Kirkan Wind Farm Ltd

Kirkan Onshore Wind Farm

Additional Information

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RSK

RSK GENERAL NOTES

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PREFACE

This is an additional information (AI) report pursuant to the (29th March 2019) Environmental Impact Assessment Report (EIAR) for the proposed Kirkan Wind Farm (hereafter referred to as "the proposed development"), located approximately 5.8 km northwest of Garve, Highlands, on the southern side of the A835 trunk road southeast of Loch Glascarnoch dam. The EIAR accompanied the application for consent under Section 36 of the Electricity Act 1989 and deemed planning permission under Section 57(2) of the Town and Country Planning (Scotland) Act 1997, as submitted to the Scottish Government's Energy Consents & Deployment Unit in March 2019. A Supplementary Environmental Information (SEI) report was subsequently issued in October 2019, which was produced in order to address specific hydrogeological, peat, and landscape and visual issues raised during the statutory consultation period pertaining to the original application.

This AI responds to the views of and further with consultees regarding the proposed development. Specifically it contains additional information on amendments to the proposed development that have been made in response to an objection maintained by Scottish Environment Protection Agency (SEPA) (see Figure 1.1 for the amended layout). It provides clarification on the subject of recreational walkers and rights of way in response to an objection submitted by the Scottish Rights of Way and Access Society (ScotWays). It provides further clarification in relation to Landscape and Visual Impact Assessment (LVIA) in response to objections maintained by NatureScot (formerly Scottish Natural Heritage, SNH) and The Highland Council (THC). Further clarification is also provided in relation to operational noise in response to a concern raised by THC environmental health regarding cumulative noise effects.

Dissemination of the Additional Information Report

This AI report will be provided to all stakeholders issued with a copy of the original EIA Report and the SEI report, as well as to the Reporter appointed by the Department for Planning and Environmental Appeals (DPEA). The AI report will also be placed on the DPEA website page dedicated to this proposed development, and will be advertised in accordance with the Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2017.

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Backround

1.1 This is an additional information (AI) report pursuant to the (29th March 2019) Environmental Impact Assessment Report (EIAR) for the proposed Kirkan Wind Farm (hereafter referred to as "the proposed development"), located approximately 5.8 km northwest of Garve, Highlands, on the southern side of the A835 trunk road southeast of Loch Glascarnoch dam. The EIAR accompanied the application for consent under Section 36 of the Electricity Act 1989 and deemed planning permission under Section 57(2) of the Town and Country Planning (Scotland) Act 1997, as submitted to the Scottish Government's Energy Consents & Deployment Unit in March 2019. A Supplementary Environmental Information (SEI) report was subsequently issued in October 2019, which was produced in order to address specific hydrogeological, peat, and landscape and visual issues raised during the statutory consultation period pertaining to the original application.

1.2 This report includes AI to be submitted following receipt of consultation responses and discussions with consultation bodies and non-statutory consultees regarding the proposed development. It contains additional information, including amendments to the proposed development, in response to the following:

- Amendments to the proposed development in relation to peat impacts at two turbine locations in response to an objection maintained by Scottish Environment Protection Agency (SEPA).
- Clarification on the subject of recreational walkers and rights of way in response to an objection submitted by the Scottish Rights of Way and Access Society (ScotWays).
- It provides further clarification in relation to Landscape and Visual Impact Assessment (LVIA) in response to objections maintained by NatureScot (formerly Scottish Natural Heritage, SNH) and The Highland Council (THC).
- Further clarification is provided in relation to Noise in response to a concern raised by THC environmental health regarding cumulative noise effects.

Design changes

1.3 The AI contains includes one change to the proposed development design. Figure 1.1 (Appendix 1) shows proposed changes to the locations and connecting track orientations for Turbines 5 and 7 in response to an objection maintained by SEPA, following the SEI.

1.4 In summary:

- Turbine 5 has moved 35.9 m east-southeast from its former location
- Turbine 7 has moved 35.3 m north from its former location.

1.5 Further clarification on this matter is provided in Chapter 2: Hydrology and Peat.

1.6 The AI report also includes a summary assessment from the other environmental specialists involved in the EIA on the implications of the design revision for their respective disciplines, namely: archaeology and cultural heritage; ecology; ornithology; traffic and transportation; aviation, radar and telecoms; climate change; and forestry.

Consultation process

1.7 This AI report will be provided to all stakeholders issued with a copy of the original EIA Report and the SEI report, as well as to the Reporter appointed by the Department for Planning and Environmental Appeals (DPEA). The AI report will also be placed on the DPEA website page dedicated to this proposed development, and will be advertised in accordance with the Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2017.

Structure of the AI report

1.8 The AI Report is presented in six sections, with the most relevant consultation bodies/stakeholders identified in parentheses:

- Chapter 2: Hydrology and Peat (SEPA)
  - Appendix 1: Hydrology and Peat Figures
- Chapter 3: Recreational Walkers and Rights of Way (Scotways)
- Chapter 4: Landscape and Visual Impact (NatureScot, THC)
  - Appendix 2: Landscape & Visual Impact Figures
- Chapter 5: Noise (THC Environmental Health)
- Chapter 6: Concluding remarks (all)

1.9 Further commentary is also provided with respect to any additional mitigation measures/environmental commitments recommended within the assessments of this AI Report.

EIA team

1.10 The relevant expertise and qualifications of the technical specialists involved in production of this AI report are detailed in Table 1.1 below.

Table 1.1: Technical Specialists

Name	Qualifications	Company	Role and expertise
Catherine Isherwood	MA, MSci, MSc, PhD	RSK	Technical lead – Hydrology, Geology and Peat Chartered Geologist, Fellow of the Geological Society of London, Professional Graduate of the Institute of Materials, Minerals and Mining
Brian Denney	BA(Hons) Dip LA CMLI MIEMA C.Env	Pegasus Group	Technical Lead - Landscape
Malcolm Spaven	MA, MSc.	Aviatica	Technical Lead – Aviation lighting

Name	Qualifications	Company	Role and expertise
Professor Phillip Best	Professor of Extragalactic Astrophysics	The University of Edinburgh	Aviation warning light – light propagation

All other technical specialists remain the same as described in the EIAR submitted in March 2019.

2 GEOLOGY, HYDROGEOLOGY AND SOILS

Background

2.1 The EIA Report for Kirkan Wind Farm was submitted in March 2019. Following submission, the Applicant received feedback from a number of consultees regarding the content and findings of the assessments. An SEI Report was submitted to address these concerns in October 2019.

2.2 This section of the report relates to SEPA's response concerning Chapter 9 (Geology, Hydrogeology and Soils) of the EIA Report and the technical appendices produced in support of those chapters, and the subsequent SEI (October 2019). In particular, SEPA objected to the development on the basis that Turbines 5 and 7 were partially located in deep peat. Further consultation with SEPA in July 2021 confirmed that a small relocation of these two turbines would provide sufficient information for SEPA to withdraw their objection. It is on that basis that the following assessment has been made.

Response to SEPA

2.3 In response to SEPA's concerns, both turbines 5 and 7 have been relocated by a small amount and are now located in areas with considerably less peat than at their previous positions (See Figure 1.1). Small consequential adjustments to the track layout have been required to accommodate these changes.

2.4 An overall reduction in anticipated peat excavation of 15% from the original layout, and 9.4% from the SEI layout, have been achieved by these small adjustments, the details of which are provided below.

Revised Assessments

2.5 Following adjustment of the proposed development design, revisions have been undertaken with respect to the Peat Management Plan (Technical Appendix 9.4). Details of the revisions are provided below.

Peat management plan

2.6 This section should be read with reference to Technical Appendix 9.4 of the EIA Report and to the Peat management plan section of the SEI.

Peat excavation volumes – Layout A

2.7 Minor changes to the locations of Turbines 5 and 7, and to the associated sections of access track, have necessitated some minor reassessment of the calculated estimated volumes of peat that need to be excavated for the development.

2.8 The positions of the relocated Turbines 5 and 7, and associated peat depth records, are provided on Figures 2.1 and 2.2.

2.9 In line with the initial calculations provided in Technical Appendix 9.4, the acrotelm has been assumed to form the uppermost 0.5 m where peat is present. Acrotelm is known to vary in thickness, but it is recommended that peat turves are excavated to approximately 0.5 m where possible, including the uppermost part of the catotelm, to promote quicker regeneration of disturbed areas following reinstatement.

2.10 Volumes of peaty soil and topsoil have not been included, in line with the definition of peat quoted in the main appendix text. Soils will also require excavation but are less sensitive than peat to both excavation and restoration.

2.11 The revised volumes of peat that would require excavation for track construction are set out in Table 2-1 below, together with the calculated volumes from the original layout and revised SEI layout for comparison.

Table 2.1: Peat excavation volumes for access tracks, including passing places and turning heads, and trackside drainage. Table includes previous volumes for comparison. Overall difference is the change from the original calculations.

Scheme element	Acrotelm (m^3)	Catotelm (m^3)	Total (m^3)	Overall Difference (m^3)
Track section 1 (unchanged)	2,298	276	2,574	0
Track section 2 (original)	5,777	4,287	10,064	-1,116
Track section 2 (SEI)	5,588	4,051	9,639	
Track section 2 (AI-2021)	5,123	3,825	8,948	
Track section 3 (original)	7,540	5,920	13,460	+289
Track section 3 (SEI)	7,734	6,015	13,749	
Track section 4 (original)	6,207	6,083	12,290	-2,205
Track section 4 (SEI)	5,793	4,292	10,085	
Track section 5 (unchanged)	3,338	3,093	6,431	0
Track section 6 (original)	7,899	8,639	16,538	-4,402
Track section 6 (SEI)	7,017	6,559	13,576	
Track section 6 (AI-2021)	6,577	5,559	12,136	
Track section 7 (original)	5,131	6,624	11,755	-3,320
Track section 7 (SEI)	5,143	3,292	8,435	
Total (original)	**38,190**	**34,922**	**73,112**	**-10,754**
Total (SEI)	**36,911**	**27,578**	**64,489**	
Total (AI-2021)	**36,006**	**26,352**	**62,358**	

2.12 Track section 2 includes the revised access to Turbine 5, which is slightly shorter than the previous track link. Track section 6 includes the new access to Turbine 7, which is also slightly shorter than the previous track link.

2.13 Overall, reduction in excavation volumes from the access track of approximately 15% has been achieved from the original layout, with the most recent changes providing a 3.3% decrease from the SEI layout.

2.14 The revised volumes of peat that would require excavation for construction of turbine foundations, hardstanding areas and crane pads, plus associated drainage, are provided in **Table 2-2**.

Table 2.2: Peat excavation volumes for turbines, hardstandings, crane pads and associated drainage. Table includes previous volumes for comparison

Scheme element	Acrotelm (m^3)	Catotelm (m^3)	Total (m^3)	Overall Difference (m^3)
Turbine 1 (unchanged)	462	102	564	0
Turbine 2 (original)	No peat			+505
Turbine 2 (SEI)	404	101	505	
Turbine 3 (unchanged)	359	40	399	0
Turbine 4 (unchanged)	924	721	1,645	0
Turbine 5 (original)	1,010	1,124	2,134	-1,667
Turbine 5 (SEI)	970	931	1,901	
Turbine 5 (AI-2021)	359	108	467	
Turbine 6 (unchanged)	606	501	1,107	0
Turbine 7 (original)	1,386	1,843	3,229	-2,127
Turbine 7 (SEI)	1,078	1,970	3,048	
Turbine 7 (AI-2021)	808	294	1,102	
Turbine 8 (unchanged)	462	32	494	0
Turbine 9 (unchanged)	404	445	849	0
Turbine 10 (unchanged)	1010	715	1,725	0
Turbine 11 (unchanged)	No peat			0
Turbine 12 (unchanged)	808	740	1,548	0
Turbine 13 (unchanged)	No peat			0
Turbine 14 (unchanged)	180	65	245	0
Turbine 15 (unchanged)	1010	736	1,746	0
Turbine 16 (original)	898	1,308	2,206	-709
Turbine 16 (SEI)	736	761	1,497	
Turbine 17 (unchanged)	202	12	214	0
Total (original)	**9,721**	**8,384**	**18,105**	**-3,998**
Total (SEI)	**9,615**	**7,872**	**17,487**	
Total (AI-2021)	**8,734**	**5,373**	**14,107**	

2.15 The relocation of Turbines 5 and 7 into areas of shallower peat have resulted in a substantial reduction in required peat excavation of 78% and 66% respectively from the original calculations. This equates to reductions of 75% and 64% from the recalculated SEI volumes.

2.16 There have been no changes to any of the additional infrastructure, so revised peat volume calculations have not been provided.

2.17 A summary of the total revised peat volumes is provided in Table 2-3. Overall, a reduction in excavation volumes of approximately 15% has been achieved.

Table 2.3: Summary of peat excavation volumes

Scheme element	Acrotelm (m^3)	Catotelm (m^3)	Total (m^3)	Overall Difference (m^3)
All tracks (original)	38,190	34,922	73,112	-10,754
All tracks (SEI)	36,911	27,578	64,489	
All tracks (AI-2021)	36,006	26,353	62,359	
All turbine infrastructure (original)	9,721	8,384	18,105	-3,998
All turbine infrastructure (SEI)	9,615	7,872	17,487	
All turbine infrastructure (AI-2021)	8,734	5,373	14,107	
All other infrastructure (unchanged)	3,652	1,332	4,984	0
Total (original)	**51,563 (54%)**	**44,638 (46%)**	**96,201**	**-14,752**
Total (SEI)	**50,178 (58%)**	**36,782 (42%)**	**86,960**	
Total (AI-2021)	**48,392 (59%)**	**33,057 (41%)**	**81,449**	

Peat reuse volumes – Layout A

2.18 Options for peat reuse remain unchanged from those presented in Appendix 9.4 of the EIA Report.

2.19 As the changes to the infrastructure layout are minor in nature, the calculated volumes of peat that can be reused have not been amended.

3 RECREATIONAL WALKERS AND RIGHTS OF WAY

Background

3.1 Socio-economic and tourism impacts were scoped out of the EIA for Kirkan via the formal EIA scoping process. Consideration of recreational users of the land, paths and rights of way were included within the Landscape and Visual Impact Assessment, Chapter 4 of the EIA report (March 2019), with further information presented in Chapter 3 of the SEI (October 2019). Consideration of the cultural heritage and archaeological value of historical drove roads was undertaken in Chapter 5 Archaeology and Cultural Heritage of the EIA report.

3.2 In its correspondence to the Energy Consents Unit (ECU) in response to the application, dated 12/06/2019, ScotWays objected to the proposed development due to potential impacts to HR46, the Fish Road. The EIA report stated (in 5.7.5 of the EIA report Volume 1) "access along this footpath and historic drovers route will not be permitted, leading to a temporary loss of public access and recreational amenity", but did not include provision for a diversion of right of way HR46 during the construction period. ScotWays' application response stated it would "expect that any diversion would be in place prior to construction work commencing and recommend that this is done in consultation with the access team at Highland Council."

3.3 ScotWays' response also noted that some of the information in relation to Figure 4.4 Transportation Routes, Recreational Routes and Summits in the EIA report Volume 3 Graphics was incomplete, and requested confirmation of the length of HR46 that would be upgraded.

3.4 In its emailed correspondence to the ECU in response to the SEI later submitted, dated 19/11/2019, ScotWays confirmed that its objection of 12/06/2019 remained.

Additional Information

3.5 This section addresses the comments made and the objection maintained by ScotWays, as follows.

Temporary diversion of HR46 Fish Road

3.6 In order to provide additional mitigation, a temporary diversion will be put in place for HR46 Fish Road. The temporary diversion will be agreed with THC access team in advance of construction and will remain in place for the duration of the construction programme.

Transportation Routes, Recreational Routes and Summits Figure

3.7 For reasons of completion, an updated version of Figure 4.4 Transportation Routes, Recreational Routes and Summits is provided to accompany this report, as Figure 3.1 (Appendix 1).

Confirmation of minimum distance between drovers road an nearest turbines

3.8 Based on the proposed layout identified in this AI report (Figure 1.1), the distance between HR46 and the nearest turbines 132 m (to Turbine 10).

3.9 Note that the above calculation does not account for the proposed 50 m tolerance for micro-siting of turbines.

Length of drovers road that will be upgraded

3.10 As a result of the proposed development, an 860 m-long section of the drovers road HR46 would be upgraded.

4 LANDSCAPE AND VISUAL IMPACT

Introduction

4.1 This section of the AI Report provides an update in relation to landscape and visual effects. The update considers three principal matters:

- The potential for any changes to the landscape and visual effects previously identified in the EIA and SEI, following the micrositing of T5 and T7.
- The potential for any changes to the cumulative effects previously identified in the EIA and SEI as a result of changes to cumulative situation within the 45 km study area.
- Confirmation of the landscape and visual effects of the proposed aviation lighting strategy following confirmation that the Civil Aviation Authority have approved the Cardinal Lighting Scheme of 6no. lit turbines.

4.2 The section has been prepared by Pegasus Group supervised and reviewed by Brian Denney. Brian is a Fellow of the Landscape Institute and has over 25 years' experience as a Landscape Architect. He has appeared as an expert witness in the field of Landscape and Visual Assessment at over 100 public inquiries, including for numerous wind farms, and is fully familiar with the landscape in and around the Kirkan site, having visited on several occasions prior to and during the preparation of this AI. He has also reviewed the previous LVIA material prepared in the EIA and SEI to which this AI serves to complement.

Potential for any changes to the landscape and visual effects previously identified in the EIA and SEI, following the micrositing of T5 and T7

4.3 Figure 1.1 shows proposed changes to the locations and connecting track orientations for Turbines 5 and 7 in response to an objection maintained by SEPA on following the SEI. A review has been undertaken to establish whether this micrositing would be of such a nature to bring about any change to the extent of significant landscape and visual effects previously identified in the EIA and SEI.

4.4 Given the very minor difference in location between the previous turbine locations and those currently proposed (with Turbine 5 having moved 35.9 m east-southeast from its former location, and Turbine 7 having moved 35.3 m north), it is not considered that there would be any such change. Indeed, it is noted that the changes are within the 50 m micrositing allowance which was already considered as part of the assessment work undertaken. It is acknowledged that a new 50 m micrositing allowance would now apply to the revised turbine locations, but again the assessments would continue to be applicable..

Updated Cumulative Position

4.5 An assessment of cumulative landscape and visual effects was provided in the EIA. The EIA included a plan of cumulative sites at Figure 4.6, with details provided at Table 4.6.

In turn, the SEI identified that the Lochluichart Extension II (LL Ext 2) had subsequently come into planning and an updated assessment was provided in relation to that scheme. Since submission of the SEI it is noted that there have been updates to the cumulative schemes within 45 km. These include a revised application for the Lochluichart II Extension (LL Ext 2b), which was submitted in June 2021 (for 5no. 149.9 turbines).

4.6 An updated version of Table 4.6 now updated to reflect the current position as of August 2021 is set out in **Table 4-1** below. An updated plan cumulative sites is also provided at **Figure 4.1**.

Table 4.1: Cumulative Wind Farms

Wind Farm	No. of Turbines	Maximum height to blade tip (m)	Direction from the site	Distance from the site
Operational				
Corriemoillie (CM)	17 (19 were consented, but only 17 constructed)	126.25	West	380 m
Lochluichart (LL)	17	125	West	2.3 km
Lochluichart Extension (LL Ext1)	6	125	West	2.4 km
Fairburn	20	100	South	14.5 km
Novar	34	60	East	16 km
Novar extension	16	106	East	15.5 km
Auchmore	1	79	South-east	20.8 km
Auchmore extension	1	79	South-east	21.8 km
Coire na Cloiche	13	99.5	North-east	23 km
Corrimony	5	100	South	42 km
Achany	19	100	North-northeast	37.50 km
Rosehall	19	90	North-northeast	36.8 km
Lairg	3	100	North-northeast	41.8 km
Bienn nan Oighrean	2	80	North-east	26.7 km
Beinn Tharsuinn	17	80	North-east	26.4 km
Bhlaraidh	32	135	South	44.7 km
Yellow Wells	1	78	East	20.8 km
Consented				
Braemore	18	126	North-northeast	35.7 km
Belladrum Kiltarlity	1	61	South-east	30 km
Lochluichart Extension II (LL Ext2)	5	133	North-west	2.5 km
Lairg 2	10	7x180; 3x150	North-northeast	43 km

Application				
Lochluichart Extension II (revised application) (LL Ext 2b)	5	149.9	North-west	2.5 km
Bhlariadh Extension	18	180	South	45 km
Garvary	37	180	North-northeast	40 km
Strathrory	8	180	North-east	27 km
Meall Buidhe	8	149.9	North-northeast	30 km
Achany Extension	20	149.9	North-northeast	43 km
Lairg 2 (revised application)	10	6x200; 1x190; 3x150	North-northeast	43 km

4.7 Having considered those schemes which are now located with 45 km of the site which were not previously considered in the cumulative assessment set out in the EIA and SEI, it is noted that other than LL Ext 2b all of the schemes lie beyond 27 km from the site, with the majority located beyond 40 km. On that basis it is not considered that there would be any potential for significant cumulative effects to arise in relation to these schemes. This updated assessment therefore focuses solely on LL Ext 2b.

