Eskdalemuir Working Group Meeting – 2 December 2020

Introduction

The Scottish Government commissioned Xi Engineering to undertake a technical analysis of the budget calculation tool currently used by MoD. The purpose of this was used to investigate potential headroom within the assumed seismic contribution of existing sites within the area.

The results of the initial phases of this work were presented to EWG in July 2020 and members determined that this work should proceed on to Phase 3 – a desktop based audit of what has been built in the area, and what is in planning, breaking down by site make/model/size of turbines.

Phase 3 was undertaken following that meeting and its results were shared with EWG members.

Presentation of Phase 3

Dr Mark-Paul Buckingham (Xi Engineering) presented '*Desktop Audit of EKA Budget SheetWork' to determine scale of measurement requirements'* to the group. In this presentation the scope of the study was outlined along with the range of scenarios factoring in the revised budget sheet.

Using the updated information, supplied by EWG members and other developers for their sites within the consultation zone, the report concluded that:

1. The current budget management tool used by MoD is no longer suitable given it is designed to stop once the budget is reached and does not take account of projects in the 'waiting list'.
2. Significant additional budget can be released if projects in planning conduct seismic measurements pre and post build – effectively removing background seismic noise and isolating the actual budget use of a site.
3. Taking measurements from 7 additional sites already built within the area, capturing make, model and size, should sufficiently reduce any risk of replacing the existing 'worst-case', standard EKA algorithm.
4. If no increase is made to the 'exclusion zone', the budget is rapidly consumed with minimal MW deployed.

Dr Buckingham noted that the 7 proposed sites had been discussed with David Bowers prior to the meeting and that there was general agreement that this was an appropriate number and selection of sites in the area.

Phase 4 Proposal

Following the summary of Phase 3, Dr Buckingham provided an overview of the requirements for Phase 4:

- Access to each of the 7 identified sites to deploy 4 seismic pits (at each site)
- Wind speed data from sites and confirmation that turbines are in normal operation
- A short shut down for 1 to 2 hours, during a period of high wind speed, to identify and estimate local background noise.

The data obtained from these site measurements would then be factored in to the methodology used in Phases 1, 2 and 3 to provide a modified algorithm effectively replacing the 'worst-case', Standard EKA algorithm and potentially removing the need for candidate measurements.

It was noted that seismic data already conducted by sites in the area could be used as supplement to this work however would not replace the need to measure the 7 sites identified in Phase 3.

Summary of Group Discussions

- SG officials reminded members that the focus of this discussion should remain on the technical analysis presented. Policy considerations are to be tabled in 2021.
- Members queried the level of input MoD had throughout this technical analysis and how this is applied in the real world, raising concerns that there would still be need for the 'worst-case' safety factor. It was clarified that this analysis does not address budget allocation policy and rather presents a series of 'what if' scenarios to be considered. However the work so far has highlighted a lack of alignment between the planning process and the allocation tool currently used by MoD – upon interrogation of the budget sheet it was noted that majority of sites had differences, e.g. micro-siting, number of turbines, etc. On the point around safety factors, Dr Buckingham maintained that this can be reduced accurately through Phase 4 measurements.
- It was also noted that there are concerns the measurement campaign must provide a proper data set and any duration under six months may not be reliable. Dr Buckingham clarified that the methodology used when deploying sensors at a site is robust and, subject to wind conditions, it is possible to achieve a clear data set after approximately one month. Given the number of sites and sensors, this process would take around six months to complete.
- Members questioned, in the event that there were no policy changes, what would the effect of this revised algorithm be? It was highlighted that in Phase 2 it was shown that this would not release enough budget to accommodate any more sites on the budget list.
- Members again considered the effects of planning constraints on the area and its relevance to this technical work, reflecting on the analysis shared by Community Wind Power following the July meeting. It was commented that

the constraints outlined in the analysis shared were no 'hard constraints' and that there will be different appetite among developers as to which they see as being barriers to deployment. There was not consensus among members to pursue this particular work-strand further for the moment.
- It was noted that Little Hart Fell appeared to be missing from Table 2. Dr Buckingham agreed to check this table post meeting.
- Following the Phase 4 presentation, it was clarified that Xi would not require more than 1-2 hours at around 12m/s wind speeds, this would be sufficient to assess the background seismic noise factor.
- Where there are sites in close proximity to another, Xi are confident that they are able to identify which seismic noise attributes to which site. This is another reason why a short shutdown of the site in question is required.
- Timescales for Phase 4 was noted as a concern. Members would be apprehensive to continue this work if it was going to take in excess of 24 months with little to no impact on the 'waiting list'. Dr Buckingham clarified that if funding can be agreed that this would take roughly six months to complete and compile a final report.
- The overall cost of conducting Phase 4 work, as set out by Dr Buckingham, is likely to be around £450,000. The Scottish Government would be minded to contribute to this however clarified that this would need to be majority funded by EWG members.
- It was noted that Scottish Government intend to undertake a refresh of their Energy Strategy and Onshore Wind Policy Statement (OnWPS) over the course of 2021/2022. Scottish Government officials clarified that, in the case of the OnWPS, this is in early scoping stages and therefore detail on what will be included in this is not yet available.

Funding Phase 4:

Members recognised there is potential value in pursuing Phase 4 however it was highlighted that members do not think this can be accurately reflected without also considering budget allocation policy, the exclusion zone and other interdependencies, such as Scottish Government publications (e.g. NPF4, Energy Strategy and OnWPS).

Therefore the Scottish Government suggestion to agree funding by end of January does not seem feasible. It was proposed instead that the group consider all of these factors at once, through programme management tools, and in a format that can clearly be presented to member organisations to consider if/how much they are able to contribute.

Scottish Government officials, with assistance from RUK, agreed to develop a base draft to be considered by members. The funding model for this work has not yet

been determined and it was noted that officials would welcome members thoughts on this.

Members were keen to see these issues tabled as soon as possible, with broad agreement that this could be considered in a meeting to be held in February 2021. This timeframe was agreed factoring in the Christmas break, the programme management work agreed and taking into account the ability of all members to participate at this time.

