoping

| Wind Farm | Status | Manufacturer | Synthetic Model | SIL 1.0 GW | | SIL 2.0 GW | | SIL 2.5 GW | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Amplitude (nm) | Cumulative (nm) | Amplitude (nm) | Cumulative (nm) | Amplitude (nm) | Cumulative (nm) |
| Land SE of Scotston Bank Farm | Operational | unknown | GE | 0.000164 | 0.207559 | 0.000164 | 0.207559 | 0.000164 | 0.207559 |
| Little Hartfell | Approved | Nordex | Nordex | 0.059846 | 0.216014 | 0.042317 | 0.211829 | 0.037850 | 0.210982 |
| Faw Side | In Planning | unknown | Vestas | | 0.216014 | | 0.211829 | | 0.210982 |
| Little Hartfell 2nd Sub | In Planning | Nordex | Nordex | 0.059846 | 0.224151 | 0.042317 | 0.216014 | 0.037850 | 0.214350 |
| Scoop Hill | In Planning | unknown | Vestas | 0.171237 | 0.282074 | 0.121083 | 0.247636 | 0.108300 | 0.240156 |
| Harestanes South | In Planning | unknown | GE | 0.028465 | 0.283507 | 0.028465 | 0.249266 | 0.028465 | 0.241837 |
| Daer | In Planning | unknown | GE | 0.039895 | 0.286300 | 0.039895 | 0.252439 | 0.039895 | 0.245105 |
| Cloich Forest | In Planning | unknown | Vestas | 0.006445 | 0.286373 | 0.006445 | 0.252521 | 0.006445 | 0.245190 |
| Greystone Knowe | In Planning | unknown | Vestas | 0.006266 | 0.286441 | 0.006266 | 0.252599 | 0.006266 | 0.245270 |
| Grayside | In Planning | unknown | GE | 0.027374 | 0.287746 | 0.027374 | 0.254077 | 0.027374 | 0.246793 |
| Callisterhall | In Planning | unknown | Vestas | 0.050983 | 0.292228 | 0.038290 | 0.256946 | 0.034247 | 0.249158 |
| Teviot | In Planning | unknown | Vestas | 0.166147 | 0.336158 | 0.119516 | 0.283382 | 0.106899 | 0.271122 |
| Scawd Law | In Planning | unknown | Vestas | 0.009172 | 0.336283 | 0.009172 | 0.283531 | 0.009172 | 0.271277 |
| Liitle Gala | In Planning | unknown | Vestas | 0.003219 | 0.336298 | 0.003219 | 0.283549 | 0.003219 | 0.271296 |
| Bloch | In Planning | unknown | GE | 0.058260 | 0.341308 | 0.058260 | 0.289472 | 0.057218 | 0.277264 |
| Millmoor Rig | In Planning | unknown | GE | 0.017249 | 0.341743 | 0.017249 | 0.289986 | 0.017249 | 0.277800 |
| Bodinglee | In Planning | unknown | Vestas | 0.012636 | 0.341977 | 0.012636 | 0.290261 | 0.012636 | 0.278087 |
| Rivox Farm | In Planning | unknown | Vestas | 0.073345 | 0.349754 | 0.073345 | 0.299384 | 0.072140 | 0.287292 |
| Westerkirk | S36 planning | unknown | Vestas | | 0.349754 | | 0.299384 | | 0.287292 |
| West Andershaw | S36 planning | unknown | Vestas | | 0.349754 | | 0.299384 | | 0.287292 |
| Brown Rig | S36 planning | unknown | Vestas | | 0.349754 | | 0.299384 | | 0.287292 |
| Oliver Forest | S36 planning | unknown | GE | | 0.349754 | | 0.299384 | | 0.287292 |
| Harestanes West | S36 planning | unknown | GE | | 0.349754 | | 0.299384 | | 0.287292 |
| Liddesdale | S36 planning | unknown | Vestas | | 0.349754 | | 0.299384 | | 0.287292 |
| Hearthstanes | S36 planning | unknown | Vestas | | 0.349754 | | 0.299384 | | 0.287292 |
| **M74 West** | | **unknown** | **Vestas** | 0.012654 | 0.349982 | 0.012654 | 0.299652 | 0.012654 | 0.287571 |

| Key | |
|---|---|
| | Site cannot be built within 0.336nm budget |
| | Site can be built within 0.336nm budget |
| | Site omitted from cumulative calculation as assumed unsuccessful in planning |

Table 12 – Results for queue Scenario 4 – All wind farms included except Faw Side and those in Scoping.