4.8 A Cumulative ZTV has been prepared which identifies those areas where the current LL Ext 2b proposals would be visible when compared with the consented LL Ext 2 scheme (Figure 4.2). This illustrates that there would not be any substantive visibility from additional areas for the revised scheme compared with that which has already been consented. Noting also the very limited difference in the turbine height between the consented scheme and that which is now proposed of only 16.9 m, it is not considered that there would be any material change to the findings of the previous assessment set out in the SEI. In summary, these were that the inclusion of the LL Ext 2 would add to the significant sequential cumulative effect on the A835, but that in all other respects the scheme would not alter the findings of the earlier cumulative assessment work from the EIA, with no further significant effects arising.

Confirmation of the landscape and visual effects of the proposed aviation lighting strategy

Introduction

4.9 This section of the AI concerns the landscape and visual effects of the proposed aviation lighting strategy. It serves to update the previous assessment work regarding this matter set out in the EIA and SEI. It should be read in conjunction with two Appendices which have been prepared to help inform the assessment work. Appendix 4, prepared by Malcolm Spaven of Aviatica, provides an estimation of the frequency with which the lights on the turbines would be switched on by passing aircraft if a transponder-activated lighting system was fitted to the wind farm. Appendix 5, prepared by Professor Philip Best of the Institute for Astronomy at the University of Edinburgh, provides a scientific assessment of the propagation of light from the aviation lighting, during the times that this is activated, taking into account the range of atmospheric conditions typically found in Scotland. It further considers how the human eye perceives light.

4.10 Regulation 322 of the Air Navigation Order 2016 (the ANO) would apply to the turbines proposed at Kirkan since their tip height exceeds 150 m. However, the Civil Aviation Authority (CAA) approved a reduced lighting scheme in August 2021 which would require only 6 of the 17 turbines (T1, 3, 7, 10, 16 and 17, as shown in Figure 1.1) to be lit with a single 2000 candela light on each of the 6 turbines at hub height, as opposed to the otherwise required 17 such lights and a further 3 x 32 candela lights on each turbine at mid-tower height, a total of 68 lights. The 6 lights which would now be required can be operated at a reduced source brightness of 200 candela when visibility of more than 5 km in all directions from the turbines is available

4.11 It is noted that the potential for such a Cardinal Lighting Scheme of 6no. lit turbines was identified in the EIA and SEI. However, the main focus of the assessment work in the EIA and SEI was with regard to the scenario whereby all 17no. turbines would be lit. As such, this report provides confirmation of the landscape and visual effects which would be applicable for the Cardinal Lighting Scheme for each of the 19 assessment viewpoints and the two Wild Land Areas in the vicinity of the site.

4.12 In turn, it is additionally proposed that the 6 hub height lights will only be switched on when aircraft are passing the wind farm. This would be achievable through the operation of a permanently installed Transponder Activated Lighting Scheme (TALS), otherwise known as an electronic conspicuity lighting system. This is understood to be likely to be approved by the CAA, and would be secured within the section 36 consent and/or a deemed planning permission by a condition preventing the operation of any turbine until such a system is approved as installed by the CAA and is capable of operation. On the basis of the data in Appendix 4 to this AI, the lights would only be switched on for about 0.1% of the night hours, that is to say the time between half an hour after sunset and half an hour before sunrise. Only if the approved and commissioned TALS was out of operation would the 6 turbines designated to be lit under the August 2021 CAA approved reduced lighting scheme require to be on during the 99+% of the time when no aircraft are within the TALS prescribed airspace round the wind farm.

4.13 The remaining issue to be addressed is the acceptability of a TALS scheme to the MoD, and this matter is being pursued through current discussions. For that reason this AI, while assessing visual effects of lighting with the intended TALS in operation, nevertheless also assesses such effects with 6 hub heights switched on during all night hours. This scenario is though very different from that assessed in the EIAR when it had to be assumed that 17 x 2000 candela hub height lights and 34 x 32 candela mid-tower lights would be permanently on during night hoursThe consultation response of NatureScot dated 12th February 2020 set out an objection to the scheme in relation to the effects on Wild Land Areas 28 and 29. However, the response confirmed that NatureScot ***'consider that a wind farm may be accommodated on this site subject to the significant effects of the turbine lighting being substantially reduced'***. The now approved Cardinal Lighting Scheme of 6no. lit turbines represents is, objectively, a substantial reduction in the effects of the aviation lighting on the two Wild Land Areas when compared with the scenario whereby all 17no. turbines would be lit with a total of 68 lights. In turn, the additionally proposed TALS would further reduce the effect of this lighting to a substantive degree, given the lighting would only be switched on for about 0.1% of the night hours.

4.14 It is also noted that NatureScot suggested that further consideration of the effects of the turbine lighting on the wild land qualities of the two Wild Land Areas would be beneficial. In this regard it is noted that the NatureScot guidance ‘Assessing impacts on Wild Land Areas – Technical Guidance’ was published in September 2020, after the production of the SEI. This section of the AI has therefore also been mindful of the overarching approach to considering Wild Land set out this guidance and also of the wild land qualities of each of the Areas, as set out in the NatureScot 2017 published descriptions of each area. In turn, regard has also been given to how the matter of impact of aviation lighting on the landscape has been considered in recent Inquiries and Decisions for other wind energy developments, including Crystal Rig IV Wind Farm, which is discussed further subsequently in this section of the AI.

Summary of Previous Assessment of Cardinal Lighting set out in the EIA and SEI

<u>*EIA*</u>

4.15 Having provided an assessment of the scenario whereby all 17no. turbines would be lit paragraph 4.7.110 of the LVIA then set out that *‘There is some potential for additional mitigation of these effects through the reduction in turbine lighting (i.e. to cardinal lighting only) and/or adoption of a radar activated lighting system, both of which would reduce impacts and effects’*. Appendix 4.9 of the EIA went on to note that such a Cardinal Lighting Scheme could comprise of 6no. lit turbines (T1, 3, 7, 10, 16 and 17).

4.16 It was also noted in Appendix 4.9 of the EIA that should such a Cardinal Lighting Scheme be approved it would result in only two lights being seen from Loch Glascarnoch (VP 17) rather than the six turbines which would otherwise be seen if all turbines were to be lit. However, this appears to have been a typographical error as this should in fact have said 3no lights would be seen from VP17 with the Cardinal Lighting Scheme [T3, T10, and T16]. Appendix 4.9 of the EIA also set out that from Aultguish Inn (VP 1) only 3 lights would be visible rather than the current 10. However, this also appears to have been a typographical error as this should in fact have said 4no lights would be seen from VP1 with the Cardinal Lighting Scheme [T1, T3, T7 and T10]. Full updated assessments for each of these viewpoints are presented subsequently in this section of the AI.

4.17 The conclusions presented about the Cardinal Lighting Scheme in the EIA were that it would ‘*reduce impacts and effects’ (LVIA para 4.7.110)* beyond those identified for the 17 turbine scheme.

<u>*SEI*</u>

4.18 The SEI provided further information with regard to the potential effects of the aviation lighting. This included further assessment of the effects on Wild Land Areas 28 and 29. The assessment was supported by, dusk period visualisations for 3no. assessment viewpoints (VPs 6, 13 and 14) including a separate sheet illustrating the potential Cardinal Lighting Scheme, and annotated wireframes illustrating the lit turbines for each of the 19no. viewpoints. The SEI also included a Figure (Figure 5.1) illustrating the theoretical visibility of the Cardinal Lighting Scheme of 6no. lit turbines. The visualisations within the SEI also included a separate sheet illustrating the potential

Cardinal Lighting Scheme. The conclusions presented in the SEI about the Cardinal Lighting Scheme were that *'effects on the WLAs would not be significant'* (SEI para 3.13).

4.19 This section of the AI therefore serves to provide confirmation of the night-time effects which would arise at each of the 19 LVIA viewpoints with the Cardinal Lighting Scheme and should the TALS be in operation. It also provides further assessment with regard to the effects of the turbine lighting on the wild land qualities of the two Wild Land Areas.

Summary of Existing Aviation Lighting in Proximity to the site

4.20 The other wind farm projects within 45 km of the site are set out in Table 4-1 of this AI and illustrated in Figure 4.1. Within 5 km of the site, there are 3no. operational wind farms Corriemoillie (CM), Lochluichart (LL) and Lochluichart Extension (LL Ext 1). It was identified in Appendix 4.9 of the EIA that aviation lighting was present on the Corriemoillie, Lochluichart wind farms, noting, ***'both of the neighbouring Lochluichart and Corriemoillie wind farms have ultimately agreed cardinal lighting schemes with the MoD and THC for discharge of their relevant planning conditions'.*** For clarity, it can be confirmed that 25 candela steady state visible aviation lights are provided on 6no. of the turbines across the Lochluichart and Lochluichart Extension schemes. There are also 4no. turbines in the Corriemoillie scheme which are fitted with 200 candela steady state visible aviation lights.

Assessment of Night-time Effects at LVIA Viewpoints

4.21 The following Table 4-2 summarises the assessment of effects of the Cardinal Lighting Scheme on each of the LVIA assessment viewpoints, both in the scenario with and without the TALS.

4.22 It is noted that a 'high' sensitivity was ascribed to each of the viewpoints the daytime period in the EIA. However, it is understood that for the night-time period a different sensitivity would apply. This because the value of views during the night-time period is reduced and is considered to be low. This may be due to the transient nature of views as people travel through the landscape, or that they may have some form of personal light for their safety, which would create an element of baseline light. It also reflects the limited time period during which the lights would be one when the features of the landscape could be perceived and appreciated before full darkness occurs. It is noted that the matter of value concerning night-time views is not specifically addressed in the Guidelines for Landscape and Visual Impact Assessment due to the relatively new nature of this issue and that a bespoke approach to considering the value of night-time views is therefore required. In this regard, the findings of the Reporters concerning this matter in the Crystal Rig IV Wind Farm Report to the Scottish Ministers are noted as they serve to confirm this position of a low value during the night-time period. It was concluded by the Reporters in paragraph 4.146 that *'we agree with the applicant that the value that can attributed to a view at night is low'.* Therefore, the approach taken in this assessment is that the susceptibility of people to changes in their night-time amenity should be combined with a low value when determining overall sensitivity for the night-time period.

4.23 In turn, the susceptibility of people experiencing night-time outdoors would depend in part on the degree to which their perception is affected by existing baseline lighting. In brightly lit areas, or when travelling on roads from where sequential views of lighting may already be experienced, the susceptibility of receptors is likely to be lower than from areas where the baseline contains no or limited existing lighting. The same terminology has been used for sensitivity as used in the in the LVIA (High/Medium/Low).

4.24 The magnitude of impact was then identified using the same terminology as outlined in Table 4.3 of the EIA (substantial/moderate/slight/negligible/none). In considering the magnitude of change which may be applicable at each viewpoint it is important to consider the additional mitigation which would also be applicable further to the use of the Cardinal Lighting Scheme. These measures were originally set out in Appendix 4.9 of the EIA. This confirmed that in conditions where horizontal meteorological visibility exceeds a 5 km radius from the position of the light, significant reductions in light intensity (also referred to as source brightness) would be experienced, as lighting intensity or brightness would be reduced to 10% of the maximum intensity or brightness. The proportion of time when such conditions might be applicable has been assessed by reference to local weather/climate data and it has been established to be around 5% of the time when visibility is below 5 km (paragraph 3.2.8, Appendix 5) meaning that for around 95% of the time the lights would be reduced to 200 candela. Furthermore, in the poor visibility conditions when the 2,000 candela lighting is required, they would actually have a lower illuminance than the 200 candela lights seen in typical clear conditions, for all distances beyond 5 km (Appendix 5). In addition, depending upon the angle of receptors relative to the turbine lights, the illuminance will vary. This vertical suppression will be relevant both for observers close to the turbines and those at a lower altitude Further details of this in relation to the LVIA viewpoints are provided in Appendix 5 and discussed where relevant in the viewpoint assessment below.

4.25 It is also noted that a transponder-activated lighting system (TALS) may be fitted to the wind farm, such that the Cardinal Lighting Scheme were only to be switched on for part of the time, estimated in Appendix 4 to be 0.1% of night-time hours. In this case the magnitude of any effects would be near absolutely reduced in terms of the time period in which they would arise, noting that duration is a factor to be considered as part of the consideration of magnitude.

4.26 It is also important to recognise that the number of receptors who would be likely to experience the effects identified at the viewpoints would be highly limited in the case of many of the viewpoints. This is because they represent remote summits which are highly unlikely to have receptors present during the low-light period, given the logistical challenge of accessing these locations in low light conditions.

The Effect for each viewpoint has been identified by applying the approach set out in paragraphs 4.2.62-64 of the EIA, with regard to the accompanying Table 4.5 of the EIA. In short, by combining the identified sensitivity and magnitude in order to derive the effect, with ‘significant’ effects being those which are ‘major’ or ‘major/moderate’. The exception to this is where a negligible magnitude has been identified, as it is considered that such a low magnitude would not give rise to effects that were themselves any greater than negligible.

Table 4.2: Assessment of Effects of the Cardinal Lighting Scheme on LVIA Viewpoints

Viewpoint	Assessment of lighting effects of 6 turbine cardinal lighting scheme
1 - Aultguish Inn	Distance to nearest Turbine: 2.3 km Number of lit turbines visible: 4 (T1, 3, 7 and 10) Susceptibility: Medium Value: Low Sensitivity: Low-Medium Magnitude (assuming no TALS): Slight Magnitude (TALS): Negligible Effect (assuming no TALS): **Minor** Effect (TALS): **Negligible /none** **---** **Viewpoint 1** Aultguish Inn is located 2.3 km from the nearest proposed turbine. It represents the view from the A685 and users of the Aultguish Inn public house. It lies outside the identified Wild Land Areas. The night-time view from the viewpoint was illustrated in EIA Figure 4.8e, which showed the worse-case scenario lighting scheme of 17no. lit turbines, with 9no of the 17 turbines visible above the intervening landform from this location. However, following confirmation of the acceptance of the cardinal lighting scheme of 6 lit turbines, only 4no. lit turbines would now be visible from this location (T1, 3, 7 and 10) the locations of which are shown in the wireframe at EIA Figure 4.8c. It is important to recognise that, although the 53.5 degree view directly towards the site (as illustrated in Figure 4.8e) includes no existing artificial light sources, the wider angle of view includes lit turbines in LL Ext 1 and also both the A835 and the Aultguish Inn itself (as illustrated in Figure 4.8b), both of which provide further existing sources of lighting in this location. The susceptibility of people taking in the view from this location during the night-time period is therefore reduced to Medium, as whilst it is a generally dark landscape, the adjacent road means that lighting is a familiar element of the view in this location. As previously discussed, the value of the view during the night-time period has been established to be low. A medium susceptibility and a low value combine to create a low-medium sensitivity. When considering the magnitude of the impact, it is noted that only 4no. of the 6 lit turbines would be visible, at a distance of 2.3 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 0.09 at this viewpoint, based on its elevation compared to the viewpoint and its distance from the nearest lit turbine. The result being that under typical 'clear' conditions, for nearby receptors on the A835 (Viewpoint 1), the aviation lighting will appear of comparable brightness to some of the brightest stars in the sky, or to car brake lights at distances of about 6 km. In this context it is considered that a slight magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A slight magnitude combined with a low-medium sensitivity would equate to a minor effect. Should the TALS be implemented the negligible magnitude combined with a low-medium sensitivity would equate to an effect of negligible /none.

2 - Old Drovers Road, Corriemoillie	Distance to nearest Turbine: 700m Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Moderate Magnitude (TALS): Negligible Effect (assuming no TALS): **Moderate** Effect (TALS): **Negligible** **---** **Viewpoint 2** Old Drovers Road, Corriemoillie is located 700 m from the nearest turbine. It lies outside the identified Wild Land Areas. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.9a that the turbines would lie in close proximity to the viewpoint. The 6no. lit turbines in the approved cardinal lighting scheme (T1, 3, 7, 10, 16 and 17) would be seen from the viewpoint in a landscape which is largely free from existing sources of artificial light. The susceptibility of people taking in the view from this location during the night-time period is therefore high. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 700m. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 0.09 at this viewpoint, based on its elevation compared to the viewpoint and its distance from the nearest lit turbine. In this context it is considered that a moderate magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A moderate magnitude combined with a medium sensitivity would equate to a moderate effect. Should the TALS be implemented the negligible magnitude combined with a medium sensitivity would equate to an effect of negligible.

3 - A835, Tarvie	Distance to nearest Turbine: 9.5 km Number of lit turbines visible: none Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): none Magnitude (TALS): none Effect (assuming no TALS): **none** Effect (TALS): **none** **---** **Viewpoint 3** A835, Tarvie is located 9.5 km from the nearest turbine. It lies outside the identified Wild Land Areas. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.10a that the turbines would lie behind plantation forestry with no lit turbines visible. There would therefore be no effect during the night-time period.
4 - A832, Gorstans	Distance to nearest Turbine: 4.4 km Number of lit turbines visible: none Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): none Magnitude (TALS): none Effect (assuming no TALS): **none** Effect (TALS): **none** **---** **Viewpoint 4** A832, Gorstans is located 4.4 km from the nearest turbine. It lies outside the identified Wild Land Areas. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.11a that the turbines would lie behind roadside trees with no lit turbine visible. There would therefore be no effect during the night-time period.

5 -Summit of Sgurr Marcasaigh	Distance to nearest Turbine: 11.9 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Slight Magnitude (TALS): Negligible Effect (assuming no TALS): **Moderate/Minor** Effect (TALS): **Negligible** **---** **Viewpoint 5** Summit of Sgurr Marcasaigh is located 11.9 km from the nearest turbine. It lies outside the identified Wild Land Areas. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.12a that the turbines would lie in the middle distance of the view with all 6no. cardinal turbine visible. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 11.9 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 1.26 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. In this context it is considered that a slight magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A slight magnitude combined with a medium sensitivity would equate to a moderate/minor effect. Should the TALS be implemented the negligible magnitude combined with a medium sensitivity would equate to an effect of Negligible.

6 - Ben Wyvis	Distance to nearest Turbine: 9.1 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Slight Magnitude (TALS): Negligible Effect (assuming no TALS): **Moderate/Minor** Effect (TALS): **Negligible** **---** **Viewpoint 6** Ben Wyvis is located 9.1 km from the nearest turbine. It lies within Wild Land Area 29 which is discussed in further detail subsequently in this AI. The night-time view from the viewpoint was illustrated in SEI Figure 5.4c, which showed the cardinal lighting scheme of 6no. lit turbines. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 9.1 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 0.43 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. The result being that the aviation lighting will be observed to be comparable in brightness to typical bright stars such as those in Orion, or to car brake lights at distances of about 10 km. In this context it is considered that a slight magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A slight magnitude combined with a medium sensitivity would equate to a moderate/minor effect. Should the TALS be implemented the negligible magnitude combined with a medium sensitivity would equate to an effect of Negligible.

7 - Avenue of Fairburn Estate	Distance to nearest Turbine: 17.5 km Number of lit turbines visible: 2 (T1 and 7) Susceptibility: medium Value: Low Sensitivity: Low-Medium Magnitude (assuming no TALS): Negligible Magnitude (TALS): Negligible Effect (assuming no TALS): **Minor** Effect (TALS): **Negligible/none** **---** **Viewpoint 7** Avenue of Fairburn Estate is located 17.5 km from the nearest turbine. It lies outside the identified Wild Land Areas. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.14a that the turbines would lie in the distance of the view with 2no. of the cardinal turbines visible. The view towards the site includes existing artificial light sources from residential properties and minor roads, with the minor road on which the viewpoint is located also in the wider angle of view includes (as illustrated in Figure 4.14b). The susceptibility of people taking in the view from this location during the night-time period is therefore reduced to Medium, as whilst it is a generally dark landscape, lighting is a familiar element of the view in this location. As previously discussed, the value of the view during the night-time period has been established to be low. A medium susceptibility and a low value combine to create a low-medium sensitivity. When considering the magnitude of the impact, it is noted that only 2no. of the 6 lit turbines would be visible at a distance of 17.5 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 0.40 at this viewpoint, based on its elevation compared to the viewpoint and its distance from the nearest lit turbine. In this context it is considered that a negligible magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible/none. A negligible magnitude combined with a low-medium sensitivity would equate to an effect which is minor/none. Should the TALS be implemented the negligible magnitude combined with a low-medium sensitivity would equate to an effect an effect which is Negligible /none.