It was also recognised that keeping to early 2021 would also allow members to meet ahead of the NPF4 position statement consultation deadline of 19th February. It was suggested that there may be value in extending an invitation to Planning & Architecture Division (PAD) colleagues within Scottish Government for the next meeting.

Agreed Actions

- Following the suggestion to set out a PPM style document, outlining the key work to take place over the course of 2021, Scottish Government officials agreed to draft and circulate, before the Christmas break, a skeleton document which EWG members could review and contribute to. This would be done with assistance from RUK.
- Dr Buckingham to review Table 2 of the Phase 3 final report.
- Scottish Government officials to scope a meeting date during the first week of February.
- Scottish Government officials to approach PAD colleagues and invite them to participate in the next EWG meeting.
- All members to provide any comments on the PPM document or the planning constraints analysis provided by Community Wind Power by close Friday 29th January 2021.

Xi Engineering Consultants

Desktop Audit of EKA Budget Sheet

Work to determine scale of measurement requirements

Presented to The Scottish Government

Issue Date: 20/11/2020
Document No: SGV_203_Tech_Report_v12

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Document Summary

This document assumes a knowledge of the previous two studies by Xi Engineering Consultants for the Scottish Government – documents; *Xi Headroom Analysis Report Final (Phase1).pdf* and *Xi Headroom Analysis Report Final (Phase2).pdf.* It is recommended that these reports are read in order to fully understand the work covered in this document.

The detection capabilities of the Eskdalemuir seismic array (EKA) are protected from seismic vibration and the MoD manage a budget spreadsheet which allows data to be collected up to the point at which the seismic budget of 0.336nm is reached.

Having reached this point, further work is necessary to audit the full queue and asses the likely consumed budget based on the current worst-case turbine algorithm and measured actual data.

Several scenarios have been assessed to determine the likely actual seismic budget consumed, should the sites be measured to provide quantitative data for the MoD. Recommendations are made for proposed site measurements and are made based on this desktop audit, in order to release budget through delivery of quantified empirical data.

		Date	Version	Amendment
Originator	Dr MP Buckingham	15/10/2020	v1	Issue
Review	Rebecca Horton	16/10/2020	v2	Review
Review	Dr M P Buckingham	27/10/2020	v3-4	Additional data
Review	Rebecca Horton	29/10/2020	v5-7	Review
Review	Dr M P Buckingham	29/10/2020	V8-9	Final Issue
Review	Dr M P Buckingham	16/11/2020	V10	Issue following EWG feedback
Review	Rebecca Horton	16/11/2020	V11	Review
Review	Dr M P Buckingham	17/11/2020	V12	Review

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1 INTRODUCTION

In order to better assess the current position regarding the Seismic Budget status and likely measurements needed to release budget, this desk-based exercise has been conducted by Xi Engineering. Fundamentally, this desktop audit has been to verify what has been built within a 50km radius of Eskdalemuir Seismic Array (EKA) (as opposed to what had been planned prior to deployment) and what is currently in planning within the area. The output of this exercise is to both understand the current budget position, estimate the additional budget likely to be released if proposed sites are measured, and make recommendations with regards to measurement locations.

The aim of this desk-based study is three-fold:

- Update the Budget Spreadsheet to confirm the current number of turbines built and in planning
- Analyse the updated spreadsheet and use it to confirm the need for a series of measurements to be undertaken in order to release more headroom from the budget. Several scenarios will be assessed in order to robustly demonstrate the need for a field audit of existing sites to progress the re-assessment of the budget while ensuring the protection of the EKA.
- Use the updated spreadsheet to recommend the minimum number and location of measurement sites required to be able to justify the release of further budget

Since the data is collated and held on lengthy Spreadsheets with well over 100 lines of data it is extremely difficult to include these within a word document. This document includes summary tables, and often just the budget including and post Fawside wind farm only. However, several spreadsheets accompany this report for the various scenarios assessed.

2 METHODOLOGY

2.1 Desktop Audit Process

Best endeavours have been used to gather and collate data from members of the Eskdalmuir Working Group (EWG), and developers and owner operators who are not members of the EWG. Both Xi Engineering and the Scottish Government are grateful for the industry's engagement in this process.

The foundation of this desktop Audit has been the MoD's spreadsheet up to and including Fawside Wind farm. Subsequent wind farms have been added based on date of submission order in line with current MoD practises.

This desktop study has produced a revised budget sheet with the following inputs and assumptions;

- As built information – size (rotor diameter & hub height), make, model, number of turbines and locations
- Additional sites in planning have been added to the queue using the submission date and the current 'first come first served' approach adopted by the MoD

2.1.1 SCENARIOS ASSESSED

With a view to demonstrating the definite need for a measurement of existing sites in order to release budget headroom, several scenarios have been assessed using the now updated budget. These scenarios will show, in different ways, either the point where the budget is consumed or the amount of headroom that could be released if different and more accurate input data is used. It is expected that all scenarios will show that, with more empirical data, it is very likely that budget will be released. They will also help to determine which measurements should take place. These scenarios are not intended to propose alternative methods of managing the queue, solely to show how much budget becomes available on a 'what if' basis. Most scenarios assessed contain both initial sites and resubmitted sites, each calculated as an independent site. This is intentional.

The scenarios modelled are as follows;

A. Current budget with sites added to queue. i.e. past the consumption of the budget based on planning information received- Using current 'worst case' algorithm for 'as built' turbines and those in queue
B. Using a mixed model with 'worst case' and measured data where possible (i.e. Siemens 2.3 for Clyde, Senvion data for Middle Muir data etc)
C. Using Middle Muir data to represent all turbines in queue
D. Scenarios B with sites with turbines located within 15km of the array excluded
E. Scenario C with sites with turbines located within 15km of the array excluded
F. Same as E except all sites post original budget consumption at Fawside using Middle Muir with background levels mathematically removed. (see note on background removal)
G. Same as F except initial submissions for sites that have been resubmitted have been excluded to prevent duplication (this is a mathematical approach to prevent duplication and is in no way intended to suggest reordering of sites)

2.1.2 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 EKA algorithm includes a noise floor based on the measurements of Clyde wind farm.