### 6.2.1. Scenario 5 – All wind farms included

| Wind Farm | Status | Manufacturer | Synthetic Model | SIL 1.0 GW | | SIL 2.0 GW | | SIL 2.5 GW | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Amplitude (nm) | Cumulative (nm) | Amplitude (nm) | Cumulative (nm) | Amplitude (nm) | Cumulative (nm) |
| Land SE of Scotston Bank Farm | Operational | unknown | GE | 0.000164 | 0.207559 | 0.000164 | 0.207559 | 0.000164 | 0.207559 |
| Little Hartfell | Approved | Nordex | Nordex | 0.059846 | 0.216014 | 0.042317 | 0.211829 | 0.037850 | 0.210982 |
| Faw Side | In Planning | unknown | Vestas | 0.148296 | 0.262019 | 0.104861 | 0.236363 | 0.093791 | 0.230890 |
| Little Hartfell 2nd Sub | In Planning | Nordex | Nordex | 0.059846 | 0.268766 | 0.042317 | 0.240121 | 0.037850 | 0.233971 |
| Scoop Hill | In Planning | unknown | Vestas | 0.171237 | 0.318681 | 0.121083 | 0.268922 | 0.108300 | 0.257821 |
| Harestanes South | In Planning | unknown | GE | 0.028465 | 0.319950 | 0.028465 | 0.270425 | 0.028465 | 0.259387 |
| Daer | In Planning | unknown | GE | 0.039895 | 0.322428 | 0.039895 | 0.273351 | 0.039895 | 0.262437 |
| Cloich Forest | In Planning | unknown | Vestas | 0.006445 | 0.322492 | 0.006445 | 0.273427 | 0.006445 | 0.262516 |
| Greystone Knowe | In Planning | unknown | Vestas | 0.006266 | 0.322553 | 0.006266 | 0.273499 | 0.006266 | 0.262591 |
| Grayside | In Planning | unknown | GE | 0.027374 | 0.323712 | 0.027374 | 0.274866 | 0.027374 | 0.264014 |
| Callisterhall | In Planning | unknown | Vestas | 0.050983 | 0.327702 | 0.038290 | 0.277520 | 0.034247 | 0.266226 |
| Teviot | In Planning | unknown | Vestas | 0.166147 | 0.367415 | 0.119516 | 0.302161 | 0.106899 | 0.286886 |
| Scawd Law | In Planning | unknown | Vestas | 0.009172 | 0.367530 | 0.009172 | 0.302300 | 0.009172 | 0.287033 |
| Liitle Gala | In Planning | unknown | Vestas | 0.003219 | 0.367544 | 0.003219 | 0.302318 | 0.003219 | 0.287051 |
| Bloch | In Planning | unknown | GE | 0.058260 | 0.372132 | 0.058260 | 0.307880 | 0.057218 | 0.292698 |
| Millmoor Rig | In Planning | unknown | GE | 0.017249 | 0.372532 | 0.017249 | 0.308363 | 0.017249 | 0.293206 |
| Bodinglee | In Planning | unknown | Vestas | 0.012636 | 0.372746 | 0.012636 | 0.308622 | 0.012636 | 0.293478 |
| Rivox Farm | In Planning | unknown | Vestas | 0.073345 | 0.379894 | 0.073345 | 0.317217 | 0.072140 | 0.302214 |
| Westerkirk | S36 planning | unknown | Vestas | 0.091148 | 0.390675 | 0.064451 | 0.323699 | 0.057647 | 0.307663 |
| West Andershaw | S36 planning | unknown | Vestas | 0.006489 | 0.390729 | 0.006489 | 0.323764 | 0.006489 | 0.307732 |
| Brown Rig | S36 planning | unknown | Vestas | 0.091530 | 0.401307 | 0.064722 | 0.330169 | 0.057889 | 0.313129 |
| Oliver Forest | S36 planning | unknown | GE | 0.038533 | 0.403152 | 0.038533 | 0.332410 | 0.038533 | 0.315491 |
| Harestanes West | S36 planning | unknown | GE | 0.022021 | 0.403753 | 0.022021 | 0.333139 | 0.022021 | 0.316259 |
| Liddesdale | S36 planning | unknown | Vestas | 0.059365 | 0.408094 | 0.059365 | 0.338387 | 0.059365 | 0.321782 |
| Hearthstanes | S36 planning | unknown | Vestas | 0.055235 | 0.411815 | 0.040934 | 0.340854 | 0.036612 | 0.323858 |
| **M74 West** | | **unknown** | **Vestas** | 0.012654 | 0.412010 | 0.012654 | 0.341088 | 0.012654 | 0.324105 |

| Key | |
|---|---|
| | Site cannot be built within 0.336nm budget |
| | Site can be built within 0.336nm budget |
| | Site omitted from cumulative calculation as assumed unsuccessful in planning |

Table 13 – Results for queue Scenario 5 – All wind farms included.