8 - Summit of Sgur a'Muillin	Distance to nearest Turbine: 14.8 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Slight Magnitude (TALS): Negligible Effect (assuming no TALS): **Moderate/minor** Effect (TALS): **Negligible** **---** **Viewpoint 8** Summit of Sgur a'Muillin is located 14.8 km from the nearest turbine. It lies outside the identified Wild Land Areas. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.15a that the turbines would lie in the middle distance of the view with all 6no. cardinal turbines visible. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 14.8 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 1.13 at this viewpoint as a result of its elevated location above the turbines. In this context it is considered that a slight magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A slight magnitude combined with a medium sensitivity would equate to a moderate/minor effect. Should the TALS be implemented the negligible magnitude combined with a medium sensitivity would equate to an effect of Negligible.

9 - Summit of Beinn aBha'ach Ard	Distance to nearest Turbine: 23.2 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Negligible Magnitude (TALS): Negligible Effect (assuming no TALS): **Minor** Effect (TALS): **Negligible/none** **---** **Viewpoint 9** Summit of Beinn aBha'ach Ard is located 23.2 km from the nearest turbine. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.16a that the turbines would lie in the middle distance of the view with all 6no. cardinal turbines visible. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 23.2 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 1.25 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. In this context it is considered that a Negligible magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible/none. A Negligible magnitude combined with a medium sensitivity would equate to a minor effect. Should the TALS be implemented the negligible/none magnitude combined with a medium sensitivity would equate to an effect of Negligible/none.

10 - Summit of Sgurr a' Choire Ghlais	Distance to nearest Turbine: 26 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Negligible Magnitude (TALS): Negligible Effect (assuming no TALS): **Minor** Effect (TALS): **Negligible/none** **---** **Viewpoint 10** Summit of Sgurr a' Choire Ghlais is located 26 km from the nearest turbine. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.17a that the turbines would lie in the middle distance of the view with all 6no. cardinal turbines visible. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 26 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 1.19 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. In this context it is considered that a Negligible magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible/none. A Negligible magnitude combined with a medium sensitivity would equate to a minor effect. Should the TALS be implemented the negligible/none magnitude combined with a medium sensitivity would equate to an effect of Negligible /none.

11 - Summit of Moruisg	Distance to nearest Turbine: 30.7 km Number of lit turbines visible: 5 (T1, 3, 7, 10 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Negligible Magnitude (TALS): Negligible Effect (assuming no TALS): **Minor** Effect (TALS): **Negligible/none** **--** **Viewpoint 11** Summit of Moruisg is located 30.7 km from the nearest turbine. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.18a that the turbines would lie in the middle distance of the view with all 6no. cardinal turbines visible. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that only 5no. of the 6 lit turbines would be visible at a distance of 30.7 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 1.26 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. In this context it is considered that a Negligible magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible/none. A Negligible magnitude combined with a medium sensitivity would equate to a minor effect. Should the TALS be implemented the negligible/none magnitude combined with a medium sensitivity would equate to an effect of Negligible none.

12 - Leathad Buidhe, Beinn Eighe	Distance to nearest Turbine: 36.4 km Number of lit turbines visible: none Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): None Magnitude (TALS): None Effect (assuming no TALS): **no effect** Effect (TALS): **no effect** **---** **Viewpoint 12** Summit of Moruisg is located 30.7 km from the nearest turbine. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.18a that the turbines would lie in the middle distance of the view with none of the 6no. cardinal turbine lights visible. There would therefore be no effect during the night-time period.

13 - Summit of An Coileachan, Fannich Range (microsited to Summit of Faire nam Fiadh, Fannich Range for night-time assessment)	Distance to nearest Turbine: 11.3 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Slight Magnitude (TALS): Negligible Effect (assuming no TALS): **Moderate/minor** Effect (TALS): **Negligible** **--** **Viewpoint 13** Summit of An Coileachan, Fannich Range was microsited to the Summit of Faire nam Fiadh, Fannich Range for the night-time assessment and is located 11.3 km from the nearest turbine. It lies within Wild Land Area 28 which is discussed in further detail subsequently in this AI. The night-time view from the viewpoint was illustrated in SEI Figure 5.5c, which showed the cardinal lighting scheme of 6no. lit turbines. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 11.3 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 0.82 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. The result being that the aviation lighting will be observed to be comparable in brightness to typical bright stars such as those in Orion, or to car brake lights at distances of about 10 km. In this context it is considered that a slight magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A slight magnitude combined with a medium sensitivity would equate to a moderate/minor effect. Should the TALS be implemented the negligible magnitude combined with a medium sensitivity would equate to an effect of Negligible.

14 - Summit of Beinn Dearg	Distance to nearest Turbine: 16.4 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Slight Magnitude (TALS): Negligible Effect (assuming no TALS): **Moderate/minor** Effect (TALS): **Negligible** **---** **Viewpoint 14** Summit of Beinn Dearg is located 16.4 km from the nearest turbine. It lies within Wild Land Area 29 which is discussed in further detail subsequently in this AI. The night-time view from the viewpoint was illustrated in SEI Figure 5.6c, which showed the cardinal lighting scheme of 6no. lit turbines. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 16.4 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 0.86 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. The result being that the aviation lighting will be observed to be comparable in brightness to typical bright stars such as those in Orion, or to car brake lights at distances of about 10 km. In this context it is considered that a slight magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A slight magnitude combined with a medium sensitivity would equate to a moderate/minor effect. Should the TALS be implemented the negligible magnitude combined with a medium sensitivity would equate to an effect of Negligible.

15 - Summit of Meall a' Ghrianain	Distance to nearest Turbine: 9.2 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Slight Magnitude (TALS): Negligible Effect (assuming no TALS): **Moderate/minor** Effect (TALS): **Negligible** **---** **Viewpoint 15** Summit of Meall a' Ghrianain is located 9.2 km from the nearest turbine. It lies within Wild Land Area 29 which is discussed in further detail subsequently in this AI. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.22a that the turbines would lie in the middle distance of the view with all 6no. cardinal turbines visible. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 9.2 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 1.11 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. The result being that the aviation lighting will be observed to be comparable in brightness to typical bright stars such as those in Orion, or to car brake lights at distances of about 10 km. In this context it is considered that a slight magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A slight magnitude combined with a medium sensitivity would equate to a moderate/minor effect. Should the TALS be implemented the negligible magnitude combined with a medium sensitivity would equate to an effect of Negligible.

16 - Summit of Meall Mor	Distance to nearest Turbine: 15.7 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude(assuming no TALS): Slight Magnitude (TALS): Negligible Effect (assuming no TALS): **Moderate/minor** Effect (TALS): **Negligible** **--** **Viewpoint 16** Summit of Meall Mor is located 15.7 km from the nearest turbine. It lies within Wild Land Area 29 which is discussed in further detail subsequently in this AI. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.23a that the turbines would lie in the middle distance of the view with all 6no. cardinal turbines visible. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 15.7 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 1.23 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. The result being that the aviation lighting will be observed to be comparable in brightness to typical bright stars such as those in Orion, or to car brake lights at distances of about 10 km. In this context it is considered that a slight magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A slight magnitude combined with a medium sensitivity would equate to a moderate/minor effect. Should the TALS be implemented the negligible magnitude combined with a medium sensitivity would equate to an effect of Negligible.

17 -Layby Loch Glascarnoch	Distance to nearest Turbine: 7.2 km Number of lit turbines visible: 3 (T3, 10 and 16) Susceptibility: medium Value: Low Sensitivity: Low-Medium Magnitude (assuming no TALS): Slight Magnitude (TALS): Negligible Effect (assuming no TALS): **Moderate/Minor** Effect (TALS): **Negligible/none** **---** **Viewpoint 17** Layby Loch Glascarnoch is located 7.2 km from the nearest proposed turbine. It represents the view from the A835 and lies outside the identified Wild Land Areas. The night-time view from the viewpoint was illustrated in EIA Figure 4.24e, which showed the worse-case scenario of all 17no. lit turbines. However, following confirmation of the acceptance of the cardinal lighting scheme of 6 lit turbines, only 3no. lit turbines would now be visible from this location (T1, 3, 10 and 16) the locations of which are shown in the wireframe at EIA Figure 4.24c. It is important to recognise that the A835 provides existing sources of lighting in this location from vehicle lighting, in the same angle of view as the turbines. The susceptibility of people taking in the view from this location during the night-time period is therefore reduced to Medium, as whilst it is a generally dark landscape, the road means that lighting is a familiar element of the view in this location. As previously discussed, the value of the view during the night-time period has been established to be low. A medium susceptibility and a low value combine to create a low-medium sensitivity. When considering the magnitude of the impact, it is noted that only 3no. of the 6 lit turbines would be visible, at a distance of 7.2 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 0.39 at this viewpoint based on its elevation compared to the viewpoint and its distance from the nearest lit turbine. In this context it is considered that a slight magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A slight magnitude combined with a low-medium sensitivity would equate to a minor effect. Should the TALS be implemented the negligible magnitude combined with a low-medium sensitivity would equate to an effect of Negligible /none.

18 - Summit of An Teallach	Distance to nearest Turbine: 33.4 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Negligible Magnitude (TALS): Negligible Effect (assuming no TALS): **Minor** Effect (TALS): **Negligible/None** **--** **Viewpoint 18** Summit of An Teallach is located 33.4 km from the nearest turbine. It lies within Wild Land Area 28 which is discussed in further detail subsequently in this AI. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.25a that the turbines would lie in the distance of the view with all 6no. cardinal turbines visible. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 33.4 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 1.25 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. In this context it is considered that a Negligible magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible/none. A Negligible magnitude combined with a medium sensitivity would equate to a minor effect. Should the TALS be implemented the negligible/none magnitude combined with a medium sensitivity would equate to an effect of Negligible /none.

19 - Summit of Little Wyvis	Distance to nearest Turbine: 6.6 km Number of lit turbines visible: 6 (T1, 3, 7, 10, 16 and 17) Susceptibility: High Value: Low Sensitivity: Medium Magnitude (assuming no TALS): Slight Magnitude (TALS): Negligible Effect (assuming no TALS): **Moderate/Minor** Effect (TALS): **Negligible** **---** **Viewpoint 19** Summit of Little Wyvis is located 6.6 km from the nearest turbine. It lies within Wild Land Area 29 which is discussed in further detail subsequently in this AI. Night-time photography was not provided in the EIA or SEI for this location, but it can be seen from the daytime visualisation at EIA Figure 4.26a that the turbines would lie in the middle distance of the view with all 6no. cardinal turbines visible. The viewpoint represents a mountain summit in a landscape which is largely free from existing sources of artificial light. The susceptibility of anyone taking in the view from this location during the night-time period is therefore high. However, the remote nature of the viewpoint is likely to notably restrict the number of receptors who would be present during low light conditions in order to take in the view. As previously discussed, the value of the view during the night-time period has been established to be low. A high susceptibility and a low value combine to create a medium sensitivity. When considering the magnitude of the impact, it is noted that all 6 lit turbines would be visible at a distance of 6.6 km. In addition, regard has been made to the analysis in Appendix 5 which has established that there would be a vertical suppression factor of 0.99 at this viewpoint as a result of its elevated location above the turbines and its distance from the nearest lit turbine. The result being that the aviation lighting will be observed to be comparable in brightness to typical bright stars such as those in Orion, or to car brake lights at distances of about 10km. In this context it is considered that a slight magnitude of change would arise from the Cardinal Lighting Scheme. Should the TALS be implemented, and the lights only be switched on for about 0.1% of the night hours this magnitude would reduce to negligible. A slight magnitude combined with a medium sensitivity would equate to a moderate/minor effect. Should the TALS be implemented the negligible magnitude combined with a medium sensitivity would equate to an effect of Negligible.

Effects of the cardinal lighting scheme on the wild land qualities of Wild Land Areas 28 and 29

Assessment of WLA 28 - Fisherfield – Letterewe – Fannichs

4.27 The Fisherfield – Letterewe – Fannichs WLA extends over 804 km^2 between Poolewe and Gruinard in the north west and the Fannich range in the south east. The area is broadly oval in shape, with a cnocan landscape in the north west, sweeping peatland in the north east, and a range of high rugged mountains and lochs extending over the remainder. The WLA lies approximately 3.6 km to the west of the proposed development at its closest point. Within the WLA are 18 Munros and nine Corbetts. These include An Coileachan (923 m AOD) the summit of which was included as assessment viewpoint 13 in the LVIA (micro-sited to the nearby summit of Faire nam Fiadh for the night-time visualisations) and which lies 11.2 km from the proposed development.

4.28 A plan showing the boundary of WLA 28 along with the theoretical visibility to blade tip of the turbines was included as Figure 4.3b of the EIA. This illustrated that the potential for visibility of any part of the development from within WLA was extremely limited and largely restricted to a small number of elevated summits. Further, analysis contained in the letter from RSK to the Energy Consents Unit and Highland Council dated 12th March 2020 demonstrated the limited proportionate extents to which WLAs – and particularly higher value (class 7 and 8 wildness Jenks class) would be affected by visibility of turbine tips, alone or in combination with LL and CM. A further plan was provided as part of the Lighting Assessment at Appendix 4.9 to illustrate the potential visibility of the turbine lighting (Figure 4.9.1). This demonstrated that the number of locations from which the turbine lights could be seen within WLA28 would be further reduced when compared with the visibility of the blade tips.

4.29 The SEI noted that the LL turbine lights, as well as vehicle headlights on the A835 and other public highways, and also within scattered settlements, are already visible in views out from the WLA, in particular from elevated summits within the eastern half of the WLA.

4.30 It was identified that the proposed lighting (whether all 17no. turbines or the Cardinal Lighting Scheme of 6no. lit turbines) would remain within the same geographical extent of WLA 28 from which the LL or CM lights were already visible. This was demonstrated with reference to the cumulative ZTV at Figure 5.2 of the SEI. It was therefore noted that the principal impact of the lighting associated with the proposed development was the additional effect of the Kirkan lighting, alongside the existing lit turbines, in terms of both overall effect of the lighting and the increased extent of the view in which the lights would be seen.

4.31 With regard to Viewpoint 13 specifically (in its micro-sited location of the summit of Faire nam Fiadh), it was identified that 10no. lit turbines would be visible with the turbines seen alongside the existing lit LL turbines. Figure 5.5b of the SEI illustrated that 2no lit turbines in the LL scheme would be seen to the left of the 10no lit Kirkan turbines. It was noted that should the Cardinal Lighting Scheme of 6no. lit turbines be adopted then this would reduce to only 3 visible lit Kirkan turbines alongside the 2no lit turbines in the LL scheme. This scenario was illustrated in Figure 5.5c

4.32 It was set out in the conclusion presented in the SEI that there would be limited extent of visibility of the lighting within the WLA and that there would be no new areas of the WLA where turbine lighting would become visible where the LL or CM lights were not already visible were also identified. On that basis it was concluded that there would be no significant effects on the WLA should the Cardinal Lighting Scheme of 6no. lit turbines be adopted.

4.33 In their consultation response it is noted that NatureScot suggested that further consideration should be given to the wild land qualities of the WLA. They then proceeded to provide their own consideration of Quality 1 of WLA 28 *'An awe inspiring range of colossal, steep, rocky and rugged mountains interlinked around deep and arresting corries, glens and lochs'.* The conclusion at paragraph 2.10 was that *'The introduction of 17 additional lights to those in the baseline would introduce a substantial new cluster of lights clearly separated from the existing lights from some locations. The effects of these lights would substantially amplify the adverse effects of the exiting lights on the attributes (sense of naturalness and remoteness) and responses (sanctuary and solitude) which underpin this wild land quality'.* NatureScot did not however provide a conclusion in relation to the effects should the Cardinal Lighting Scheme of 6no. lit turbines be adopted. Given the substantial reduction in the number of lit turbines from 17no. to 6no. and with specific regard to Viewpoint 13 where only 3no. visible turbines would be seen, it is considered that the conclusion of the SEI that the effects would not be significant would be applicable to this scenario for this quality of the WLA.

4.34 The other wild land qualities identified for WLA28 are:

- Quality 2 - 'A very large mountain interior with a strong sense of remoteness and sanctuary that attracts intrepid visitors'
- Quality 3 - 'Wide open lochs that highlight the profile of surrounding mountains and offer a contrast of experience in relation to access, human elements and activity'
- Quality 4 - 'Extensive open cnocan and sweeping peatland that contrasts to the high mountains, emphasising the arresting qualities of each'

4.35 With regard to these additional wild land qualities it is considered that none of these would be impacted by the proposed lighting. There would be no visibility of the lighting from the large mountain interior of the WLA, nor from any of the wide open lochs (including Loch Fannich), nor from the areas of extensive open cnocan or sweeping peatland within the north-west and north-east of the WLA.

4.36 NatureScot guidance *'Assessing impacts on Wild Land Areas – Technical Guidance'* notes in paragraph 31 that *'measures to reduce any anticipated effects should be considered' and identifies example measures which might be applied in Box 1. This includes 'identifying lighting options that minimise impacts'*. In this case the applicant has sought to agree mitigation to reduce the number of visible lights from 17no. to 6no. This is a substantial reduction. In turn, further mitigation in the form of a TALS system is also proposed, which would further reduce the potential for any effects almost completely. The Guidance sets out that once mitigation has been considered the residual effects should then be identified. Paragraph 33 identifies that in judging the significance of the residual effects, the following factors should be considered:

- The sensitivity and magnitude of change on the qualities of the WLA.
- The contribution of areas affected to the wider WLA.

- The nature and extent of any likely cumulative effects.
- Whether the impacts are adverse or beneficial, and their longevity

4.37 Each of these matters are addressed in turn below:

The sensitivity and magnitude of change on the qualities of the WLA

4.38 It is acknowledged that the sensitivity of the 4no. Wild Land Qualities is generally speaking high during the daytime period. However, as was noted in the Wild Land Assessment at Appendix 4.6 of the EIA, towards the eastern extent of the WLA the sensitivity may reduce to medium as the sense of remoteness within the WLA is lessened by the presence of the existing LL and CM turbine lights in the baseline landscape. The existing lit turbines representing 'existing detractors' which may reduce sensitivity of the kind referred to in paragraph 23 of the Guidance. Likewise, the value component of sensitivity is also reduced during the night-time period, compared to the daytime, for the reasons discussed previously and this low value also contributes to a reduction in the sensitivity of the Wild Land Qualities,

4.39 In terms of magnitude, there would be no magnitude of change in relation Wild Land Qualities 2-4. For Quality 1 it is noted that paragraph 24 of the Guidance sets out that the consideration of magnitude should include *'the size or scale of change, geographical extent of the area influenced, and their duration and reversibility'*. In this regard it is clear from the ZTV mapping that the geographical extent of the WLA influenced is very limited. In terms of the size or scale of the change, this is limited by the distance between the proposed turbines and the WLA, with the WLA being located a minimum of 3.6 km from the proposed development and Viewpoint 13 in particular located at 11.2 km from the proposed development. It is also limited by the existing presence of aviation lighting in all views from the WLA in which the proposed lighting would be seen. It is also now further limited by the reduction in lit turbines to only 6no, with the further potential for TALS to reduce the time the lights would be switched on to only 0.1% of the night hours.

4.40 The Wild Land Assessment which considered daytime effects of the scheme at Appendix 4.6 of the EIA used the following 5 point scale to consider magnitude:

- Substantial: Total loss or considerable alteration/influence on WLA aspects.
- Moderate: Conspicuous loss or alteration/influence on WLA aspects.
- Slight: Notable, but localised loss, alteration/influence on WLA aspects.
- Negligible: Minor loss or alteration/influence to baseline aspects.
- None: No loss or alteration to baseline aspects

4.41 Following this same approach, it is considered that the magnitude of impact on Wild Land Quality 1 would be Negligible and Negligible to None if the TALS scheme were in operation. Indeed with the TALS scheme there would be almost no effect, noting the operational period of the lights would be about 0.1% of the night hours. The magnitude for Qualities 2-4 would be none.

4.42 The Wild Land Assessment then used the following table to combine sensitivity and magnitude judgements into an overall assessment of effect.

Table 4.3: Magnitude of Change

		Magnitude of Change				
		Substantial	*Moderate*	*Slight*	*Negligible*	*None*
Sensitivity	*High*	Major	Major/moderate	Moderate	Moderate/ minor	None
	Medium	Major/moderate	Moderate	Moderate/minor	Minor	None
	Low	Moderate	Moderate/minor	Minor	Minor/none	None

4.43 Based on this same approach, when the Negligible magnitude is combined with a medium sensitivity this would result in a minor effect for Quality 1, reducing to minor/none with the TALS scheme. The effect for Qualities 2-4 would be none.