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. 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. The authors note that the approach of removing all background noise from the algorithm is contrary to the precautionary approach used to design the worst-case 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 further understanding of how close to this best-case scenario results will be.

2.2 Analysis of Scenarios

The final calculations to determine which sites should be measured are based on both nm per turbine and make model and size. To better understand the seismic signature of different turbines we need to capture all manufacturers and ensure we are not using a single data point for those that have already been measured.

2.3 Measurement Audit Recommendations

Following the analysis of the scenarios, measurement recommendations will be made. These will take into consideration: location, manufacturer, size of budget allocation, whether the site has already been measured, proportion of turbines across the entirety of the EKA and corresponding representation in the audit, accessibility and alternatives.

3 RESULTS

3.1 Scenario Results

NOTE – for all the scenarios the following windfarms have been removed from the list as they can no longer obtain planning for the original application lodged;

1. Birneyknowe Windfarm submitted 14th May 2014, 15 turbines
2. Harryburn Windfarm submitted 8th June 2016, 17 turbines
3. Barrelaw Windfarm submitted 14th September, 7 turbines

NOTE – all small wind turbines under 1MW have NOT been audited with respect to location or size due to the difficulty of contacting owners and their minimal contribution to the budget.

NOTE – Scenarios A through F contain both initial sites and resubmitted sites, each calculated as an independent site. This is intentional as there is significant variation in the route these sites have reached planning and ultimately the queuing system. Scenario G shows what the impact would be on the cumulative budget assuming that there is no replication of sites and that the resubmissions are included as per this audit.

3.1.1 SCENARIO A – WORST CASE ALGORITHM/CURRENT BUDGET

Current budget with sites added to queue. i.e. past the consumption of the budget based on planning information received – all using standard 'Worst Case algorithm'

Site #	Wind_Farm	Operator/Developer	Date of submission	Number_of_ Turbines	Manufacturer	MW rating	Total MW	Size	StandardEKA	Selection	Budget Standard (nm)	Cum Total Scenario Model (nm)
114	Cliffhope	Community Windpower	29/92017	46	unknown	7.00	322.0	125/150	0.06528	StandardEKA	0.27619	0.21852
115	Faw Side	Community Windpower	11/01/2018	45	unknown	7.00	315.0	125/150	0.65524	StandardEKA	0.71107	0.69072
116	Little Heart Fell	Energiekontor	1/2/2018	9	Nordex	5.70	51.3	105/149	0.15546	Craig	0.72787	0.70184
117	Twentyshilling hill revised	Statkraft	14/2/2018	9	Vestas	4.20	37.8	81.5/117	0.00397	StandardEKA	0.72788	0.70185
118	Daer	RWE	11/12/2018	15	unknown	5.80	87.0	102.5/155	0.05827	StandardEKA	0.73021	0.70426
119	Scoop Hill	Community Windpower	8/5/2019	78	unknown	7.00	546.0	125/150	0.85383	StandardEKA	1.12349	1.10680
120	Callisterhall	Epower	4/10/2019	13	Vestas	6.00	78.0	155/150	0.10932	StandardEKA	1.12880	1.11219
121	Priestgill resub	Muirhall Energy	2/12/2019	7	Vestas	5.60	39.2	125/150	0.01434	StandardEKA	1.12889	1.11228
122	Westerkirk	Oakridge Energy	7/1/2020	20	unknown	4.00	80.0	120/136	0.47780	StandardEKA	1.22584	1.21056
123	Loganhead resub	Muirhall Energy	23/3/2020	8	Nordex	4.80	38.4	113.4/133	0.09898	Craig	1.22983	1.21310
124	Hopsrig resub	Muirhall Energy	23/3/2020	12	Vestas	4.15	49.8	125/150	0.19493	StandardEKA	1.24518	1.22866
125	Harestaines South	Scottish Power	3/04/2020	8	unknown	5.50	44.0	125/150	0.04141	StandardEKA	1.24587	1.22936
126	Greystone Knowe	Coriolis	15/5/2020	15	unknown	4.50	67.5	105/150	0.00853	StandardEKA	1.24590	1.22939
127	Whitelaw resub	Baywa	22/6/2020	12	unknown	4.20	50.4	136.5/117	0.05914	StandardEKA	1.24730	1.23081
128	Scawd Law	Fred Olsen	31/07/2020	12	unknown	4.20	50.4	120/180	0.01272	StandardEKA	1.24736	1.23088
129	Grayside	ARCUS	24/8/2020	25	unknown	6.60	165.0	122.5/155	0.04621	StandardEKA	1.24822	1.23175

Figure 1 Final rows of Scenario A and B cumulative budget nm

3.1.2 SCENARIO B – REPRESENTATIVE TURBINE/MIXED MODEL

This scenario uses a mixed model to predict the budget levels. It uses measured data where the data is available for the same manufacturer type i.e. Siemens 2.3 from Clyde for any Siemens machine - Senvion data from Middle Muir data for Senvion or Nordex from Craig data. For manufacturers without data (GE, Enercon, Vestas Games, SGRE or EWT) the worst-case algorithm is used. **NOTE** – it has not been shown from

measurements that this approach is representative as there is only a single point of data for each manufacturer.

3.1.3 SCENARIO C - ALL TURBINES INCLUDING <1MW ASSUMED RECENT DATA AS PER MIDDLEMUIR

All sites and small turbines <1MW in the region have been assumed to have the same seismic levels as the data gathered from Middlemuir as this represents the most recent installation within the region and the seismic levels lie between the measured data of the siemens at Clyde and the Nordex at Craig. .