# 7. Discussion

## 7.1. Modelled Budget Requirements

The mathematical approach used in this document assesses the level of seismic budget required to build M74 West Wind Farm. The required seismic budget ranges from 0.017515 nm using the current MoD algorithm down to the predicted 0.002549 nm when using data from an SG155 with the background noise removed.

The budget range based on Phase 4 measurements including background is between 0.017074 nm for the no longer available Gamesa Machine and 0.007878 nm for the Senvion Machine.

The availability of budget will be subject to the ongoing work with Scottish Government, MoD and Eskdalemuir Working Group.  It is envisaged that a significant amount of budget will be released. This budget is finite and there will likely be a significant demand for this precious resource. Submitting Planning the application sooner will reduce the risk associated with budget availability.

## 7.2. Modelled SIL Requirements

The Seismic Impact Levels for the M74 West Wind Farm have been assessed for a range of 1 GW to 2.5 GW deployment within the Eskdalemuir region. The 1 GW and 2.5 GW SIL limits represent a turbine SIL of 0.00836 nm.$MW^{-0.5}$ and 0.00528nm·$MW^{-0.5}$ respectively. It should be noted that these figures might change during the SG and MoD signoff process. For the proposed 6.3 MW turbines at M74 West Wind turbine the permitted PSVs are 0.021009 nm and 0.013278 nm (again for 1 GW and 2.5 GW respectively).

All turbines at M74 West Wind Farm are above the Turbine Mitigation Ratio, which would indicate that no mitigation would be required should either a 1GW or 2.5GW SIL be adopted.

## 7.1. Queue Scenarios

Five queue scenarios were assessed based on the worst-case Phase 4 model (in this case the Vestas). SILs of 1.0, 2.0 and 2.5 GW were considered.

For a SIL of 1.0 GW, the only scenario where M74 West Wind Farm falls within the 0.336 nm budget is Scenario 3 (All wind farms except Faw Side, Scoop Hill and Teviot). For a SIL of 2.0 GW, M74 West Wind Farm falls within the budget for all scenarios except for Scenario 5 (All wind farms included). For a SIL of 2.5 GW, M74 West Wind Farm falls within the budget for all scenarios.



# 8. Conclusion

- M74 West Wind Farm, as proposed, represents 22 turbines, each with a power rating of 6.3 MW and has an average distance to the Eskdalemuir seismic array of ~43 km.
- The levels of Seismic Budget required by M74 West Wind Farm have been calculated using the best available science and most up to date data in the public domain.
- M74 West Wind Farm will likely be subject to proposed Seismic Impact Limits being assessed by the Scottish Government.
- The levels of Seismic Impact Limit have been calculated for all available data and Phase 4 measurements.
- The analysis shows that all turbine models could be built within the 1 GW or 2.5 GW Seismic Impact Limit under assessment by the EWG without mitigation.
- Due to the ~43 km distance from the array the M74 West Wind Farm is an efficient use of any available seismic budget.
- If background noise were removed the seismic budget requirement reduces substantially.
- Renewco Power would minimise seismic levels through performing candidate turbine, before and after measurements, should a process be available.
- Five queue scenarios with 1.0 GW, 2.0 GW or 2.5 GW SILs were considered.
- For a SIL of 1.0 GW, the only scenario where M74 West Wind Farm falls within the 0.336 nm budget is Scenario 3 (All wind farms except Faw Side, Scoop Hill and Teviot).
- For a SIL of 2.0 GW, M74 West Wind Farm falls within the budget for all scenarios except for Scenario 5 (All wind farms included).
- For a SIL of 2.5 GW, M74 West Wind Farm falls within the budget for all scenarios.

# 9. Reference Documents

Phase 1: 'Seismic Vibration produced by wind turbines in the Eskdalemuir region Release 2.0 of Substantial Research Project'
Phase 2: 'SGV_202_Tech_Report_v07'
Phase 3: 'SGV 203 Technical report v12.pdf'
Phase4 (Refinement): 'AIFCL-101-Phase4-Rev-v1:- Field audit of Selected sites within the EKA Consultation Zone to support Government Policy Decisions'
Phase 5 (Revision): 'AIFCL-101-Phase5-Rev-v11'
Onshore wind - policy statement refresh 2021: consultative draft

All publicly available documents can be downloaded here