The contribution of areas affected to the wider WLA

4.44 The extent of the areas of the WLA affected would be very limited. It is not considered that these areas make a particularly substantive contribution to the wider WLA. The elevated summits have some intervisibility with aspects of the wider WLA, but as previously identified, there would be no effects on the large mountain interior of the WLA, nor from any of the wide open lochs (including Loch Fannich), nor from the areas of extensive open cnocan or sweeping peatland within the north-west and north-east of the WLA.

The nature and extent of any likely cumulative effects

4.45 The existing lit turbines have already been considered as part of the baseline landscape in the discussion of effects above. In turn, it is understood that the proposed LL Ext 2 would not require any visible aviation lighting.

4.46 However, it is recognised that it is important to consider the collective impact to the WLA of the combined effects of the proposed development alongside the lit turbines of LL and CM. In this regard, it is noted that there would still be a relatively small number of lit turbines visible from only a relatively small part of the WLA. It is therefore considered that when the combined effect of the lighting is considered the effect on the WLA would remain not significant.

Whether the impacts are adverse or beneficial, and their longevity

4.47 It is accepted that the impacts are considered to be adverse and long term for the purpose of this assessment.

WLA 28 - Overall Conclusion

4.48 A Cardinal Lighting Scheme of 6no. lit turbines has now been approved. This represents a substantial difference when compared with the worse case scenario of 17no. lit turbines previously considered. The four identified wild land qualities of WLA 28 have been considered with regard to the approach set out in *'Assessing impacts on Wild Land Areas – Technical Guidance'*. This has identified that there would be no effect from the Cardinal Lighting Scheme on wild land qualities 2-4 and only a minor effect on wild land quality 1, reducing to minor/none with the TALS scheme. It is noted that NatureScot set out that they *'consider that a wind farm may be accommodated on this site subject to the significant effects of the turbine lighting being substantially reduced'*. It is considered that the now approved Cardinal Lighting Scheme of 6no. lit turbines represents such a substantial reduction in the effects of the aviation lighting on the Wild Land Area when compared with the scenario whereby all 17no. turbines would be lit. Furthermore, should the TALS be in operation this effect would reduce to almost no effect, noting the operational period of the lights would be about 0.1% of the night hours.

Assessment of WLA 29- Rhiddoroch – Beinn Dearg – Ben Wyvis

4.49 The Rhiddoroch – Beinn Dearg – Ben Wyvis WLA extends 905 km^2 across the north west of Ross-shire and south Sutherland. It comprises a long oval-shaped area extending between Ullapool in the north west to the mountain of Ben Wyvis in the south east. From the north and east, cnocan and open peatland hills extend into a complex composition of high and steep mountains within the central section, and then into simpler rounded hills and plateaux in the south. The WLA lies approximately 3.9 km to the north-east of the proposed development at its closest point. Within the WLA are seven Munros and five Corbetts. These include Ben Wyvis (1,046 m AOD), the summit of which was included as assessment viewpoint 6 in the LVIA and which lies 9.1 km from the proposed development. They also include Beinn Dearg (1,084 m AOD), the summit of which was included as assessment viewpoint 14 in the LVIA and which lies 16.3 km from the proposed development. Viewpoints 15 (Summit of Meall à Ghrianain, 9.1 km from the site), 16 (Summit of Meall Mor, 15.7 km from the site) and 19 (Summit of Little Wyvis, 6.6 km from the site) also lie within WLA 29.

4.50 A plan showing the boundary of WLA 29 along with the theoretical visibility to blade tip of the turbines was included as Figure 4.3b of the EIA. This illustrated that the potential for visibility of any part of the development from within WLA was relatively limited and largely restricted to more elevated summits. A further plan was provided as part of the Lighting Assessment at Appendix 4.9 to illustrate the potential visibility of the turbine lighting (Figure 4.9.1). This demonstrated that the number of locations from which the turbine lights could be seen within WLA29 would be further reduced when compared with the visibility of the blade tips.

4.51 The SEI noted that the LL turbine lights, as well as vehicle headlights on the A835 and other public highways, and also within scattered settlements, are already visible in views out from the WLA, in particular from elevated summits within the southern area of the WLA. Views of existing lighting from built development in the Cromaty Firth were also identified.

4.52 It was identified that the proposed lighting (whether all 17no. turbines or the Cardinal Lighting Scheme of 6no. lit turbines) would largely remain within the same geographical extent of the WLA 29 where the LL and CM lights were already visible. This was demonstrated with reference to the cumulative ZTV at Figure 5.2 of the SEI. It was therefore noted that the principal impact of the lighting associated with the proposed development was the additional effect of the Kirkan lighting, alongside the existing lit turbines, in terms of both overall effect of the lighting and the increased extent of the view in which the lights would be seen.

4.53 With regard to Viewpoint 6, the summit of Ben Wyvis, specifically, it was identified that all 17no. lit turbines would be visible with the turbines seen alongside the existing lit LL and CM turbines. Figure 5.4b of the SEI illustrated that 3no lit turbines would already be seen in the same angle of view slightly beyond the 17no. lit Kirkan turbines. It was noted that should the Cardinal Lighting Scheme be adopted then this would reduce to only 6 visible lit Kirkan turbines alongside the 3no. existing lit turbines. This scenario was illustrated in Figure 5.4c.

4.54 It was set out in the conclusion presented in the SEI that the wild land characteristics of WLA 29, as described in the published Wild Land Areas Descriptions, do not include reference to night characteristics or darkness. The relatively limited extent of visibility of the lighting within the WLA and that there would very few new areas of the WLA where turbine lighting would become visible where the LL or CM lights were not already visible were also identified. Nonetheless, it was noted that the scenario whereby all 17 turbines were lit would have the potential to reduce the perceived remoteness of the landscape at a number of summits, but that this potential would be reduced by the Cardinal Lighting Scheme. On that basis it was concluded that there would be no significant effects on the WLA should the Cardinal Lighting Scheme of 6no. lit turbines be adopted.

4.55 In their consultation response it is noted that NatureScot suggested that further consideration should be given to the wild land qualities of the WLA. They then proceeded to provide their own consideration of both Quality 1 (*'A range of* awe-*inspiring massive, high rounded hills and plateaux, as well as steep rocky peaks and ridges, offering elevated panoramas'*) and Quality 3 (*'A very large interior with a strong sense of remoteness and sanctuary that seems even more extensive where appearing to continue into neighbouring wild land areas'*) of WLA 29. The conclusion at paragraph 2.8 was that the effects on both Quality 1 and Quality 3 of the WLA were *'of a magnitude that is significant'*. NatureScot did not however provide a conclusion in relation to the effects should the Cardinal Lighting Scheme of 6no. lit turbines be adopted. Given the substantial reduction in the number of lit turbines from 17no. to 6no., it is considered that the conclusion of the SEI that the effects would not be significant would be applicable to the Cardinal Lighting Scheme for these two qualities of the WLA. This would then be further substantially reduced by the implementation of the TALS scheme. Both Quality 1 and Quality 3 of the WLA are discussed further below.

4.56 The other wild land qualities identified for WLA29 are:

- Quality 2 - 'Long and deep penetrating glens with steep, arresting side slopes that limit views, some containing access routes and clearly influenced by estate management'
- Quality 4 – 'Rocky hills, cnocan and peatland slopes that appear simple and awe-inspiring at a broad scale, but harbour intricate features at a local level, as well as a strong sense of sanctuary and solitude'

4.57 With regard to these additional wild land qualities, it is considered that Quality 2 would not be impacted by the proposed lighting, as the physical nature of the glens would not be altered. It is however recognised that there may be the potential for impacts to the sense of sanctuary and solitude referred to in Quality 4 and so this Quality is also addressed further below alongside Quality 1 and 3.

4.58 NatureScot guidance 'Assessing impacts on Wild Land Areas – Technical Guidance' notes in paragraph 31 that 'measures to reduce any anticipated effects should be considered' and identifies example measures which might be applied in Box 1. This includes 'identifying lighting options that minimise impacts'. In this case the applicant has sought to agree mitigation to reduce the number of visible lights from 17no. to 6no. This is a substantial reduction. In turn, further mitigation in the form of a TALS system is also proposed, which would further reduce the potential for any effects almost completely. The Guidance sets out that once mitigation has been considered the residual effects should then be identified. Paragraph 33 identifies that in judging the significance of the residual effects, the following factors should be considered:

- The sensitivity and magnitude of change on the qualities of the WLA.
- The contribution of areas affected to the wider WLA.
- The nature and extent of any likely cumulative effects.
- Whether the impacts are adverse or beneficial, and their longevity

4.59 Each of these matters are addressed in turn below:

<u>The sensitivity and magnitude of change on the qualities of the WLA</u>

4.60 It is acknowledged that the sensitivity of the 4no. Wild Land Qualities is generally speaking high. However, as was noted in the Wild Land Assessment at Appendix 4.6 of the EIA, reductions in sensitivity occur at locations around the edges of the WLA and at a small number of especially high summits from where the influence of man-made elements such as dwellings, tracks, roads and adjacent wind farms are evident in views and detract from the more natural landscape composition within the WLA, most notably the southernmost extents of the WLA. Again, in some cases the sense of remoteness within the WLA is lessened by the presence of the existing LL and CM turbines, which are already lit in the baseline landscape. The existing lit turbines represent 'existing detractors' of the kind which may reduce sensitivity referred to in paragraph 23 of the Guidance.

4.61 In terms of magnitude, there would be no magnitude of change in relation Wild Land Quality 2. For Qualities 1, 3 and 4 it is noted that paragraph 24 of the Guidance sets out that the consideration of magnitude should include *'the size or scale of change, geographical extent of the area influenced, and their duration and reversibility'*. In this regard it is clear from the ZTV mapping that the geographical extent of the WLA influenced is relatively limited. In terms of the size or scale of the change, this is limited by the existing presence of aviation lighting in the majority of views from the WLA in which the proposed lighting would be seen. It is also now limited by the reduction in lit turbines to only 6no. It is also reduced by the WLA being located a minimum of 3.9 km from the proposed development, with Viewpoint 19 (Little Wyvis) located at 6.6 km from the proposed development and Viewpoint 6 (Ben Wyvis) located at 9.1 km.

4.62 The Wild Land Assessment which considered daytime effects of the scheme at Appendix 4.6 of the EIA used the following 5 point scale to consider magnitude:

- Substantial: Total loss or considerable alteration/influence on WLA aspects.
- Moderate: Conspicuous loss or alteration/influence on WLA aspects.
- Slight: Notable, but localised loss, alteration/influence on WLA aspects.
- Negligible: Minor loss or alteration/influence to baseline aspects.

- None: No loss or alteration to baseline aspects.

4.63 Following this same approach, it is considered that the magnitude of impact on Wild Land Qualities 1, 3 and 4 would be Negligible, reducing to Negligible to none were the TALS scheme to be implemented. Indeed with the TALS scheme there would be almost no effect, noting the operational period of the lights would be about 0.1% of the night hours. The magnitude for Quality 2 would be none.

4.64 The Wild Land Assessment then used the following table to combine sensitivity and magnitude judgements into an overall assessment of effect:

		Magnitude of Change				
		Substantial	*Moderate*	*Slight*	*Negligible*	*None*
Sensitivity	*High*	Major	Major/moderate	Moderate	Moderate/ minor	None
	Medium	Major/moderate	Moderate	Moderate/minor	Minor	None
	Low	Moderate	Moderate/minor	Minor	Minor/none	None

4.65 Based on this same approach, when the Negligible magnitude is combined with a High sensitivity this would result in a moderate/minor effect for Qualities 1, 3 and 4, which is not considered to be significant, reducing to minor/none with the TALS scheme. The effect for Quality 2 would be none.

The contribution of areas affected to the wider WLA

4.66 The extent of the areas of the WLA affected would be limited. It is not considered that the majority of these areas make a particularly substantive contribution to the wider WLA, albeit that the importance of the Wyvis massif within the WLA as a whole is acknowledged.

The nature and extent of any likely cumulative effects

4.67 The existing lit turbines have already been considered as part of the baseline landscape in the discussion of effects above. In turn, it is understood that the proposed LL Ext 2 would not require any visible aviation lighting.

4.68 However, it is recognised that it is important to consider the collective impact to the WLA of the combined effects of the proposed development alongside the lit turbines of LL and CM. In this regard, it is noted that there would still be a relatively small number of lit turbines visible from only a relatively small part of the WLA. It is therefore considered that when the combined effect of the lighting is considered the effect on the WLA would remain not significant.

Whether the impacts are adverse or beneficial, and their longevity

4.69 It is accepted that the impacts are considered to be adverse and long term for the purpose of this assessment.

WLA 29 - Overall Conclusion

4.70 A Cardinal Lighting Scheme of 6no. lit turbines has now been approved. This represents a substantial difference when compared with the worse case scenario of

17no. lit turbines previously considered. The four identified wild land qualities of WLA 29 have been considered with regard to the approach set out in 'Assessing impacts on Wild Land Areas – Technical Guidance'. This has identified that there would be no effect from the Cardinal Lighting Scheme on wild land quality 2 and only a moderate/minor effect, which is not significant, on wild land qualities 1, 3 and 4, reducing to minor/none with the TALS scheme. It is noted that NatureScot set out that they '**consider that a wind farm may be accommodated on this site subject to the significant effects of the turbine lighting being substantially reduced**'. It is considered that the now approved Cardinal Lighting Scheme of 6no. lit turbines represents such a substantial reduction in the effects of the aviation lighting on the Wild Land Area when compared with the scenario whereby all 17no. turbines would be lit. Furthermore, should the TALS be in operation this effect would reduce to almost no effect, noting the operational period of the lights would be about 0.1% of the night hours.

5 NOISE

Background

5.1 **Chapter 10** of the Environmental Impact Assessment Report (EIAR) contained a detailed assessment of the noise and vibration impacts of the proposed development. This chapter was accompanied by **Appendix 10.1** which provided additional details regarding the assessment, in particular regarding the baseline noise survey and operational noise predictions. Finally, **Figure 10.1** indicated the location of the different noise-sensitive properties considered and baseline noise locations.

5.2 The operational noise assessments presented in the EIAR and Appendix 10.1 considered operational noise from the proposed development as well as cumulative impacts from other operational or consented sites in the area: the neighbouring Corriemoillie Windfarm (CM) and the Lochluichart Windfarm (LL) and its first Extension (“LL Ext 1”). In addition, an assessment of the potential impact of operational noise from the Lochluichart Windfarm Extension II (“LL Ext 2”) was presented based on an early indicative layout of 9 turbines, as the application for that scheme had not been submitted at the time the EIAR was being finalised.

Supplementary Assessment

5.3 Subsequent to the submission of the EIAR, the application for LL Ext 2 was submitted based on a layout comprising 5 turbines with a tip height of up to 133 m, and the scheme was subsequently consented[1] on this basis. Subsequently, an additional application[2] (“LL Ext 2b”) was made in 2021 to vary the consent for LL Ext 2 to increase the maximum turbine tip height to 149.9 m: this was supported by an updated noise assessment and EIAR. This application remains undetermined.

5.4 The Environmental Health officer of the Highland Council (THC) noted in his response[3] to the application for the proposed development there were differences in the results of the respective operational noise assessments between the EIAR for the proposed development and that of LL Ext 2, which therefore introduced difficulties when conditioning the schemes. These differences were due to the EIAR for the LL Ext 2 being based on the final layout of that wind farm (with 5 turbines), instead of a preliminary 9-turbine layout which was assumed in the cumulative assessment for Kirkan Wind Farm. In addition, the cumulative analysis in the EIAR for the LL Ext 2 did not include an assessment of the proposed development. The present chapter therefore presents an updated cumulative assessment including the consented LL Ext 2 wind farm, and also considers a subsequent application to increase the maximum tip height of the LL Ext 2 windfarm (LL Ext 2b).

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[1] Highland Council planning reference 19/01284/FUL, consent dated 01 July 2020.

[2] Highland Council planning application reference 21/02985/FUL, June 2021.

[3] Highland Council, Kirkan Wind Farm, Handling Report for Cases Recommended For Refusal, planning reference 19/01861/S36, paragraph 10.99.

5.5 In addition, changes are proposed to the layout of the proposed development, as described above in **Section 1** (Figure 1.1), and therefore the effect of these changes in terms of operational noise are also assessed.

5.6 The EIAR previously assessed the temporary impacts of noise associated with the construction of the proposed development. The proposed changes would either not materially affect this assessment or lead to reduced impacts, but the overall conclusions and proposed mitigation measures would still be considered applicable. Construction noise is therefore not considered further in the present assessment.

Applicable noise limits

5.7 The baseline noise environment described in the EIAR remains representative and suitable for the basis of the analysis and deriving noise limits in accordance with ETSU-R-97, with no adverse comments received from THC in this regard.

5.8 The EIAR (**chapter 10 and Appendix 10.1**) previously presented noise limits determined in line with ETSU-R-97 guidance (based on site-specific considerations), with fixed lower limits of 38 dB and 43 dB L_{A90} for day-time and night-time respectively.

5.9 In the present assessment, it is proposed to increase the minimum day-time limit for Aultguish Inn to a level of 40 dB, because of an update in the cumulative noise situation in the area associated with the permission for the LL Ext 2 windfarm which was made subsequent to the submission of the EIAR. The proposed day-time limit is within the range of 35 to 40 dB set out in the ETSU-R-97 guidance and is justified by the site-specific considerations which are considered in further detail later in this chapter (see paragraphs 5.17-5.18 below). The resulting set of noise limits are set out below in **Tables 5-1 and 5-2**, and these apply to cumulative noise levels.

Table 5.1: Revised day-time ETSU-R-97 noise limits (L_{A90}, dB)

	Standardised 10 m Wind Speed (m/s)								
Property	4	5	6	7	8	9	10	11	12
Aultguish Inn	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Black Bridge	38.0	38.0	38.0	38.0	38.7	41.0	41.0	41.0	41.0
Hydro House	38.0	38.0	38.0	38.0	38.7	41.0	41.0	41.0	41.0
Lubfearn	38.1	38.9	40.0	41.1	42.4	43.9	43.9	43.9	43.9

Table 5.2: Revised night-time ETSU-R-97 noise limits (L_{A90}, dB)

	Standardised 10 m Wind Speed (m/s)								
Property	4	5	6	7	8	9	10	11	12
Aultguish Inn	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0
Black Bridge	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0
Hydro House	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0

Lubfearn	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0

Operational noise predictions – scheme in isolation

5.10 The proposed changes to the locations of turbines 05 and 07 (as shown in **Figure 1.1**), with all other details unchanged, lead to only small and inconsequential differences in the resulting noise levels predicted at nearby noise-sensitive properties because of their respective locations. No other changes are proposed to the proposed development which would affect operational noise levels. For completeness, **Table 5-3** presents revised predicted noise levels for the proposed development in isolation at the relevant noise assessment locations. This corresponds to differences of 0.1 dB or less compared with the corresponding predictions previously set out in **Appendix 10.1** of the EIAR.

Table 5.3: Revised predicted noise levels for the proposed development in isolation (L_{A90}, dB)

	Standardised 10 m Wind Speed (m/s)								
Property	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Aultguish Inn	20.5	26.0	30.2	31.5	31.5	31.5	31.5	31.5	31.5
Black Bridge	19.1	24.6	28.8	30.1	30.1	30.1	30.1	30.1	30.1
Hydro House	19.0	24.5	28.7	30.0	30.0	30.0	30.0	30.0	30.0
Lubfearn	20.0	25.5	29.7	31.0	31.0	31.0	31.0	31.0	31.0

Operational noise predictions – cumulative

5.11 The previous EIAR for the proposed development (**chapter 10 and Appendix 10.1**) described the assumptions made in relation to the neighbouring CM and LL and LL Ext 1 windfarms. These are considered robust and in line with current best practice: in addition to assuming robust noise emission data for the installed turbine models, an additional uplift was also applied if such an increase could be accommodated within the noise limits in the individual consents for each of these respective sites. For reference, the resulting predictions are set out below in **Tables 5-4** for the relevant noise-sensitive properties.

Table 5.4: Predicted noise levels (L_{A90}, dB) - CM, LL and LL Ext 1 windfarms (combined)

	Standardised 10 m Wind Speed (m/s)								
Property	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Aultguish Inn	26.5	30.2	33.8	35.7	36.3	36.3	36.3	36.3	36.3
Black Bridge	23.0	26.9	30.8	32.7	33.4	33.4	33.4	33.4	33.4
Hydro House	22.6	26.3	30.0	31.9	32.5	32.5	32.5	32.5	32.5

Lubfearn	20.1	23.6	26.8	28.7	29.2	29.2	29.2	29.2	29.2

5.12 In the present supplementary assessment, the cumulative assessment also includes and updated assessment of LL Ext 2, based on the consented[4] layout of 5 turbines with a maximum tip height of 133 m. Subsequently, an application was more recently submitted to increase the allowable turbine tip height of up to 150 m (LL Ext 2b). Although not currently consented, to reflect this potential development, the LL Ext 2 wind farm was modelled using the same Nordex N133 4.8 MW candidate wind turbine modelled for the proposed development, with a 83 m hub height, representing a maximum tip height of 149.5 m: the relevant noise emission levels are described in **Appendix 10.1**, and are considered robust in this regard. It was also noted that the 2021 noise assessment for the LL Ext 2b proposal assumed the same noise limits for that scheme as those set out in the 2020 extant consent.