Site #	Wind_Farm	Operator/Developer	Date of submission	Number_of_ Turbines	Manufacturer	MW rating	Total MW	Size	StandardEKA	Selection	Budget Standard (nm)	Cum Total Scenario Model (nm)
114	Cliffhope	Community Windpower	29/92017	46	unknown	7.00	322.0	125/150	0.06528	Middlemuir	0.27619	0.19889
115	Faw Side	Community Windpower	11/01/2018	45	unknown	7.00	315.0	125/150	0.65524	Middlemuir	0.71107	0.51305
116	Little Heart Fell	Energiekontor	1/2/2018	9	Nordex	5.70	51.3	105/149	0.15546	Middlemuir	0.72787	0.52466
117	Twentyshilling hill revised	Statkraft	14/2/2018	9	Vestas	4.20	37.8	81.5/117	0.00397	Middlemuir	0.72788	0.52467
118	Daer	RWE	11/12/2018	15	unknown	5.80	87.0	102.5/155	0.05827	Middlemuir	0.73021	0.52626
119	Scoop Hill	Community Windpower	8/5/2019	78	unknown	7.00	546.0	125/150	0.85383	Middlemuir	1.12349	0.81003
120	Callisterhall	Epower	4/10/2019	13	Vestas	6.00	78.0	155/150	0.10932	Middlemuir	1.12880	0.81361
121	Priestgill resub	Muirhall Energy	2/12/2019	7	Vestas	5.60	39.2	125/150	0.01434	Middlemuir	1.12889	0.81368
122	Westerkirk	Oakridge Energy	7/1/2020	20	unknown	4.00	80.0	120/136	0.47780	Middlemuir	1.22584	0.88625
123	Loganhead resub	Muirhall Energy	23/3/2020	8	Nordex	4.80	38.4	113.4/133	0.09898	Middlemuir	1.22983	0.88902
124	Hopsrig resub	Muirhall Energy	23/3/2020	12	Vestas	4.15	49.8	125/150	0.19493	Middlemuir	1.24518	0.89962
125	Harestaines South	Scottish Power	3/04/2020	8	unknown	5.50	44.0	125/150	0.04141	Middlemuir	1.24587	0.90009
126	Greystone Knowe	Coriolis	15/5/2020	15	unknown	4.50	67.5	105/150	0.00853	Middlemuir	1.24590	0.90012
127	Whitelaw resub	Baywa	22/6/2020	12	unknown	4.20	50.4	136.5/117	0.05914	Middlemuir	1.24730	0.90109
128	Scawd Law	Fred Olsen	31/07/2020	12	unknown	4.20	50.4	120/180	0.01272	Middlemuir	1.24736	0.90114
129	Grayside	ARCUS	24/8/2020	25	unknown	6.60	165.0	122.5/155	0.04621	Middlemuir	1.24822	0.90174

Figure 2 Final rows of Scenario A and C cumulative budget nm

3.1.4 SCENARIO D – 15KM EXCLUSION ZONE/MIXED MODEL

This scenario excludes sites with turbines within 15Km of the array and uses a mixed model to predict the budget levels. It uses measured data where the data is available for the same manufacturer type i.e. Siemens 2.3 from Clyde for any Siemens machine - Senvion data from Middle Muir data for Senvion or Nordex from Craig data. For manufacturers without data (GE, Enercon, Vestas Games, SGRE or EWT) the worst-case algorithm is used.

Site #	Wind_Farm	Operator/Developer	Date of submission	Number_of_ Turbines	Manufacturer	MW rating	Total MW	Size	StandardEKA	Selection	Cum Total Budget Standard (nm)	Cum Total Scenario Model (nm)
114	Cliffhope	Community Windpower	29/92017	46	unknown	7.00	322.0	125/150	0.06528	StandardEKA	0.27619	0.21852
115	Faw Side	Community Windpower	11/01/2018	45	unknown	7.00	315.0	125/150	0.65524	Excluded	0.71107	0.21852
116	Little Heart Fell	Energiekontor	1/2/2018	9	Nordex	5.70	51.3	105/149	0.15546	Craig	0.72787	0.25146
117	Twentyshilling hill revised	Statkraft	14/2/2018	9	Vestas	4.20	37.8	81.5/117	0.00397	StandardEKA	0.72788	0.25149
118	Daer	RWE	11/12/2018	15	unknown	5.80	87.0	102.5/155	0.05827	StandardEKA	0.73021	0.25815
119	Scoop Hill	Community Windpower	8/5/2019	78	unknown	7.00	546.0	125/150	0.85383	Excluded	1.12349	0.25815
120	Callisterhall	Epower	4/10/2019	13	Vestas	6.00	78.0	155/150	0.10932	StandardEKA	1.12880	0.28034
121	Priestgill resub	Muirhall Energy	2/12/2019	7	Vestas	5.60	39.2	125/150	0.01434	StandardEKA	1.12889	0.28071
122	Westerkirk	Oakridge Energy	7/1/2020	20	unknown	4.00	80.0	120/136	0.47780	Excluded	1.22584	0.28071
123	Loganhead resub	Muirhall Energy	23/3/2020	8	Nordex	4.80	38.4	113.4/133	0.09898	Craig	1.22983	0.29147
124	Hopsrig resub	Muirhall Energy	23/3/2020	12	Vestas	4.15	49.8	125/150	0.19493	StandardEKA	1.24518	0.35065
125	Harestaines South	Scottish Power	3/04/2020	8	unknown	5.50	44.0	125/150	0.04141	StandardEKA	1.24587	0.35308
126	Greystone Knowe	Coriolis	15/5/2020	15	unknown	4.50	67.5	105/150	0.00853	StandardEKA	1.24590	0.35319
127	Whitelaw resub	Baywa	22/6/2020	12	unknown	4.20	50.4	136.5/117	0.05914	StandardEKA	1.24730	0.35810
128	Scawd Law	Fred Olsen	31/07/2020	12	unknown	4.20	50.4	120/180	0.01272	StandardEKA	1.24736	0.35833
129	Grayside	ARCUS	24/8/2020	25	unknown	6.60	165.0	122.5/155	0.04621	StandardEKA	1.24822	0.36130

Figure 3 Final rows of Scenario A and D cumulative budget nm

3.1.5 SCENARIO E - 15KM EXCLUSION ZONE/ ASSUMPTIONS USING MIDDLE MUIR DATA

This scenario excludes sites with turbines within 15Km. All sites and small turbines <1MW in the region have been assumed to have the same seismic levels as the data gathered from Middlemuir as this represents the most recent installation within the region and the seismic levels lie between the measured data of the siemens at Clyde and the Nordex at Craig. .