5.13 The resulting predicted noise levels are set out in **Table 5-5** below.

Table 5.5: Predicted noise levels (L_{A90}, dB) - LL Ext 2 windfarm - Nordex N133 with tip height below 150 m

	Standardised 10 m Wind Speed (m/s)								
Property	4	5	6	7	8	9	10	11	12
Aultguish Inn	18.4	23.9	28.1	29.4	29.4	29.4	29.4	29.4	29.4
Black Bridge	13.3	18.8	23.0	24.3	24.3	24.3	24.3	24.3	24.3
Hydro House	12.9	18.4	22.6	23.9	23.9	23.9	23.9	23.9	23.9
Lubfearn	9.8	15.3	19.5	20.8	20.8	20.8	20.8	20.8	20.8

5.14 The predictions of **Table 5-5** at Aultguish Inn are below the noise levels prescribed in the 2020 consent for LL Ext 2. It is therefore possible for the site as consented to produce more noise while remaining within the bounds of its consent. This would also be the case if the 2021 application for an increased tip height is consented on the same basis. **Table 5-6** therefore considers revised (conservative) predicted noise levels which have been increased such that predictions for LL Ext 2 at Aultguish Inn equal those set out in the 2020 consent, with corresponding increased noise levels at the other locations considered. This provides a robust basis for the analysis.

Table 5.6: Predicted noise levels (L_{A90}, dB) - LL Ext 2, with uplift allowed under consent for the scheme

	Standardised 10 m Wind Speed (m/s)								
Property	4	5	6	7	8	9	10	11	12
Aultguish Inn	24.5	27.8	30.7	31.1	31.1	31.1	31.1	31.1	31.1
Black Bridge	19.4	22.7	25.6	26.0	26.0	26.0	26.0	26.0	26.0

[4] Consent dated July 2020, planning reference 19/01284/FUL.

Hydro House	19.0	22.3	25.2	25.6	25.6	25.6	25.6	25.6	25.6
Lubfearn	15.9	19.2	22.1	22.5	22.5	22.5	22.5	22.5	22.5

5.15 **Table 5-7** below then sets out the resulting total cumulative noise levels, including all wind farms described above, including the proposed development, which results from the logarithmic addition of **Tables 5-3, 5-4 and 5-6**.

Table 5.7: Revised predicted cumulative noise levels (L_{A90}, dB)

	Standardised 10 m Wind Speed (m/s)								
Property	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Aultguish Inn	29.6	33.5	37.2	38.7	39.1	39.1	39.1	39.1	39.1
Black Bridge	25.7	29.9	33.8	35.3	35.7	35.7	35.7	35.7	35.7
Hydro House	25.6	29.8	33.7	35.2	35.6	35.6	35.6	35.6	35.6
Lubfearn	24.3	28.8	32.7	34.2	34.4	34.4	34.4	34.4	34.4

Table 5.8: Difference between the derived day time noise limits (Table 5.1) and the cumulative predicted wind farm noise levels (Table 5-7) at each noise assessment location. Negative values indicate the noise immission level is below the limit (L_{A90}, dB)

	Standardised 10 m Wind Speed (m/s)								
Property	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Aultguish Inn	-10.4	-6.5	-2.8	-1.3	-0.9	-0.9	-0.9	-0.9	-0.9
Black Bridge	-12.3	-8.1	-4.2	-2.7	-3.0	-5.4	-5.4	-5.4	-5.4
Hydro House	-12.4	-8.2	-4.4	-2.8	-3.1	-5.5	-5.5	-5.5	-5.5
Lubfearn	-13.8	-10.2	-7.3	-7.0	-8.0	-9.4	-9.4	-9.4	-9.4

Table 5.9: Difference between the derived night-time noise limits (Table 5-2) and the cumulative predicted wind farm noise levels (Table 5-7) at each noise assessment location. Negative values indicate the noise immission level is below the limit (L_{A90}, dB)

	Standardised 10 m Wind Speed (m/s)								
Property	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Aultguish Inn	-13.4	-9.5	-5.8	-4.3	-3.9	-3.9	-3.9	-3.9	-3.9
Black Bridge	-17.3	-13.1	-9.2	-7.7	-7.4	-7.4	-7.4	-7.4	-7.4
Hydro House	-17.4	-13.2	-9.4	-7.8	-7.5	-7.5	-7.5	-7.5	-7.5
Lubfearn	-18.7	-14.3	-10.3	-8.9	-8.6	-8.6	-8.6	-8.6	-8.6

5.16 The assessment presented in **Tables 5.8 and 5.9** shows that the predicted revised cumulative wind farm noise immission levels meet the derived noise limits under all wind speeds and at all locations. This is based on robust cumulative noise predictions, including conservative increases, with actual cumulative noise levels likely to be lower in practice.

5.17 The ETSU-R-97 fixed part of the limit during the day-time should lie within the range from 35 dB(A) to 40 dB(A). The factors to be used to determine where in this range have been discussed previously in **Chapter 10 and Appendix 10.1** of the EIAR and are set out in ETSU-R-97: the number of properties, duration and level of exposure, and the effect of the limit on generation capacity. The noise limits of **Tables 5.1** include an increased fixed level of 40 dB at Aultguish Inn. This is for a number of reasons:

- **Number of properties**: The site is in an area of very low population density, with only a very limited number of dwellings considered despite the extensive size of the site. An increased lower noise limit at the upper end of the range set out in ETSU-R-97 is only being considered for a single specific property.
- **Duration and level of exposure**: the proposed Kirkan Wind Farm is located south of Aultguish Inn, which is also the case for the other consented schemes in the area (Corriemoillie Windfarm and the Lochluichart Windfarm and Extensions). Therefore, the property will be broadly downwind from these sites and therefore exposed to noise from these consented sites during southerly winds, which will also be the case for the proposed development. During northerly wind conditions, the property would be upwind of these windfarms, resulting in reduced noise levels. Furthermore, the proposed development (in isolation), with predicted levels of less than 32 dB L_{A90} (see **Table 5.3**) only represents a marginal contribution to the cumulative total, which is dominated by levels of up to around 38 dB L_{A90} from the existing or consented sites, based on the conservative assumptions made in the cumulative noise modelling. Therefore, the proposed development would only represent make a marginal increase in the cumulative duration and level of exposure to wind turbine noise for this property.
- **Generation capacity**: The generation of the proposed development is substantial. Given that the predicted contribution of the proposed development to the cumulative total noise level is marginal, as described above, this means that the impact on the generation capacity of the proposed development of reducing the cumulative noise limit is relevant. That impact would be substantial[5] and disproportionate.

5.18 It is therefore considered wholly appropriate to assess cumulative noise levels on the basis of an increased lower noise limit of 40 dB for Aultguish Inn, as this only results in marginal increase in exposure on a single property, and would otherwise result in a disproportionate impact on generation capacity of the proposed development, given the current context. It is important to note that the same lower cumulative day-time limit was proposed for the LL Ext 2 scheme and accepted by the Council when granting permission.

[5] For example, to reduce cumulative noise levels by 0.5 dB, which would generally be considered insignificant, a reduction of more than 4 dB in the contribution of the proposal would be required, which would likely require a combination of the suppression of several of the closest turbines to the property and operation of some turbines in reduced noise operation which would correspond to a substantial loss of generation capacity for the site.

5.19 Updated values of specific noise limits for the proposed development (in isolation), are shown below in **Tables 5.10 and 5.11**. It is proposed that these should be imported into a planning condition for consent of the proposed development. These limits were derived in line with current good practice by considering the remaining noise "budget" by subtracting the contribution of schemes other than the proposed development from the total ETSU-R-97 noise limits of **Tables 5.1 and 5.2**. This was then adjusted so that the resulting noise limit did not artificially increase at low wind speeds. Satisfactory control of cumulative noise immission levels would be achieved through enforcement of the individual consent limits for each of the individual wind farms.

Table 5.10: Specific day-time noise limits proposed for the proposed development in isolation (L_{A90}, dB)

	Standardised 10 m Wind Speed (m/s)								
Property	4	5	6	7	8	9	10	11	12
Aultguish Inn	35.2	35.2	35.2	35.2	35.2	35.2	35.2	35.2	35.2
Black Bridge	36.0	36.0	36.0	36.0	36.6	39.0	39.0	39.0	39.0
Hydro House	36.0	36.0	36.0	36.0	36.7	39.1	39.1	39.1	39.1
Lubfearn	37.6	38.4	39.5	40.6	41.9	43.4	43.4	43.4	43.4

Table 5.11: Specific night-time noise limits proposed for the proposed development in isolation (L_{A90}, dB)

	Standardised 10 m Wind Speed (m/s)								
Property	4	5	6	7	8	9	10	11	12
Aultguish Inn	41.2	41.2	41.2	41.2	41.2	41.2	41.2	41.2	41.2
Black Bridge	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4
Hydro House	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4	42.4
Lubfearn	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5

5.20 In conclusion, taking into account the latest information and an updated operational noise analysis, which includes a revised cumulative assessment, noise levels are predicted to be compliant with noise limits derived in accordance with the ETSU-R-97 guidance. This could be secured in practice through appropriate planning conditions.

5.21 Depending on the levels of background noise, the satisfaction of the derived limits could lead to a situation whereby, at some locations under some wind conditions and for a certain proportion of the time, the wind farm noise may be audible. However, noise levels at the properties in the vicinity of the wind farm would still be within levels considered acceptable under the ETSU-R-97 assessment method and therefore remain not significant.

6 CONCLUDING REMARKS

Hydrology and Peat

6.1 The principal concerns raised by SEPA were in relation to peat, mostly relating to the estimated volumes of peat that would require excavation to allow wind farm construction to go ahead. Minor relocations of two turbines have allowed revised peat estimates to be reduced, while minimising changes in other respects.

6.2 The relocations of Turbines 5 and 7 have provided a considerable reduction in estimated peat excavation volumes. This is in part a result of the reorientation of the access and crane pad for Turbine 7. The changes to Turbine 5 are more minor in scope. An overall reduction in anticipated peat excavation of 15% from the original layout, and 9.4% from the SEI layout, has been achieved by these small adjustments.

Recreational walkers and rights of way

6.3 The Scottish Rights of Way and Access Society (ScotWays) objected to the application for consent (March 2019) on the basis of the recreational baseline established in Figure 4.4 of the EIA report being incomplete, and that no mitigation for blocking public access along a right of way during the construction period was provided.

6.4 Matters raised by Scotways are addressed in Section 3 above. An updated version of the recreational baseline figure is provided as Figure 3.1, and the applicant commits to putting in place a temporary diversion to allow public access in the vicinity of the right of way during the construction phase of the proposed development (see Section 3.6 above).

Landscape

6.5 Three principal landscape and visual matters have been considered in this AI:

- The potential for any changes to the landscape and visual effects previously identified in the EIA and SEI, following the micrositing of T5 and T7.
- The potential for any changes to the cumulative effects previously identified in the EIA and SEI as a result of changes to cumulative situation within the 45 km study area.
- Confirmation of the landscape and visual effects of the proposed aviation lighting strategy following confirmation that the Civil Aviation Authority have approved the Cardinal Lighting Scheme of 6no. lit turbines.

6.6 A review has been undertaken to establish whether the micrositing of T5 and T7 would be of such a nature to bring about any change to the extent of significant landscape and visual effects previously identified in the EIA and SEI. Given the very minor difference in location between the previous turbine locations and those currently proposed, it is not considered that there would be any such change.

6.7 Since submission of the SEI it is noted that there have been updates to the cumulative schemes within 45 km. These include a revised application for the Lochluichart II

Extension which was submitted in June 2021 (for five turbines of up to 149.9 m to tip). it is not however considered that there would be any material change to the findings of the previous cumulative assessment set out in the SEI. In summary, these were that the inclusion of the Lochluichart Extension II would add to the significant sequential cumulative effect on the A835, but that in all other respects the scheme would not alter the findings of the earlier cumulative assessment work from the EIA, with no further significant effects arising.

6.8 With regard to the landscape and visual effects of the proposed aviation lighting, an updated assessment of each of the LVIA Viewpoints during the night-time period has been undertaken. In addition, a further assessment with regard to the effects of the turbine lighting on the wild land qualities of Wild Land Areas 28 and 29 is also provided. In no case are any significant effects identified during the night-time period for the Cardinal Lighting Scheme of 6no. lit turbines, either on any of the LVIA Viewpoints or the wild land qualities of Wild Land Areas 28 and 29. Furthermore, should a Transponder Activated Lighting Scheme (TALS) be installed, any effects which would occur would only arise for 0.1% of the night hours.

Noise

6.9 An updated assessment of operational noise impacts, including cumulative was undertaken. This reflects the changes proposed to the layout of the proposed development, the latest information for the Lochluichart Windfarm Extension II (LL Ext 2 and LL Ext 2b), as well as updated information on the status of the nearest noise-sensitive receptor. Consultation feedback from THC was also taken into account. It is concluded that noise levels are predicted to be compliant with noise limits derived in accordance with the ETSU-R-97 guidance. This could be secured in practice through appropriate planning conditions, with suitable noise limits suggested in the relevant section.

Other environmental disciplines

6.10 As a result of the consultations undertaken with SEPA, amendments to two turbine locations and their connecting access tracks have been included in this AI report, in order to reduce the potential requirement to excavate peat (see Section 2). The revised layout is shown in Figure 1.1. Beyond the detailed assessments described above in Sections 2 (hydrology and peat), 3 recreational walkers and rights of way), 4 (landscape and visual impact) and 5 (noise), a summary of the implications for the other environmental subjects is provided below.

Archaeology and cultural heritage

6.11 The proposed revisions to the location of Turbines 5 and 7 and connecting tracks (Figure 1.1) do not impact on any previously identified heritage assets, or areas identified of being of archaeological potential.

6.12 As a result of the proposed modification, the impacts reported within Chapter 5 of the EIA Report (March 2019) remain the same, and no additional mitigation is proposed.

Ecology

6.13 The effect of the proposed development on other ecological features is predicted to be the same than what was previously determined.

6.14 There would be no substantive change in the findings of the assessment as set out in the EIA Report (March 2019) in relation to ecology.

Ornithology

6.15 The effect of the proposed development on ornithological receptors is predicted to be the same than what was previously determined.

6.16 There would be no substantive change in the findings of the assessment as set out in the EIA Report (March 2019) in relation to ornithology.

Traffic and transportation

6.17 No change in the impact assessment reported in the EIA Report (March 2019) and SEI Report (October 2019) is predicted for traffic and transportation. The overall length of access track, and therefore the raw materials required to be imported to the site, have been reduced as a result of the proposed revised layout (see Figures 1.1). However, the change in volume is not such that it would change the conclusions in Chapter 11 of the EIA Report.

Aviation, radar and telecoms

6.18 Due to the small relative change in turbine locations, it is considered that there will be no change in the impact assessment reported in the EIA Report (March 2019) and SEI Report (October 2019) is predicted for aviation, radar and telecoms.

Climate change

6.19 The proposed revisions to the location of Turbines 5 and 7 and connecting tracks (Figure 1.1) slightly reduce the potential volume of peat that would be disturbed by the proposed development. The modification to the location of Turbine 5 would also slightly reduce the potential removal of forestry associated with the proposed development. However, the impacts reported within the chapter remain the same.

Forestry

6.20 The proposed revisions to the proposed development shown in Figure 1.1, in particular the re-location of Turbine 5 and its connecting track slightly reduce the potential area of forestry that would be disturbed by the proposed development, in comparison with the calculations presented in Appendix 2.1 of the EIA report (March 2021). No additional mitigation or assessment is required.

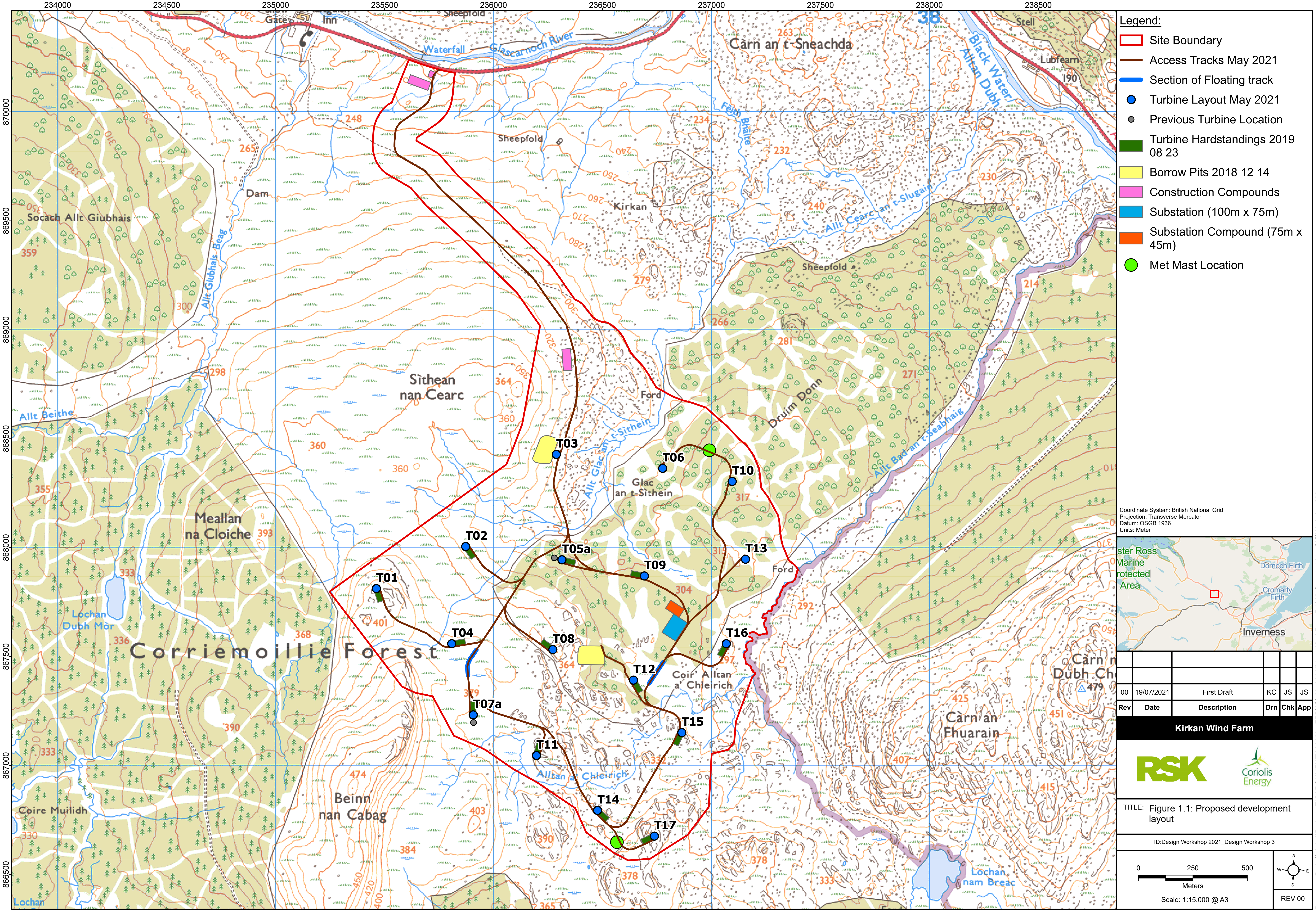
Summary of Environmental Commitments

6.21 The environmental mitigation included in Chapter 14 of the EIA Report and Table 4.1 of the SEI report would continue to be committed to by the applicant. Based on the additional information presented in this AI, the following additional mitigation (as detailed in Sections 2 to 5 above) would be committed to.