Site #	Wind_Farm	Operator/Developer	Date of submission	Number_of_ Turbines	Manufacturer	MW rating	Total MW	Size	StandardEKA	Selection	Budget Standard (nm)	Cum Total Scenario Model (nm)
114	Cliffhope	Community Windpower	29/92017	46	unknown	7.00	322.0	125/150	0.06528	Middlemuir	0.27619	0.19889
115	Faw Side	Community Windpower	11/01/2018	45	unknown	7.00	315.0	125/150	0.65524	Excluded	0.71107	0.19889
116	Little Heart Fell	Energiekontor	1/2/2018	9	Nordex	5.70	51.3	105/149	0.15546	Middlemuir	0.72787	0.22716
117	Twentyshilling hill revised	Statkraft	14/2/2018	9	Vestas	4.20	37.8	81.5/117	0.00397	Middlemuir	0.72788	0.22718
118	Daer	RWE	11/12/2018	15	unknown	5.80	87.0	102.5/155	0.05827	Middlemuir	0.73021	0.23083
119	Scoop Hill	Community Windpower	8/5/2019	78	unknown	7.00	546.0	125/150	0.85383	Excluded	1.12349	0.23083
120	Callisterhall	Epower	4/10/2019	13	Vestas	6.00	78.0	155/150	0.10932	Middlemuir	1.12880	0.24310
121	Priestgill resub	Muirhall Energy	2/12/2019	7	Vestas	5.60	39.2	125/150	0.01434	Middlemuir	1.12889	0.24333
122	Westerkirk	Oakridge Energy	7/1/2020	20	unknown	4.00	80.0	120/136	0.47780	Excluded	1.22584	0.24333
123	Loganhead resub	Muirhall Energy	23/3/2020	8	Nordex	4.80	38.4	113.4/133	0.09898	Middlemuir	1.22983	0.25322
124	Hopsrig resub	Muirhall Energy	23/3/2020	12	Vestas	4.15	49.8	125/150	0.19493	Middlemuir	1.24518	0.28827
125	Harestaines South	Scottish Power	3/04/2020	8	unknown	5.50	44.0	125/150	0.04141	Middlemuir	1.24587	0.28973
126	Greystone Knowe	Coriolis	15/5/2020	15	unknown	4.50	67.5	105/150	0.00853	Middlemuir	1.24590	0.28981
127	Whitelaw resub	Baywa	22/6/2020	12	unknown	4.20	50.4	136.5/117	0.05914	Middlemuir	1.24730	0.29280
128	Scawd Law	Fred Olsen	31/07/2020	12	unknown	4.20	50.4	120/180	0.01272	Middlemuir	1.24736	0.29295
129	Grayside	ARCUS	24/8/2020	25	unknown	6.60	165.0	122.5/155	0.04621	Middlemuir	1.24822	0.29481

Figure 4 Final Rows of Scenarios A and E nm

3.1.6 SCENARIO F - 15KM EXCLUSION ZONE/ MIDDLE MUIR ASSUMPTIONS WITHOUT BACKGROUND

This scenario excludes sites with turbines within 15Km. All sites post original budget consumption at Fawside have the same seismic levels as the data gathered from Middlemuir without background. There is potential

for further budget if all sites not actually constructed conducted before and after measurements, however, this is likely offset by the 'best-case' nature of the background noise removal.

Site #	Wind_Farm	Operator/Developer	Date of submission	Number_of_ Turbines	Manufacturer	MW rating	Total MW	Size	StandardEKA	Selection	Cum Total Budget Standard (nm)	Cum Total Scenario Model (nm)
114	Cliffhope	Community Windpower	29/92017	46	unknown	7.00	322.0	125/150	0.06528	Middlemuir	0.27619	0.19889
115	Faw Side	Community Windpower	11/01/2018	45	unknown	7.00	315.0	125/150	0.65524	Excluded	0.71107	0.19889
116	Little Heart Fell	Energiekontor	1/2/2018	9	Nordex	5.70	51.3	105/149	0.15546	MM NB	0.72787	0.21274
117	Twentyshilling hill revised	Statkraft	14/2/2018	9	Vestas	4.20	37.8	81.5/117	0.00397	MM NB	0.72788	0.21275
118	Daer	RWE	11/12/2018	15	unknown	5.80	87.0	102.5/155	0.05827	MM NB	0.73021	0.21472
119	Scoop Hill	Community Windpower	8/5/2019	78	unknown	7.00	546.0	125/150	0.85383	Excluded	1.12349	0.21472
120	Callisterhall	Epower	4/10/2019	13	Vestas	6.00	78.0	155/150	0.10932	MM NB	1.12880	0.22114
121	Priestgill resub	Muirhall Energy	2/12/2019	7	Vestas	5.60	39.2	125/150	0.01434	MM NB	1.12889	0.22128
122	Westerkirk	Oakridge Energy	7/1/2020	20	unknown	4.00	80.0	120/136	0.47780	Excluded	1.22584	0.22128
123	Loganhead resub	Muirhall Energy	23/3/2020	8	Nordex	4.80	38.4	113.4/133	0.09898	MM NB	1.22983	0.23211
124	Hopsrig resub	Muirhall Energy	23/3/2020	12	Vestas	4.15	49.8	125/150	0.19493	MM NB	1.24518	0.25075
125	Harestaines South	Scottish Power	3/04/2020	8	unknown	5.50	44.0	125/150	0.04141	MM NB	1.24587	0.25158
126	Greystone Knowe	Coriolis	15/5/2020	15	unknown	4.50	67.5	105/150	0.00853	MM NB	1.24590	0.25163
127	Whitelaw resub	Baywa	22/6/2020	12	unknown	4.20	50.4	136.5/117	0.05914	MM NB	1.24730	0.25313
128	Scawd Law	Fred Olsen	31/07/2020	12	unknown	4.20	50.4	120/180	0.01272	MM NB	1.24736	0.25321
129	Grayside	ARCUS	24/8/2020	25	unknown	6.60	165.0	122.5/155	0.04621	MM NB	1.24822	0.25433

Figure 5 Final Rows of Scenarios A and F nm

3.1.7 SCENARIO G - 15KM EXCLUSION ZONE/ MIDDLE MUIR ASSUMPTIONS WITHOUT BACKGROUND AND EXCLUSION OF INITIAL SITES THAT HAVE BEEN RESUBMITTED

This scenario excludes sites with turbines within 15Km. All sites not built in the region have been assumed to have the same seismic levels as the data gathered from Middlemuir without background. There is potential for further budget if all sites not actually constructed conducted before and after measurements, however, this is likely offset by the 'best-case' nature of the background noise removal. Sites which have been resubmitted have had the initial submission excluded. This is solely to optimise the mathematical output and is in no way intended to suggest a reordering of the list or loss of place in the budget queue.

Site #	Wind_Farm	Operator/Developer	Date of submission	Number_of_ Turbines	Manufacturer	MW rating	Total MW	Size	StandardEKA	Selection	Cum Total Budget Standard (nm)	Cum Total Scenario Model (nm)
114	Cliffhope	Community Windpower	29/92017	46	unknown	7.00	322.0	125/150	0.06528	Middlemuir	0.27619	0.16785
115	Faw Side	Community Windpower	11/01/2018	45	unknown	7.00	315.0	125/150	0.65524	Excluded	0.71107	0.16785
116	Little Heart Fell	Energiekontor	1/2/2018	9	Nordex	5.70	51.3	105/149	0.15546	MM NB	0.72787	0.18405
117	Twentyshilling hill revised	Statkraft	14/2/2018	9	Vestas	4.20	37.8	81.5/117	0.00397	MM NB	0.72788	0.18407
118	Daer	RWE	11/12/2018	15	unknown	5.80	87.0	102.5/155	0.05827	MM NB	0.73021	0.18634
119	Scoop Hill	Community Windpower	8/5/2019	78	unknown	7.00	546.0	125/150	0.85383	Excluded	1.12349	0.18634
120	Callisterhall	Epower	4/10/2019	13	Vestas	6.00	78.0	155/150	0.10932	MM NB	1.12880	0.19370
121	Priestgill resub	Muirhall Energy	2/12/2019	7	Vestas	5.60	39.2	125/150	0.01434	MM NB	1.12889	0.19386
122	Westerkirk	Oakridge Energy	7/1/2020	20	unknown	4.00	80.0	120/136	0.47780	Excluded	1.22584	0.19386
123	Loganhead resub	Muirhall Energy	23/3/2020	8	Nordex	4.80	38.4	113.4/133	0.09898	MM NB	1.22983	0.20614
124	Hopsrig resub	Muirhall Energy	23/3/2020	12	Vestas	4.15	49.8	125/150	0.19493	MM NB	1.24518	0.22692
125	Harestaines South	Scottish Power	3/04/2020	8	unknown	5.50	44.0	125/150	0.04141	MM NB	1.24587	0.22784
126	Greystone Knowe	Coriolis	15/5/2020	15	unknown	4.50	67.5	105/150	0.00853	MM NB	1.24590	0.22789
127	Whitelaw resub	Baywa	22/6/2020	12	unknown	4.20	50.4	136.5/117	0.05914	MM NB	1.24730	0.22955
128	Scawd Law	Fred Olsen	31/07/2020	12	unknown	4.20	50.4	120/180	0.01272	MM NB	1.24736	0.22964
129	Grayside	ARCUS	24/8/2020	25	unknown	6.60	165.0	122.5/155	0.04621	MM NB	1.24822	0.23087

Figure 6 Final Rows of Scenarios A and G nm

Scenario	Scenario Detail	Total Cumulative Budget (nm)
A	Worst Case algorithm/current Budget	**1.24822**
B	Representative turbine/Mixed Model	**1.23175**
C	All turbines assumed Middlemuir	**0.90174**
D	15km/Mixed Model	**0.36130**
E	15km Assuming Middlemuir	0.29481
F	15km assuming Middlemuir no background	0.25433
G	As per F without resubmission duplication	0.23087

Table 1 Scenario Summary total nm (red text denotes budget exceeded)

Having considered the above seven scenarios, it is clear that, with more information input into the budget spreadsheet, it is very likely that further headroom could be released. In order to input more information into the budget spreadsheet, a measurement campaign is recommended to better determine the actual seismic output of existing sites in the EKA. It is also recommended that in order to avoid any future over or under estimations that subsequent developments are measured both pre and post deployment to maximise deployment potential.

3.2 Analysis of Budget Spreadsheet and Turbines

3.2.1 SITES BY BUDGET REQUIREMENT

In order to assess what type of measurement should take place, the sites should be considered initially in order of budget size. This assessment will help to determine the which sited should be measured as well as the number. This is particularly key, as the sites with the largest budget allocation, if following the logic of the above scenarios, will have the most budget headroom to contribute. This allows the assessment to consider which sites could be the most impactful in terms of budget re-assessment.

The following are the all sites with a budget requirement over 0.01nm starting from largest to smallest nm requirement.