Table 6.1: Summary of additional Environmental Commitments identified in the AI

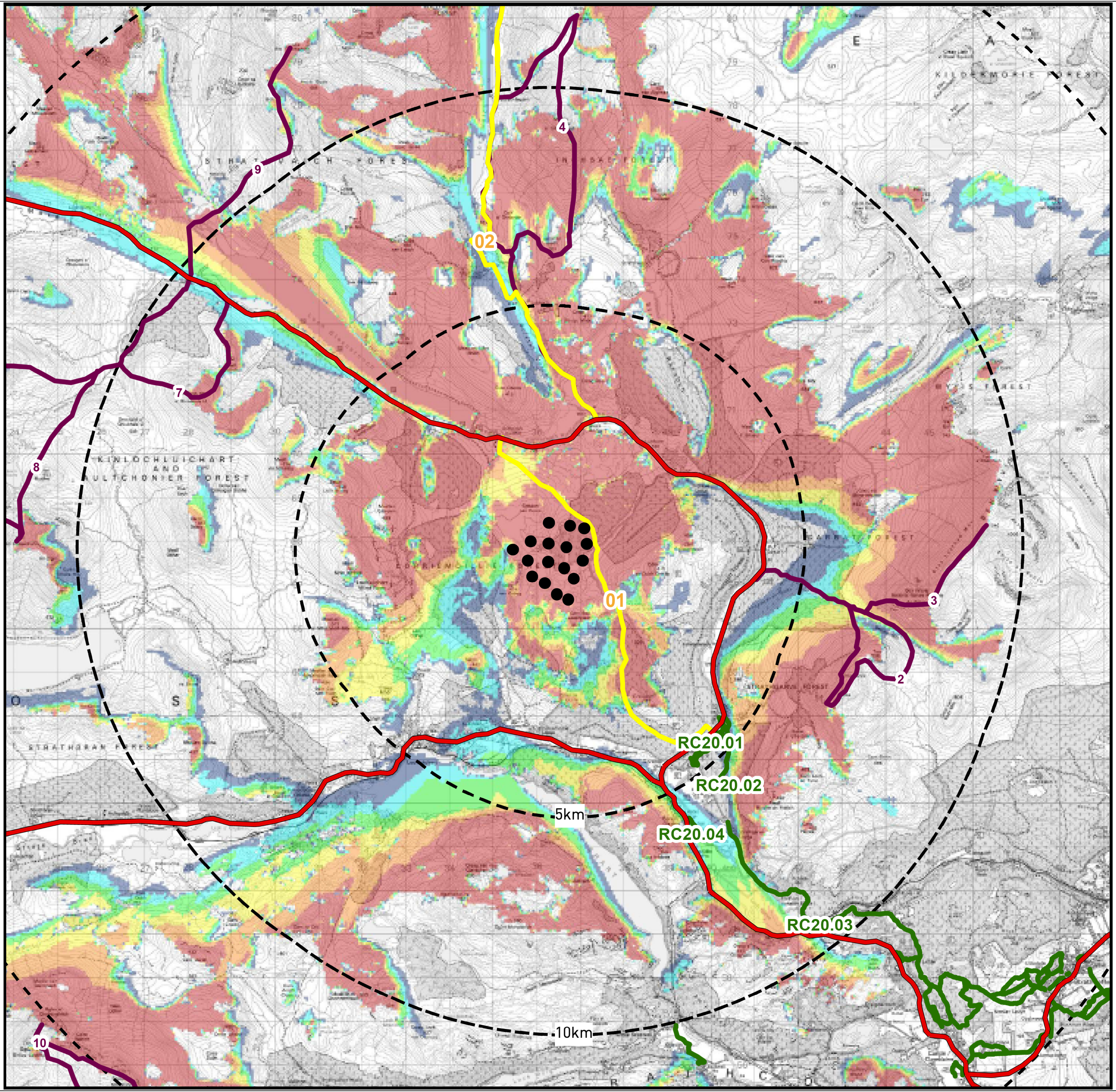
Ref	Issue	Description of mitigation measure (reference within text)	Timing	Responsible Party
Recreational walkers and rights of way				
3.6 of AI report	Block to public access along a right of way during the construction period (HR46 Fish Road)	A temporary diversion will be put in place for HR46 Fish Road. The temporary diversion will be agreed with THC access team in advance of construction and will remain in place for the duration of the construction programme.	Pre-construction and construction	Developer/ Contractor

APPENDIX 1 DEVELOPMENT LAYOUT & RECREATION ROUTES FIGURES



Map data © OpenStreetMap contributors, Microsoft, Esri Community Maps contributors, Map layer by Esri, National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Document Path: \\gl-dc1\Projects\ENVIRONMENT\660000 - EPD(G) 661694 Kirkan Wind Farm EIA\08 Graphics\01 - GIS\Workshop2021.aprx



Legend:

- Proposed Turbine
- 5 km, 10 km, 15 km radius from outermost turbines
- A road
- B Road

Heritage paths
01 The Fish Road/Drovers Road (right of way HR46)
02 Croick to Black Bridge Track

Core Paths
RC20.01 and RC20.02 – Tor Breac
RC20.03 – Kinellan to Strathgarve
RC20.04 – Village River Path

Walk Highlands website routes
2 – Little Wyvis
3 - Ben Wyvis
4 - Beinn a' Chaisteil, via Strath Vaich
7- Beinn Liath Mhòr a'Ghiubhais Li, Loch Glascarnoch
8 - Sgùrr Mòr and the eastern Fannichs
9 - Am Faochagach
10- Sgùrr a' Mhuilinn and Meallan nan Uan, Strathconon

Number of turbines visible at blade tip level (175m)

- 1 to 3
- 4 to 6
- 7 to 9
- 10 to 12
- 13 to 15
- 16 to 17

Pegasus
Environment

PLANNING | DESIGN | ENVIRONMENT | ECONOMICS | HERITAGE

Rev	Date	Description	Drn	App
	Sept. 2021	First issue	EK	DT

Kirkan Wind Farm

RSK
Coriolis Energy

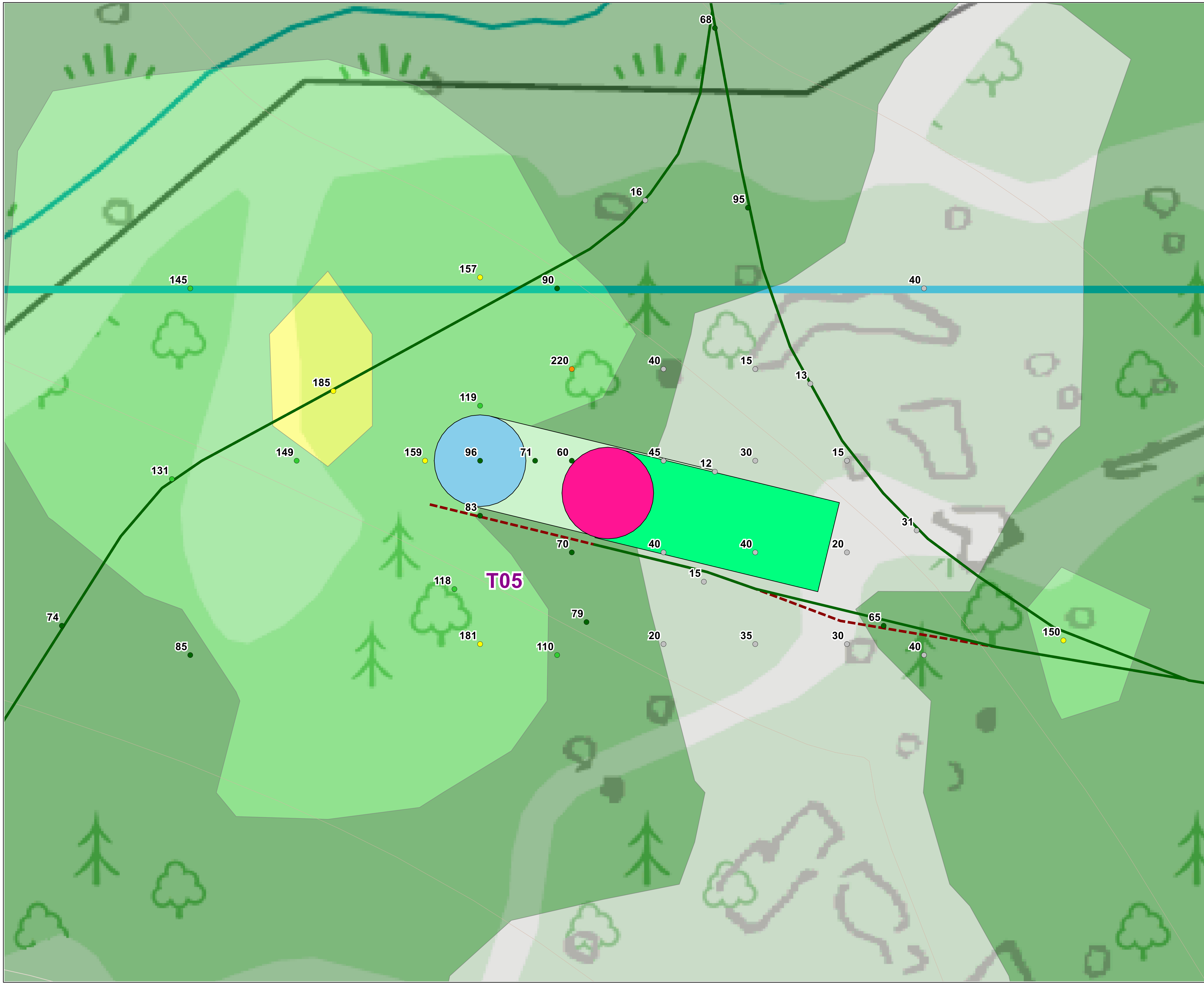
Figure 3.1 - Transportation Routes, Recreational Routes and Summits within 10km

Scale:
1:90,000 @ A3

0 500 1000 1500 2000 m

DWG:
P20-3157.001

APPENDIX 2 HYDROLOGY AND PEAT FIGURES



Legend:

Site Boundary

Previous Access Track

Previous Turbine Location

Previous Turbine Hardstanding

Revised Access Track

Revised Turbine Location

Revised Turbine Hardstanding

All peat depths are reported in centimetres

Notes:- Peat depths on map are shown in cm below ground.

This map source contains data from the following sources:
Ordnance Survey (2021)

Co-ordinate system: British National Grid
Projection: Transverse Mercator
Datum: OSGB 1936
Units: Metre

Rev	Date	Description	Drn	Chk	App
01	02/09/2021	Number update	CI	CI	JS
00	26/08/2021	First Draft	CI	CI	JS

Kirkan Wind Farm

RSK

Coriolis Energy

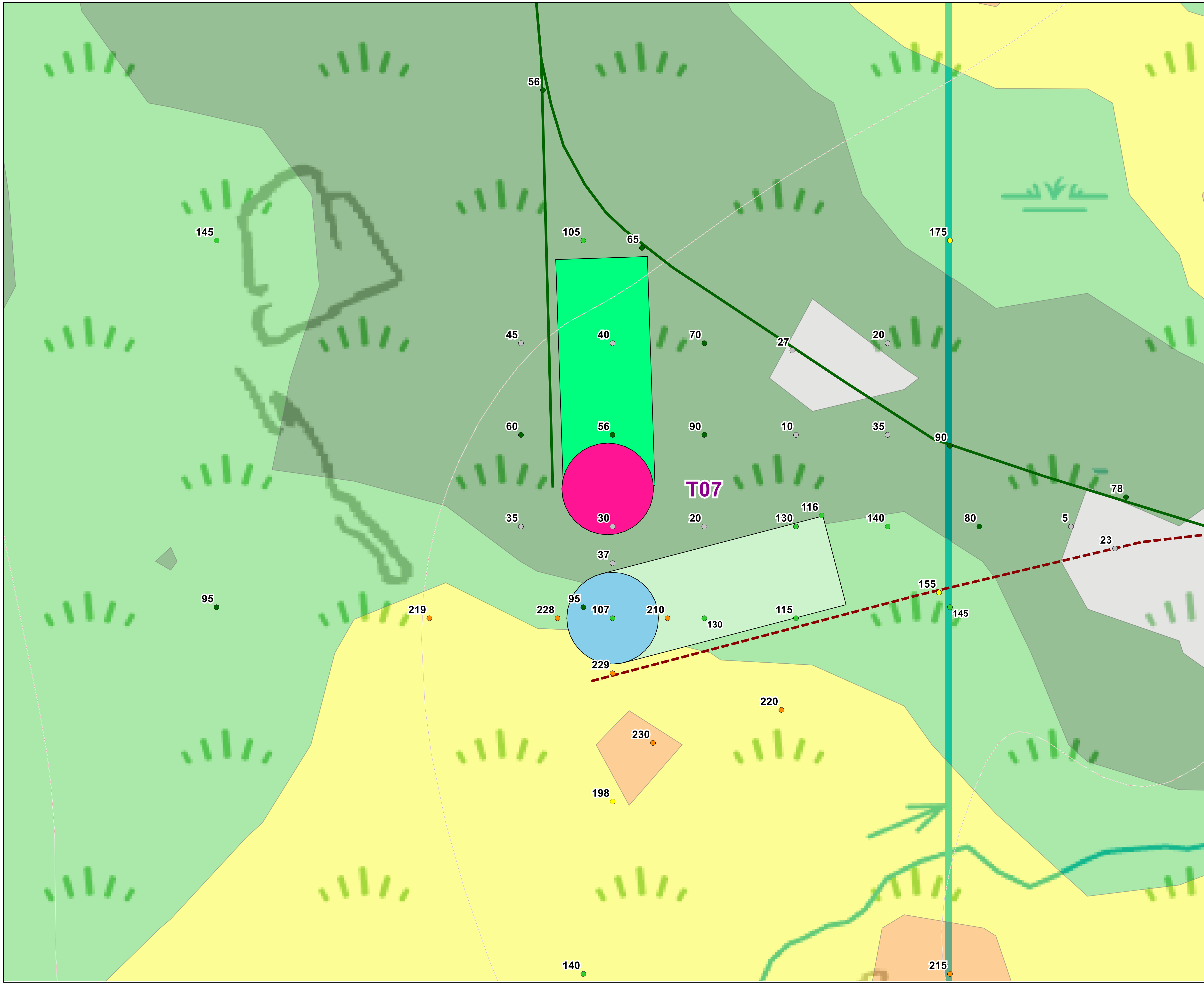
TITLE:

Figure 2.1 -
Relocated Position of Turbine 5
Map 1 of 1

0 25 m

SCALE: 1:1,000 @ A3

REV 01



Legend:

- Site Boundary
- Previous Access Track
- Previous Turbine Location
- Previous Turbine Hardstanding
- Revised Access Track
- Revised Turbine Location
- Revised Turbine Hardstanding

All peat depths are reported in centimetres

Notes:- Peat depths on map are shown in cm below ground.

This map source contains data from the following sources:
Ordnance Survey (2021)

Co-ordinate system: British National Grid
Projection: Transverse Mercator
Datum: OSGB 1936
Units: Metre

Rev	Date	Description	Drn	Chk	App
01	02/09/2021	Number update	CI	CI	JS
00	26/08/2021	First Draft	CI	CI	JS

Kirkan Wind Farm

RSK

Coriolis Energy

TITLE:

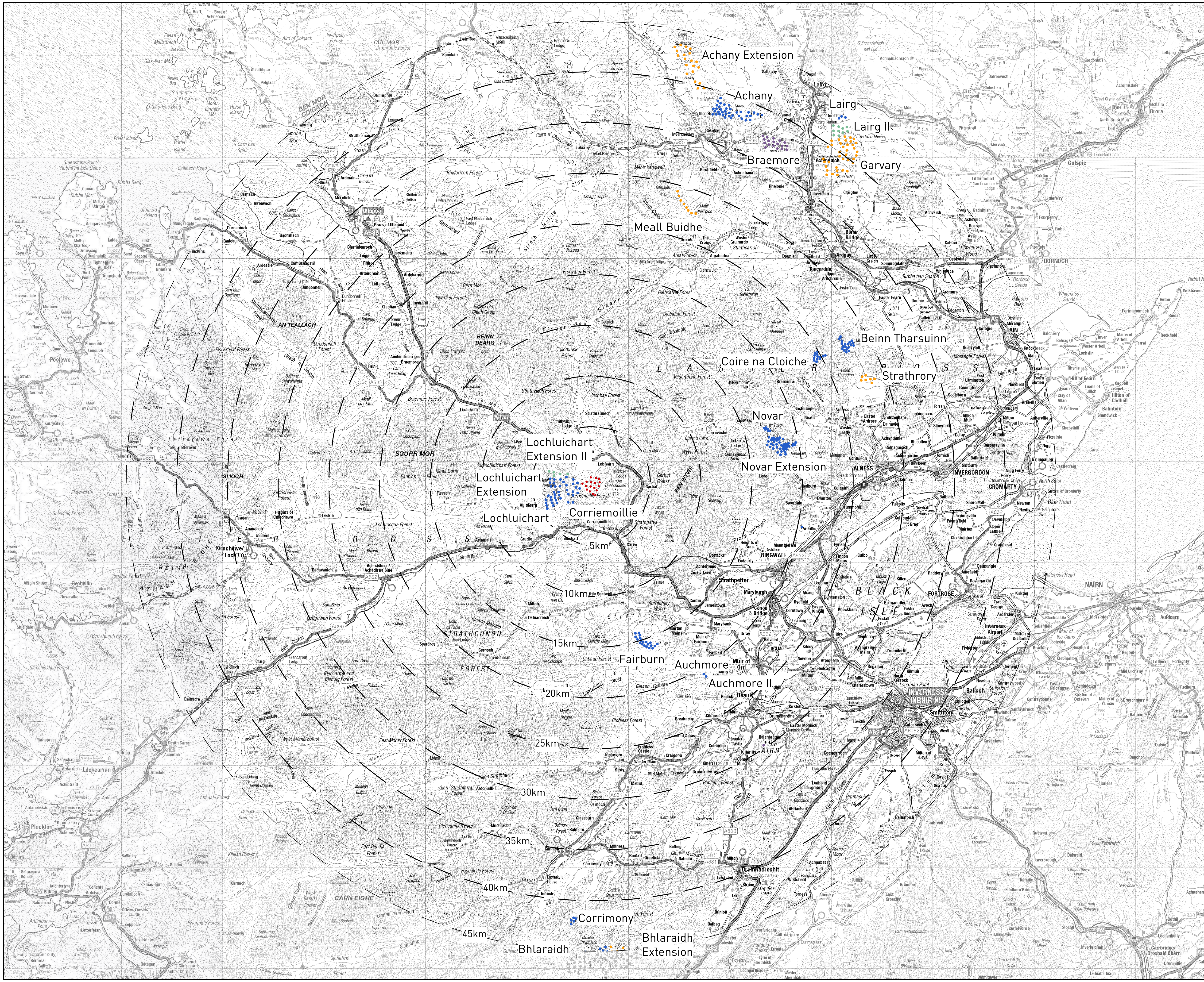
Figure 2.2 -
Relocated Position of Turbine 7
Map 1 of 1