Budget ordered by nm	Site #	Wind_Farm	Number_of_ Turbines	Total MW	Size	StandardEKA
1	119	Scoop Hill	78	546.0	125/150	0.85383
2	115	Faw Side	45	315.0	125/150	0.65524
3	122	Westerkirk	20	80.0	120/136	0.47780
4	126	Hopsrig resub	12	49.8	125/150	0.19493
5	103	Crossdykes	10	48.0	110/133	0.14086
6	110	Hopsrig	12	42.0	89.5/101	0.11239
7	120	Callisterhall	13	78.0	155/150	0.10932
8	125	Loganhead resub	8	38.4	113.4/133	0.09898
9	10	Ewe Hill	22	50.6	63.3/93	0.08858
10	105	Loganhead	8	25.6	75/120	0.08008
11	5	Clyde	152	349.6	82/93	0.07399
12	114	Cliffhope	46	322.0	125/150	0.06528
13	127	Whitelaw resub	12	50.4	136.5/117	0.05914
14	118	Daer	15	87.0	102.5/155	0.05827
15	6	Harestanes	68	136.0	78/87	0.05714
16	92	Whitelaw Brae	14	58.8	133.5/117	0.04898
17	52	Clyde Extension	54	162.0	89.5/74.5	0.04801
18	128	Grayside	25	165.0	122.5/155	0.04621
19	108	Wauchope & Newcastleton Forests	90	306.0	80/104	0.04199
20	123	Harestaines South	8	44.0	125/150	0.04141
21	4	Langhope Rig	10	15.0	80/82.5	0.04029
22	56	Solwaybank	15	30.0	76.5/100	0.03748
23	81	Windy Edge	9	202.5		0.03572
24	8	Minsca	16	36.8	80/82.4	0.03364
25	18	Minnygap	10	20.0	75/99.8	0.03168
26	2	Carlesgill	5	12.5	59/70	0.03136
27	111	Pines Burn	12	39.6		0.03108
28	12	Middle Hill - Glenkerie	11	22.0	78/80	0.01621
29	19	Carlesgill Ext	1	2.5	59/82	0.01572
30	78	Lion Hill	4	9.2	70.5/112	0.01472
31	121	Priestgill resub	7	39.2	125/150	0.01434
32	109	North Lowther	30	150.0	149/133	0.01347
33	129	Scawd Law	12	50.4	120/4180	0.01272
34	80	Crookedstane Farm	4	9.2	70.5/112	0.01182
35	76	Glenkerie Extension	6	15.0	59/82	0.01142
36	7	Dalswinton	15	30.0	80/82	0.01026
37	112	Priestgill	7	22.4		0.01015

Table 2 Sites by most budget requirement for all above 0.001nm

3.2.2 SITES MW PER NANOMETER MW/NM

A further analysis to determine which sites should be considered takes into account not only the budget allocation, but the budget allocation order in nm/MW. This analysis gives another view on which types of sites could be most impactful in terms of budget re-assessment.

The following is the top 36 sites from Table 2 ordered by nm requirement per MW. This table should be viewed with caution as at the planning stage multiple sites are predicting extremely large capacity turbines at relatively small sizes which offsets some of the sites' position in the table.

Budget ordered by nm	Site #	Wind_Farm	Total MW	StandardEKA	nm/MW
1	19	Carlesgill Ext	2.5	0.01572	0.006288
2	122	Westerkirk	80.0	0.47780	0.005972
3	126	Hopsrig resub	49.8	0.19493	0.003914
4	105	Loganhead	25.6	0.08008	0.003128
5	103	Crossdykes	48.0	0.14086	0.002935
6	4	Langhope Rig	15.0	0.04029	0.002686
7	110	Hopsrig	42.0	0.11239	0.002676
8	125	Loganhead resub	38.4	0.09898	0.002578
9	2	Carlesgill	12.5	0.03136	0.002509
10	115	Faw Side	315.0	0.65524	0.00208
11	10	Ewe Hill	50.6	0.08858	0.001751
12	78	Lion Hill	9.2	0.01472	0.0016
13	18	Minnygap	20.0	0.03168	0.001584
14	119	Scoop Hill	546.0	0.85383	0.001564
15	120	Callisterhall	78.0	0.10932	0.001402
16	80	Crookedstane Farm	9.2	0.01182	0.001285
17	56	Solwaybank	30.0	0.03748	0.001249
18	127	Whitelaw resub	50.4	0.05914	0.001173
19	123	Harestaines South	44.0	0.04141	0.000941
20	8	Minsca	36.8	0.03364	0.000914
21	92	Whitelaw Brae	58.8	0.04898	0.000833
22	111	Pines Burn	39.6	0.03108	0.000785
23	76	Glenkerie Extension	15.0	0.01142	0.000761
24	12	Middle Hill - Glenkerie	22.0	0.01621	0.000737
25	118	Daer	87.0	0.05827	0.00067
26	112	Priestgill	22.4	0.01015	0.000453
27	6	Harestanes	136.0	0.05714	0.00042
28	121	Priestgill resub	39.2	0.01434	0.000366
29	7	Dalswinton	30.0	0.01026	0.000342
30	52	Clyde Extension	162.0	0.04801	0.000296
31	128	Grayside	165.0	0.04621	0.00028
32	129	Scawd Law	50.4	0.01272	0.000252
33	5	Clyde	349.6	0.07399	0.000212
34	114	Cliffhope	322.0	0.06528	0.000203
35	81	Windy Edge	202.5	0.03572	0.000176
36	108	Wauchope & Newcastleton Forests	306.0	0.04199	0.000137
37	109	North Lowther	150.0	0.01347	8.98E-05

Table 3 Sites ordered nm per MW

3.2.3 TURBINE TYPE AND SIZE

Turbine type and size also need to be considered when determining sites for measurement.

The following is a breakdown of the manufacturer MW output and Sum of MW by manufacturer. It should be noted that a number of these turbines are in planning and not as yet erected.