0 25 m

SCALE: 1:1,000 @ A3

REV 01

APPENDIX 3
LANDSCAPE AND VISUAL IMPACT FIGURES



Key

- Proposed Kirkan Wind Farm
- Radius rings

Other Wind Farms

- Operational
- In Planning
- Consented
- Consented with revised application

Pegasus Environment

PLANNING | DESIGN | ENVIRONMENT | ECONOMICS | HERITAGE

Rev	Date	Description	Drn	App
	Sept. 2021	First issue	EK	DT

Kirkan Wind Farm

RSK Coriolis Energy

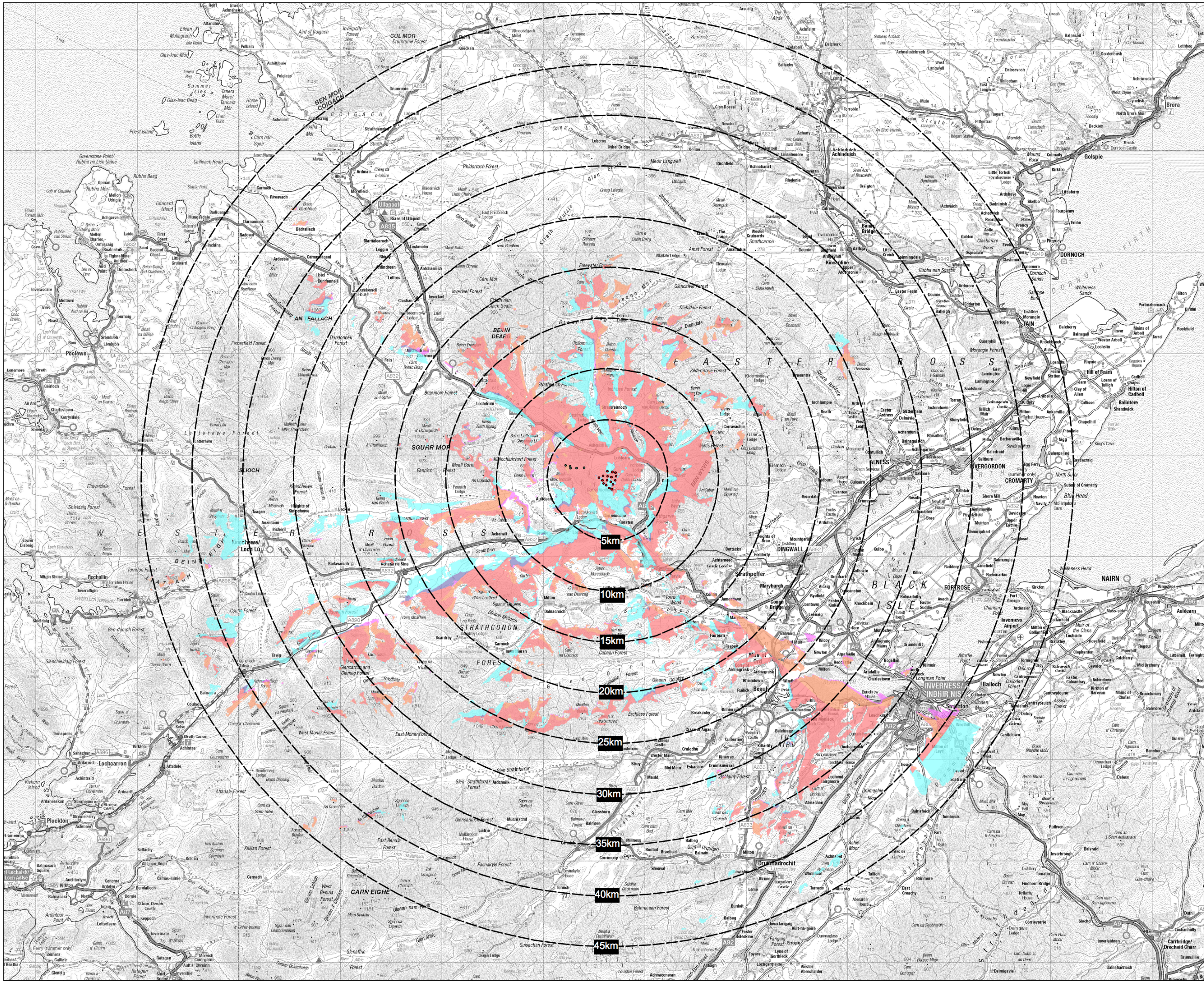
Figure 4.1 - Cumulative sites plan to 45km

Scale: 1:350,000 @ A3

0 2500 5000 7500 10000 m

N

DWG: P20-3157.003



Key

- Proposed Kirkan Turbines
- Turbine Locations of Lochluichart Extension II (Original and Revised Schemes)
- 5km Radii

Kirkan

Lochluichart Extension II (Original Scheme)

Lochluichart Extension II (Revised Scheme)

Pegasus Environment

PLANNING | DESIGN | ENVIRONMENT | ECONOMICS | HERITAGE

Rev	Date	Description	Drn	App
	Sept. 2021	First issue	TH	DT

Kirkan Wind Farm

Figure 4.2 – Cumulative ZTV Kirkan and Lochluichart Extension II (revised scheme)

Scale: 1:350,000 @A3

0 2500 5000 7500 10000 m

DWG: P20-3157.002

APPENDIX 4 NOTE ON ESTIMATED SWITCH-ON TIMES FOR TRANSPONDER-BASED LIGHTING SYSTEM

Introduction

6.1 This Annex of the AI Report provides an estimation of the frequency with which the lights on the turbines would be switched on by passing aircraft if a transponder-activated lighting system was fitted to the wind farm.

6.2 The section has been prepared by Malcolm Spaven of Aviatica. Malcolm has over 25 years' experience as a consultant assessing the impacts of wind turbines on aviation. He has appeared as an expert witness in the field of aviation at over 20 public inquiries. He has designed and obtained Civil Aviation Authority approval for reduced lighting schemes on nine wind farms with turbines 150 m or more in height. He is familiar with the airspace and aviation environment in and around the Kirkan site. He has also reviewed the aviation and aviation lighting sections of the EIA and SEI to which this AI relates.

Estimated switch-on times for a transponder-based lighting system

6.3 In addition to obtaining CAA approval for a reduced lighting scheme, in which only six of the 17 turbines will be fitted with aviation lights on the nacelles, the applicant intends to install a transponder-activated lighting system (TALS) on the Kirkan wind farm. This will switch on the lights only when an aircraft passes within specified horizontal and vertical distances from the wind farm.

6.4 This appendix assumes that the activation criteria will be as stated by the CAA in their preliminary views on TALS[1], i.e. an aircraft entering a 4 km radius bubble around the outer perimeter of the wind farm at an altitude less than 300 m (1000 ft) above the blade tips of the highest turbine and higher than 150 m (500 ft) above the ground level at the lowest turbine. In the case of Kirkan the altitude criteria translate to a bubble between 442 m (1450 ft) and 868 m (2848 ft) AOD. The lighting activation zone around the Kirkan wind farm is illustrated in Figure 1.

[1] See for example CAA letter to Aviatica, 18 March 2021: *Proposed Obstacle Lighting Scheme for Strathy South Wind Farm, Highland*.

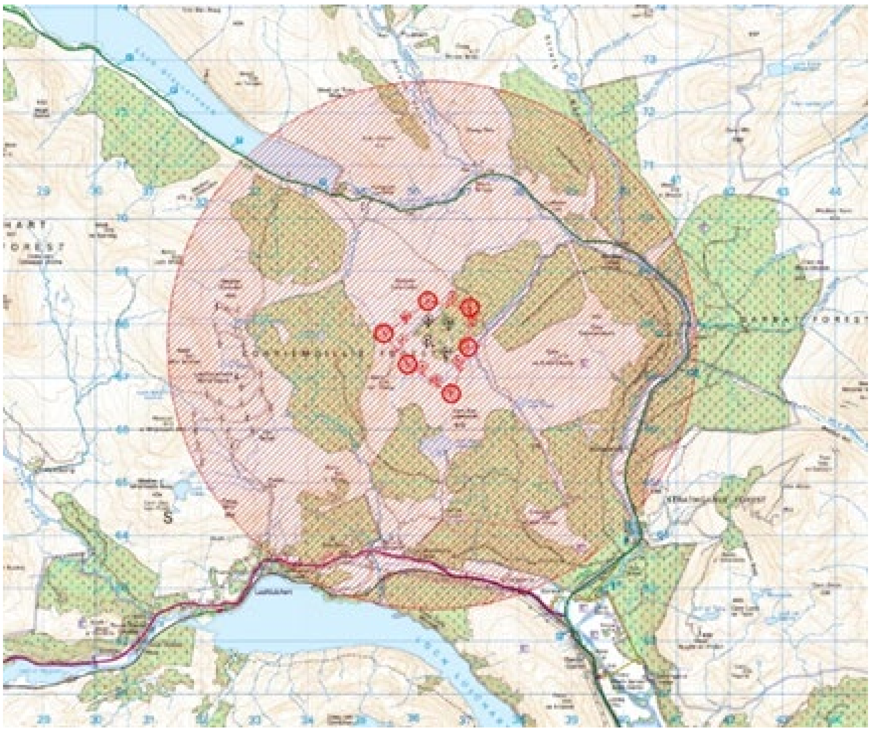


Figure 1: 4 km radius lighting activation zone around Kirkan Wind Farm[2]

Air traffic estimates

6.5 There are no data available for the volume of air traffic at low level passing a particular location. However some generic data on activity levels by particular forms of air traffic are available and have been used as a basis for the estimates generated in this note.

Military low flying

6.6 Kirkan is located in Allocated Region 1B East (AR1BE) in the military Night Low Flying System, one of five such Regions across the UK where fixed and rotary wing night low flying may take place. AR1BE covers mainland Scotland north of the Great Glen, Fort Willam and Mallaig, plus Skye and the Small Isles. There are four other sub-parts of Allocated Region 1, which together cover all of Scotland north of the Central Belt, with the exclusion of Orkney and Shetland (see Figure 2). The area covered by AR1BE is 29.4% of the total area of AR1. There are no military airfields within AR1BE but some of the night low flying in the area originates from the nearest military airfield, RAF Lossiemouth.

[2] The zone illustrated is a 5 km radius circle from the centre of the wind farm, which approximates to a 4 km radius from the perimeter of the wind farm.

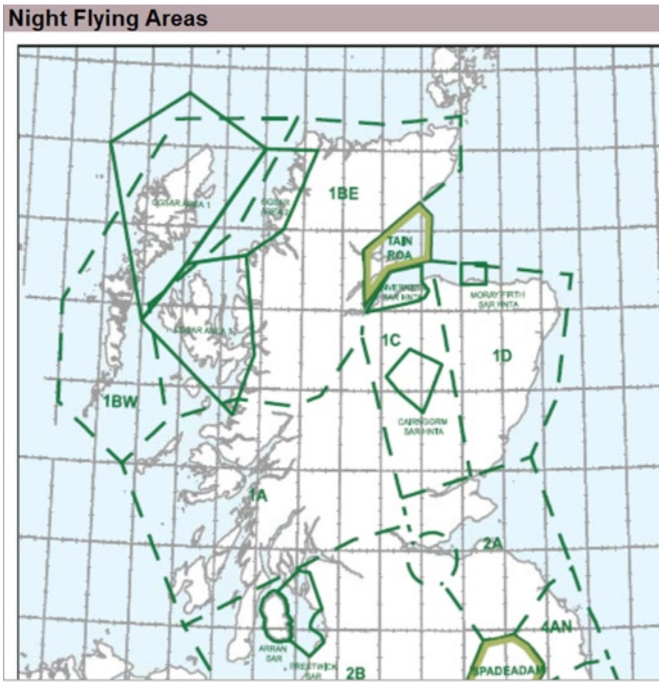


Figure 2: Night low flying areas over Scotland[3]

6.7 The MoD published figures on volumes of low flying do not provide a breakdown of the data by sub-region of AR1. In 2019-20, AR1 as a whole was the fourth busiest of the five Allocated Regions, as Table 1 shows.

Table 1: Military night low flying hours per region, year to 31 March 2020[4]		
Allocated Region	*No. of flying hours*	*% of UK night flying hours*
1	170	1.9%
2	80	0.9%
3	841	9.5%
4	229	2.6%
5	272	3.1%

6.8 The 170 night flying hours in AR1 in the year to 31 March 2020 consisted of 33.25 hours by fixed wing aircraft and 136.717 hours by helicopters. The amount of fixed wing night low flying in AR1 in 2019-20 shows little change over the previous three years. However the amount of rotary wing (= helicopter) night low flying in AR1 in 2019-20 was 650% greater than in 2016-17. This is believed to have been due to RN Merlin and RAF Chinook activity associated with trials of the RN aircraft carrier HMS Prince of Wales leading up to Exercises Griffin Strike and Joint Warrior off the north of Scotland in autumn 2019. This level of helicopter activity in AR1 is unlikely to be replicated in future years. Consequently it is assumed for the purposes of this paper

[3] Source: MoD, *The Pattern of Military Low Flying Across the UK* 2019-20, Map 2 (excerpt).

[4] Source: MoD, *The Pattern of Military Low Flying Across the UK* 2019-20, Table 2. AR2 covers central and southern Scotland; AR3 covers north west England; AR4 covers eastern England north of The Wash; AR5 covers Wales and the Midlands. The bulk of night low flying across the UK takes place in fifteen additional areas known as Night Rotary Regions (NRRs), where precedence is given to rotary wing (helicopter) low flying. All NRRs are located in the southern half of England and Wales.

that future fixed wing military night low level activity matches the average for the four years 2016-17 to 2019-20, while rotary wing night low level activity matches the average for the three years 2016-17 to 2018-19.

6.9 Some further refinement of the estimates of the amount of military night low flying in AR1BE is possible based on known figures for AR1B West (AR1BW - covering the Western Isles) for 2016-17. In that year, AR1BW saw 1.71% of the fixed wing and 12.55% of the rotary wing night low flying in the whole of AR1[5]. However AR1BW constitutes 21.5% of the total area of AR1. This indicates that AR1BW had a lower density of night low flying than the rest of AR1 in that year. If it is assumed that the relative proportions of night low flying between AR1BW and the rest of AR1 in 2016-17 are maintained, and that there is an even distribution of the amounts of night low flying across the remaining four component parts of AR1 - i.e. AR1A, AR1B East, AR1C and AR1D - then the resulting estimates for the amounts of night low flying per annum in AR1BE are as follows:

Table 2: Estimated night low flying hours per annum in Allocated Region 1B East	
Fixed wing	12.32 hrs
Rotary wing	16.74 hrs

6.10 Since the retiral of the Tornado from RAF service in March 2019, the fixed wing night low flying hours in AR1BE are likely to consist predominantly of flights by transport aircraft. Assuming each fixed wing flight in AR1BE lasts 40 minutes[6], the estimates above for fixed wing flying in AR1BE would suggest a frequency of approximately 18 flights a year, or one flight every three weeks.

6.11 In 40 minutes a transport aircraft is likely to travel approximately 150 nautical miles (278 km). Since light activation will occur when an aircraft is within 4 km of any of the wind turbines[7], the 'light activation swathe' for an aircraft on a 40-minute transit through AR1BE is 2780 km². The total area of AR1BE is some 26,000 km². If it is assumed, as a worst case, that every flight in AR1BE flies within lighting trigger distance of Kirkan, the number of activations of the lights at Kirkan by fixed wing low flying military aircraft would be once every three weeks.

6.12 For a military transport aircraft flying at a typical speed of 210 knots, the worst-case straight-line transit of the 5 km radius lighting activation 'bubble' around the Kirkan wind farm would be a distance of 10 km, taking approximately 1.5 minutes. On this basis, fixed wing military activations of the lights on the Kirkan wind farm may occur for an estimated average of 27 minutes per annum.

6.13 For military helicopters, which fly at slower speeds than fixed wing aircraft, typical time spent for each flight through AR1BE can be assumed to be one hour. Thus the estimated 16.74 helicopter hours per annum in AR1BE translate to approximately one flight though the area every three weeks. At an assumed groundspeed of 120 knots, each helicopter flight through AR1BE would cover a lighting activation swathe of 2222

[5] MoD, FOI response 2018/08643, 26 July 2018.

[6] Based on a flight of 150 nautical miles (nm), extending from the north eastern extremity of the Area in Caithness, to its south western extremity around Skye/Mallaig, at a typical transport aircraft speed of 210kts.

[7] In the case of Kirkan, this equates to approximately a 5 km radius around the centre of the wind farm.

km². If every flight in AR1BE flew within lighting trigger distance of Kirkan the number of activations of the lights by low flying military helicopters would be one every three weeks.

6.14 For a helicopter flying at a typical speed of 120 knots, the worst-case straight-line transit of the 5 km radius lighting activation 'bubble' around the Kirkan wind farm would take approximately 2.7 minutes. On this basis, military helicopter activations of the lights on the Kirkan wind farm may occur for an estimated average of 45 minutes per annum.

6.15 A further factor should be taken into account in assessing the frequency of lighting activations by low flying military aircraft. The CAA specifications for proximity-activated lighting systems are that they should switch the lights on when an aircraft enters a three-dimensional zone which is:

- 4 km from the perimeter of the wind farm;
- up to 300 m above the height of the highest blade tip in the wind farm;
- greater than 150 m above the terrain height at the lowest turbine.

6.16 Since most wind farms in Scotland - Kirkan being no exception - are located on hill tops, the third parameter above means that there will be significant numbers of aircraft flying within 4 km of the wind farm that will not trigger the lights to switch on because they are not flying high enough.

6.17 In the particular case of Kirkan, the upper limit of the lighting activation 'bubble' will be 2848 ft amsl. The lower limit of the 'bubble' will be 1450 ft amsl. Any aircraft flying within the 4 km trigger distance of Kirkan, but at less than 1450ft amsl, will not activate the lights. The surface of Loch Glascarnoch (3 km north of the Kirkan site - see Figure 1) is at an elevation of 837ft amsl. Any aircraft following the route of the A835 route between Loch Glascarnoch and Garve - most of it within 4 km of Kirkan - could do so at 600ft or less above ground level without triggering the lights. Since 500ft is a typical authorised Minimum Separation Distance (MSD) for military night low flying, it can be concluded that a proportion of the military low level flights through the Kirkan area will be flying too low to activate the lights. Similarly, any aircraft transiting through the southern part of the Kirkan lighting activation 'bubble', approximately along the line of the A832 road between Gorstan and Lochluichart, would not be crossing terrain higher than 600ft amsl. Thus aircraft flying at 800ft MSD or less on that routing would not activate the lights. This is likely to constitute a significant proportion of the military night low level flights through this area. However this aspect has not been taken into account in calculating the frequency of lighting activations at Kirkan by military aircraft; it is assumed that every military low level flight in AR1BE flies within the vertical as well as the horizontal dimensions of the lighting activation 'bubble' around Kirkan.

Search and rescue (SAR) helicopters

6.18 In the year to 31st March 2021 the Inverness-based SAR helicopter unit completed 222 taskings[8]. Of these, twelve were to incidents north of 57°30' North and west of 04°30' West and could therefore have involved search or transit flying in the vicinity of Kirkan. Four of these twelve occurred during the hours of darkness.

[8] Search and rescue helicopter statistics: year ending March 2021 - GOV.UK (www.gov.uk)

6.19 If it is assumed that:

- 2020-21 taskings are representative of future SAR flying by the Inverness-based SAR unit;
- all of the night time taskings to the north west of Inverness in 2020-21 involved flying within 4 km of the Kirkan wind farm;
- all such flights operated at less than 1000ft above the highest blade tips and higher than 500ft above the terrain height at the lowest turbine; and
- each tasking that takes the helicopter within 4 km of Kirkan involves two activations of the lights - one on the outbound flight, the other on the return;

that would result in the Inverness SAR helicopter activating the lights at Kirkan approximately twice every three months. At a typical AW189 cruise speed of 140kts, each transit of the light activation bubble would take up to 2.3 minutes. Assuming all SAR helicopter activations are by transiting aircraft, this would mean that light activations would be for an estimated 18.4 minutes per annum. For the purposes of this report, this figure is rounded up to 30 minutes per annum to allow for any SAR training flights that may additionally occur in the Kirkan area.

Air ambulance helicopters

6.20 The Scottish Ambulance Service (SAS) helicopter operation at Inverness Airport covers the Highland region. It has full 24-hour capability. Figures for the number of call-outs of the Inverness air ambulance helicopter are not available. In 2019-20, the whole of the Scottish Ambulance Service air ambulance operation - which consists of helicopters based at Glasgow and Inverness and fixed wing aircraft based at Glasgow and Aberdeen - flew 3732 missions[9]. If it is assumed that each unit flew an equal share of those missions that would equate to 943 flights a year by the Inverness-based helicopters. If it is assumed that one tasking per day (39% of all call-outs) is carried out at night;[10] that 5% of those tasks involve routing within 4 km of Kirkan;[11] and that each of these involves both an outbound and an inbound transit through the Kirkan area, that would equate to some 36 activations of the lights at Kirkan per annum. Assuming a cruise speed of 120 knots, transit time of the light activation bubble would be up to 2.7 minutes, giving a total estimated lighting activation time by the SAS helicopters of 99 minutes a year.

Police helicopters

6.21 Figures are not available for the operations of the Police Scotland Air Support Unit helicopter at Glasgow Heliport. Since the Police Scotland base is more than 100 nm from Kirkan, any operations by the helicopter in that area would normally only occur as a result of a specific tasking deployment, probably using Inverness Airport as a temporary detached base. For the purposes of this analysis it is assumed that the probability of them being active at night in the vicinity of Kirkan is based on an average

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[9] Scottish Ambulance Service - Annual Report and Accounts for year ended 31 March 2020, para 1.5.

[10] Similar to the ratio of one in three Inverness-based SAR helicopter flights towards the north west in 2020-21 which occurred at night.

[11] Direct tracks from the Inverness air ambulance base to possible task locations on land occupy some 330° of the compass. The 4 km radius 'bubble' around Kirkan would occupy 13° in azimuth as viewed from Inverness Airport - 3.9% of the possible tracks. This has been rounded up to 5% as a worst case.

of one night activation of the Police Scotland helicopter per day, with 1% of those night flights flying within 4 km of Kirkan. Assuming a cruise speed of 120 knots, transit time of the light activation bubble would be up to 2.7 minutes. If it is assumed that each tasking in the vicinity of Kirkan involves both an outbound and a return flight through the lighting activation 'bubble', total estimated lighting activation time by the Police Scotland helicopter would be 20 minutes a year.

Other night low level traffic

6.22 Other categories of night low level airspace user - private and commercial VFR helicopter flights, Private Pilot's Licence Night Rating training flights and night transits by private light aircraft - are estimated to be extremely rare in the Kirkan area. The principal commercial helicopter operator in this area, PDG Helicopters at Inverness, does not routinely operate at night, and terrain in excess of 3000ft within 10 km to the east and within 12 km to the west of Kirkan make it highly unlikely that any aircraft in the above categories will be flying at night at altitudes within the Kirkan lighting activation 'bubble'.