Manufacturer	MW rating	Sum of Number_of_Turbines	Sum of Total MW
⊟Siemens	3.00	54	162
	2.30	193	443.9
	3.50	12	42
Siemens Total		**259**	**647.9**
⊟GE	3.20	15	48
	1.50	10	15
GE Total		**25**	**63**
⊟Nordex	1.30	24	31.2
	2.50	5	12.5
	2.00	10	20
	3.30	12	39.6
	22.50	9	202.5
	4.80	30	144
	5.70	9	51.3
Nordex Total		**99**	**501.1**
⊟Vestas	2.30	8	18.4
	2.00	26	52
	3.30	11	36.3
	2.20	6	13.2
	4.20	18	75.6
	3.45	9	31.05
	6.00	13	78
	5.60	7	39.2
	4.15	12	49.8
Vestas Total		**110**	**393.55**
⊟Senvion	2.50	6	15
	2.00	34	68
	3.40	15	51
Senvion Total		**55**	**134**
⊟Gamesa	2.00	68	136
Gamesa Total		**68**	**136**
⊞unknown		500	2211.0397
⊟Enercon	2.50	1	2.5
Enercon Total		**1**	**2.5**
⊟EWT	0.50	1	0.5
EWT Total		**1**	**0.5**
⊟(blank)	(blank)		
(blank) Total			
Grand Total		**1118**	**4089.5897**

Table 4 Breakdown of manufacturer and MW within the region

3.3 Measurement Audit Recommendations

Care has been taken to assess the sites within the region and the aim of this work is to determine how to measure the minimum number of sites whilst freeing up as much budget as possible. Whilst this is not an exact science the following assumptions have been made to determine how many sites require measurement;

- Only the sites that are currently installed are considered, future sites should likely have both a before and after measurement.
- It is necessary to capture data from all manufacturer machines
- Turbines with especially large budget allocation (again only built) must be measured to release the most budget.
- No replication of measurements for sites already measured (with the exception of Carlesgill (Craig) as it has had a further 2 machines installed, again which have not yet been measured).
- Obtaining more than one data set per manufacturer for the largest three by deployment number – Siemens, Nordex and Vestas respectively (some data is already available, through previous measurements, eg Middle Muir/Seimens).
- If access to sites is not possible alternatives could be sought

	Sites for measurement	Rationale	Manufacturer
1	Ewe Hill	Siemens are the most prolific turbine within the region and to not rely on a single data point Ewe Hill represents the largest budget allocation for a siemens machines.	Siemens
2	Carlesgil and extension	One of the largest nm/MW sites and has now had additional 2 Enercon machines added which have yet to be measured	Nordex/Enercon
3	Solwaybank	There is no publicly available data for Vestas currently and Solway Bank has the largest budget requirement for a Vestas machine	Vestas
4	Harestaines	No data available for Gamesa machine and this site has largest budget for Gamesa machines	Gamesa
5	Langhope rig	There is no data for GE turbines and this site has the largest allocation for any GE machine	GE
6	Middlehill	Vestas with second highest budget allocation	Vestas
7	MinnyGap	Nordex second data point second largest nm/Mw after Carelsgill	Nordex

Table 5 Proposed sites to conduct measurement audit

NOTE – This list of proposed measurement sites has not yet been discussed with the MoD and could be subject to change.

Though the number of recommended measurement site is short, due to the distribution of turbines and budget allocation, combined with the suggested new pre & post deployment methodology, the above list or an approved version of it should adequately represent the sites with turbines currently installed in the consultation zone.

4 DISCUSSION

This exercise has highlighted a few potential improvements that could be made to the management of wind turbine development within the region specifically (but not exhaustively);

- Ensuring developers issue data to the MoD (or the organisation managing the budget) post construction – data was found to be inconsistent between data recorded in the budget spreadsheet including number of turbines, location and size of machines. All of these are crucial to understanding the level of seismic vibration from a turbine.
- Having an appropriate tool for the management of the budget. The Excel spreadsheet currently used will not calculate or maintain windfarms post budget saturation. This is how the tool was designed; however, it is clear that a more advanced tool is necessary – especially when data verification, amendments to site planning and repowering is considered.
- The need for a system which has an auditable dual signoff is needed to prevent inaccurate data entry and verification.

It is clear from looking at sites with most budget allocated that the trend to deploy larger turbine sizes has a significant impact on the budget requirement as both the Standard EKA algorithm and measured data are normalised against the size of the turbines.

The effect of removing background noise (albeit on a best-case scenario for this exercise) is significant. As with noise measurements it is standard to measure both before and after in order to remove noise not attributable to the turbines. The budget calculations above clearly show a vast improvement if this process were to be followed, even if the reduction were even half the size it still represents a significant additional deployment in the region. As this process is yet to be conducted in practice with the MoD seismic experts (the principle of this approach is agreed) it is likely that the initial background measurements would take ~ 6 months duration to be sure of a statistically significant data set. However, the likelihood is, once several have been conducted it could be possible to shorten this period to a few months assuming suitable wind conditions on site. To maximise deployment in the area it is recommended that all sites that have yet to be built are measured pre construction. It is also possible to measure during construction phases BUT before towers are erected. Data during site activities (daytime) would be excluded from the data set but all times in which there is no site activity could be used as long as the towers have not been erected.

This practice of before and after measurement also presents a solution to repowering of sites with larger turbines. As measuring background can release in the region of 30% additional budget per site- if sites were to be measured post decommissioning and pre reinstatement – significant additional budget would be freed up for the site, potentially allowing a similar number of turbines at much larger rotor diameter and height.

5 CONCLUSIONS

- A desktop audit has been conducted of all sites built, consented and in planning within 50km of the Eskdalemuir seismic array and the budget spreadsheet brought up to date
- This audit has highlighted the need for developers to issue as built information for the safeguarding of the array. (Location micro siting and turbine number, heights and rotor diameter would be necessary)
- A series of spreadsheets accompany this report for the scenarios A through G, in order to show the need for more accurate data to inform the budget.
- Significant additional budget is released if a pre and post site measurement are conducted.
- It is proposed that 7 sites are to be measured to capture make, model and sizes to sufficiently reduce any risk of replacing the worst case, standard EKA algorithm. (note this will need to be assessed by MoD experts)
- Without an increased exclusion zone, the budget is rapidly consumed with minimal MW deployed.
- To prevent the budget being consumed even if the exclusion zone is extended there is a clear need for before and after measurements.
- A best-case noise removal method has been used to calculate the effect of background noise removal.