6.23 For the purposes of this analysis it is conservatively assumed that one such flight per annum passes within 4 km of the Kirkan wind farm at an altitude lower than 1000ft above the highest blade tips. Transit speed is assumed to be 90 knots, giving a transit time of up to 3.6 minutes.

Overall estimates

6.24 The estimates of activation times for each category of air traffic, and for all air traffic, are summarised in Table 3. It can be seen that, on worst case estimates, the lights would be switched on for less than 0.1% of the periods of official night (Sunset +30 minutes until Sunrise -30 minutes).[12]

Table 3: Kirkan lighting activation time estimates

Category of air traffic	*Estimated activation time (minutes/year)*	*Percentage of official night hours*
Military fixed wing	27	0.0116%
Military helicopter	45	0.0194%
SAR helicopters	30	0.0129%
SAS helicopter	99	0.0422%
Police helicopter	20	0.0086%
Other users	4	0.0017%
Totals	225	0.0963%

6.25 It should be noted that the estimated activation times do not include periods when the lights are switched on due to a system fault. Data from manufacturers of transponder-activated lighting systems indicates that such faults are rare.

[12] The number of Official Night hours at the Kirkan site is 3889.2 hours, calculated from the UK Hydrographic Office Websurf 2.0 data on sunrise and sunset for calendar year 2020 for 57°40'N 04°45'W.

Comparison with operational TALS systems in Germany and Austria

6.26 To provide context for the estimates of lighting activation times set out above, Table 4 below shows the percentage activation times for 11 operational wind farms in Germany and Austria where Lanthan Safe Sky TALS systems are deployed.[13]

6.27 The German-Austrian data show generally higher activation times than those estimated for Kirkan. However five of the wind farms had activation times within a similar range to Kirkan (between zero and 0.1% of night time). It is understood that some of the German wind farms are located close to airfields and low flying routes that are routinely used at night. Wiemersdorf, for example, is only 1.8 km from a large Federal Police helicopter base, and has the controlled airspace of Hamburg Airport at 4500ft above the wind farm, and 1000ft above ground level 1.5 nm to the south of the wind farm, forcing many aircraft to fly at lower levels.

Table 4: Lighting activation times at eleven wind farms in Germany/Austria

Wind farm name	*Lighting switch-on times*	
	% of night time	*Minutes per week*
Wiemersdorf	1.96	88.2
Bremen 24	2.80	126
Bremen 26	0.00	0
Bremen 27	6.50	292.5
Bremen 28	1.80	81
Bremen 29	0.00	0
Bremen 30	0.00	0
Bremen 31	7.30	328.5
Mistelbach	0.10	4.5
Eisenstadt	4.80	216
Rendlbahn	0.10	4.5
Average	2.31	103.95

[13] Lanthan SafeSky, *Aircraft Detecting Lighting System based on transponder technology: ADLS Product Presentation for Aviatica Ltd*, April 2021.

APPENDIX 5 REPORT ON LIGHT PROPAGATION FROM THE AVIATION WARNING LIGHTS

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Appendix 5
Additional Information Report
Kirkan Wind Farm

Report on Light Propagation from the Aviation Warning Lights

Professor Philip Best, FRSE
Institute for Astronomy
University of Edinburgh

1/10/2021

Report prepared on behalf of Edinburgh Innovations Ltd, a wholly-owned subsidiary company of the University of Edinburgh

1. Introduction

1.1 The Kirkan Wind Farm is a proposed development of 17 turbines, all of which reach a tip height of over 150 metres (m).

1.2 The Air Navigation Order Article 222 requires turbines exceeding a tip height of 150m to display aviation lighting to indicate their presence. Appropriate visible lighting consists of a 2000 candela red light at the top of the turbine hub, which can be reduced to 200 candela in good visibility conditions, and 32 candela red lighting at intermediate height.

1.3 Dispensations for reduced lighting schemes can be agreed with the Civil Aviation Authority (CAA), according to the guidance provided in CAP-764. This generally involves the lighting of cardinal turbines in order to define the perimeter of the wind farm. For the proposed Kirkan Wind Farm, the CAA has agreed to a reduced lighting scheme whereby only 6 cardinal turbines require to be lit with visible lighting (2000 candela, reducing to 200 candela in good visibility) and the requirement for mid-tower lighting has been waived. The CAA has also approved the use of radar-activated lighting scheme, whereby the aviation lighting is only switched on when an aircraft is in the vicinity of the wind farm.

1.4 This report provides a scientific assessment of the propagation of light from the aviation lighting, during the times that it is activated, taking into account the range of atmospheric conditions typically found in Scotland. It further considers how the human eye perceives light.

1.5 This enables an assessment of how bright the warning lights for the CAA-approved aviation lighting scheme for Kirkan Wind Farm will appear to be to observers external to the wind farm. Comparison is made with other sources of light, such as the moon and stars, and man-made sources.

1.6 The main body of the report discusses these issues, and summarises the main conclusions, in a non-technical manner, in order to be understandable to a broad audience. Appendices to the report provide a full scientific and technical background, as well as details of the data used.

1.7 The author, Philip Best, is Professor of Extragalactic Astrophysics in the School of Physics and Astronomy at the University of Edinburgh. He is Head of the University's Institute for Astronomy, and a Fellow of the Royal Society of Edinburgh. As an observational astronomer he is familiar with issues related to the propagation of light at night, and issues of light pollution.

1.8 Professor Best has had previous involvement in studies of the effects of aviation lighting for wind farm development in Scotland, both onshore and offshore, dating back to 2018.

2. Measurement and visual perception of light

2.1 Overview

2.1.1 The apparent brightness of a light, and our perception of it, depends on many factors. These include:

- How intrinsically powerful the light is
- Whether the light is emitted equally in all directions
- The colour of the light
- The distance of the observer from the light
- The nature of the atmosphere through which the light passes
- The background lighting conditions in which the light is viewed
- The response of the human eye

2.1.2 This report will examine all of the issues to assess the perceived impact of the proposed aviation lighting at the proposed Kirkan Wind Farm.

2.2 Terminology and propagation of light

2.2.1 This section provides a brief overview of the propagation of light, and relevant terminology. For a more detailed technical discussion, see Appendix A.

2.2.2 The regulations on aviation warning lights are expressed in terms of *candela* requirements. Candelas are a measure of the *luminous intensity* of the light. Luminous intensity measures the amount of light, at wavelengths detectable by the human eye, which is emitted in a particular direction.

2.2.3 If a light emits anisotropically (i.e. different amounts of light in different directions) then its candela rating will depend upon direction.

2.2.4 More distant light sources appear fainter, because the light emission spreads out over a larger area. The observability of light depends upon the *illuminance* of the light, which measures the luminous intensity of light that passes through a unit area of surface at that distance. Illuminance is measured in *lumens per square metre*.

2.2.5 It is the illuminance of the light that determines how bright it appears to the observer. This is the key quantity that this report will be deriving for the aviation lighting and comparing to the illuminance of other light sources.

2.2.6 For perfect transmission of light (i.e. no light absorbed or scattered by the medium through which it is passing), the illuminance decreases as the square of the distance between the light source and the observer. Thus, a light observed from a distance of 10km will have an illuminance only 1% of that of the same light observed from a distance of 1km.

2.3 Human perception of light

2.3.1 The human eye is composed of two different types of optical sensors, known as *cones* and *rods*, each of which is adapted to function under different light conditions to maximise the overall ability of the eye (see Appendix B for a more detailed technical discussion).

2.3.2 Cones cells provide the ability for humans to discern colour. Cones are adapted to work at high ambient light levels; this is known as the *photopic* regime.

2.3.3 In contrast, rods have no ability to identify colour, but do have a much higher sensitivity than cones, allowing fainter levels of light to be detected (albeit that in such light levels the eye loses the ability to distinguish colour and objects appear grey). Rods mediate vision at low ambient light levels, known as the *scotopic* regime.

2.3.4 At intermediate light levels both cones and rods play a role; this is known as *mesopic* vision. It is not as sensitive as scotopic vision, but does allow for perception of colour.

2.3.5 In the photopic regime (daytime vision) the human eye is most sensitive to green light.

2.3.6 Luminosity intensity and illuminance are both calculated in a way that weights the colour distribution of the light with the photopic (daytime) wavelength response of the human eye. Thus, in high ambient light conditions, a blue and a red light of the same luminous intensity (candela rating), seen at the same distance, will appear equally bright.

2.3.7 In the scotopic regime (night-time vision) the eye is more sensitive to bluer light and has little sensitivity to red light. Therefore, at low ambient light levels (in the mesopic or scotopic regimes), a red light will appear fainter than a blue light of the same candela rating at the same distance.

2.3.8 The threshold sensitivity of the eye depends critically on the background ambient light level. It also varies to some extent from observer to observer (e.g. due to deterioration with age).

2.3.9 Maximum sensitivity is achieved in the darkest ambient conditions, but only after the eye has become fully dark-adapted. Dark adaptation is associated with chemical changes in the eye and is largely complete after around 30 minutes of darkness. Any (even short) exposure to bright light resets the dark adaptation process.

2.3.10 Fully dark-adapted eyes in optimal observing conditions (moonless night-time sky, away from sources of light pollution) have a typical sensitivity limit of just below 10^{-8} lumens/m^2 to a point source of white light. That sensitivity limit is fractionally higher (approximately $2x10^{-8}$ lumens/m^2) for red light, limited by the lower end of the mesopic regime.

2.3.11 Infrared lighting, produced to Ministry of Defence standards, emits in the wavelength range 750 to 900nm. The eye has essentially no sensitivity at these wavelengths, and therefore the installation of infrared lights on the proposed wind farm will have no visual impact.

3. Atmospheric attenuation of light

3.1 Atmospheric attenuation in 'clear' conditions

3.1.1 As light passes through the atmosphere, it is attenuated (decreased in brightness) by scattering and absorption processes in the atmosphere. A full technical description of this process is presented in Appendix C. Here, an outline summary is provided.

3.1.2 The attenuation process is caused both by the molecules of air in the atmosphere and by microscopic solid or liquid particles suspended in the atmosphere, known as aerosols. Aerosols can be natural, such as dust and pollen, or man-made pollutants, such as smoke or vehicle emissions. In maritime environments, sea salt is prevalent. Another common aerosol is liquid water droplets suspended in the air, as is the case for cloud or fog.

3.1.3 The total amount of attenuation depends upon the amount of material through which the light passes (known as the optical depth, or opacity, of the material). For light travelling horizontally through the atmosphere, the optical depth is proportional to the distance between the light source and the observer.

3.1.4 The optical depth is also dependent upon the wavelength of the light. The exact wavelength dependence depends upon the properties of the attenuating material, but in general blue light is more strongly attenuated than red light.

3.1.5 Attenuation by air molecules occurs due a process known as Rayleigh Scattering. This is well-quantified and varies little with time. As outlined in Appendix C, it can be calculated with high accuracy. Rayleigh scattering has a very strong wavelength dependence, with blue light being much more highly scattered (this is the reason that the sky appears blue).

3.1.6 The attenuation by aerosols can be estimated (see Appendix C) but, unlike Rayleigh Scattering, this cannot be described by a single number. The quantity and nature of aerosols varies with location and over time (for example, due to the direction that the wind is coming from). This changes the optical depth of the aerosols, the wavelength dependence of the scattering process, and the vertical distribution of aerosols in the atmosphere.

3.1.7 Extensive ground-based measurements of the distribution of properties of aerosols exist in different UK environments, and these are complemented by satellite observations. Based upon these, predictions can be made for the range of levels of attenuation of light by aerosols (see Appendix C), as a function of distance, for typical 'clear' conditions.

3.1.8 Considering this range, the calculations in Appendix C of the atmospheric attenuation of red light show that between 55% and 80% of the light remains, when viewed horizontally from a distance of 10km, at an altitude of 450m (this is the average hub height of the 6 turbines in the Kirkan Wind Farm that will carry visible lighting: hub heights of these turbines vary from around 400m to around 500m).

3.1.9 The geometric dilution of light with distance (see 2.2.6) is then scaled by this attenuation factor to determine the final observed illuminance of the light. Given the strong geometric dilution effects compared to the relatively mild atmospheric attenuation at distances below 10-15km, the choice of adopted aerosol parameters (for 'clear' conditions) does not qualitatively change the conclusions.

3.2 Visibility

3.2.1 The Air Navigation Order regulations (Article 222) and CAA CAP-764 guidance require relevant turbines to be lit with a 2000 candela light, but this may be reduced to 200 candela if the visibility is better than 5km.

3.2.2 Visibility is defined by the World Meteorological Organisation as the distance at which the intrinsic brightness of a light is reduced to 5% of its initial value due to light attenuation. It is thus directly related to optical depth.

3.2.3 In poor visibility conditions, the opacity is generally associated with larger particles such as liquid water droplets (cloud or fog).

3.2.4 The illuminance of a light can be accurately calculated as a function of distance, at the threshold visibility value. This represents a worst-case scenario for 2000 candela lighting: in better conditions the luminous intensity of the lighting can be reduced, while in poorer conditions atmospheric attenuation effects will be increased.

3.2.5 The fraction of time for which the visibility is below 5km would ideally be determined using on-site measurements. However, estimates can be made by considering publicly-available datasets from other locations within Scotland.

3.2.6 An extensive dataset from the Leuchars air base in Fife provides data on the historic visibility dating back several decades (Singh et al. 2017). The 5km visibility threshold for requirement of the 2000 candela lights is only met at Leuchars between 3% and 4% of the time in the last 20 years.

3.2.7 Met Office data from Inverness Airport (43km from the Kirkan Wind Farm) indicates a similar fraction of about 4% of the time when visibility is below 5km. Data from other airports around Scotland (albeit some closer to large population centres and subject to higher aerosol pollutants) provide typical values of between 4% and 7% of the time.

3.2.8 Many of these datasets (including Leuchars and Inverness Airport) are obtained close to the coast, and some of the measured periods of poor visibility are likely to be due to haar, which would not extend as far inland as the proposed Kirkan Wind Farm. Aerosol density also decreases with increasing altitude. On the other hand, higher altitude sites like that of the proposed Kirkan Wind Farm will be more susceptible to periods of low cloud and mist. These different effects may largely counter-balance each other. A conservative estimate is therefore that the Kirkan Wind Farm may be affected by poor visibility (and hence require the use of 2000 candela lighting) for at most 10% of the time, and probably no more than 5% of the time.

4. Illuminance of aviation lighting

4.1 Illuminance of individual turbine lights

4.1.1 Following the detailed calculations of Appendix C, the illuminance of individual turbine lights, as a function of distance, is shown in Figure 1. These are calculated for 'clear' atmospheric conditions for a luminous intensity of 200 candela. Results are shown for average assumptions of the aerosol attenuation.

4.1.2 Also shown on Figure 1 are the results for 2000 candela lights as observed at the threshold visibility limit of 5km (i.e. the worst-case scenario for these lights). In the poor visibility conditions when they are required, these 2000 candela lights have lower illuminance than the 200 candela lights seen in typical clear conditions, for all distances beyond 5km.

4.1.3 For comparison with these calculations, Figure 1 also shows the illuminance of the brightest star in the northern sky, and of typical bright stars such as those in the constellation of Orion. The latter provide a good approximation of the limiting illuminance that can be observed from street-lit locations. Also shown is the approximate visible limit under optimal conditions: fully dark-adapted eyes away from any light pollution. Table 1 provides numerical values for these illuminances, and also the illuminance of car brake lights at different distances, which provide a natural comparison.

4.1.4 Figure 1 and Table 1 make clear that from a distance of 5km, both the 200 candela light in clear conditions and the 2000 candela light in poor visibility have illuminances below that of the brightest star, and comparable to car brake lights seen from distances of a few km. At larger distances from the turbines, the 2000 candela light (in poor visibility) quickly becomes unobservable. The illuminance of the 200 candela light is comparable to that of typical bright stars at distances of 10-15km, reaching the observable threshold from street-lit areas by a distance of about 15km.

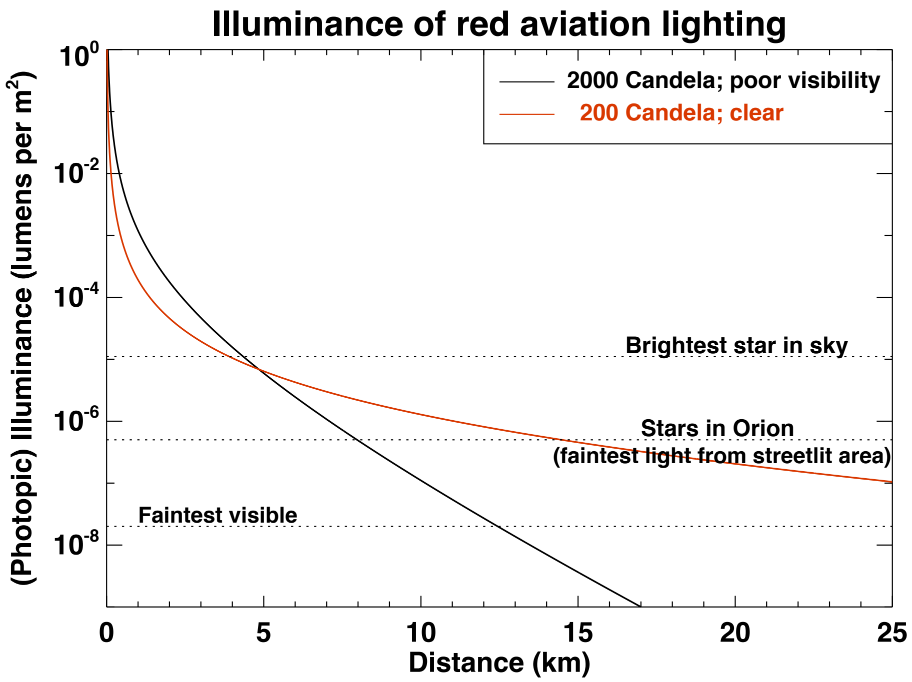

Figure 1: The illuminance of a single red light (633nm) as a function of distance, viewed horizontally at an altitude of 450m. The results are shown for a light with a luminous intensity of 200 candela for typical 'clear' atmospheric conditions. Also shown are the results for 2000 candela lights, at the threshold visibility (visibility=5km) that these are required. For comparison, the illuminance provided by the brightest star in the northern sky is shown, along with those of typical bright stars such as those in the constellation of Orion. The latter also represent the approximate visual limit of the eye from street-lit areas (see Appendix B). Also indicated is the approximate visible limit to red light under perfect conditions (away from street lighting and other light pollution; new moon; dark-adapted eyes).

Comparison object	Approx. Illuminance (Lumens per m^2)
Car brake lights at 1km distance	1×10^{-4}
Brightest star in the sky	1.3×10^{-5}
Car brake lights at 10km distance	1×10^{-6}
Typical bright stars (e.g. in Orion)	5×10^{-7}
Faintest light visible from street-lit area	4×10^{-7}
Visible limit for fully dark-adapted eyes	2×10^{-8}

Table 1: Illuminances of typical comparison objects.

4.1.5 It is important to note that Figure 1 assumes that the aviation lighting is seen horizontally. The regulations in the International Civil Aviation Organization Annex 14 to the Convention on International Civil Aviation relate to the luminous intensity emitted in the horizontal plane. At angles below the horizontal plane, the luminous intensity of modern aviation lighting (2000 or 200 candela) is strongly suppressed, resulting in significantly lower illuminance. This is shown in Figure 2 which presents technical data from an aviation LED currently on the market.

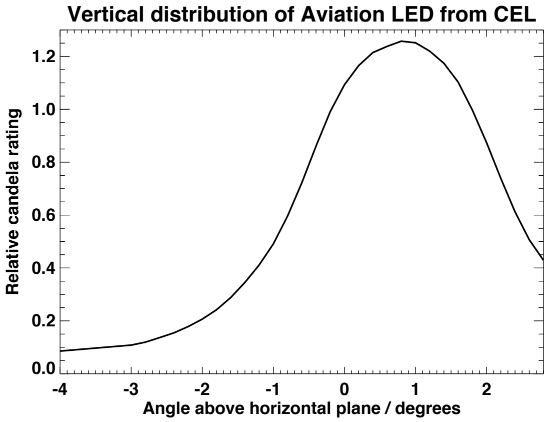

Figure 2: The attenuation of the illuminance of aviation lighting away from the horizontal plane. The figure shows technical data for an aviation LED from CEL, currently on the market. At an angle of 3 degrees below the horizontal plane, the brightness of the lights is suppressed by a factor of 10.

4.1.6 This vertical suppression will be relevant both for observers close to the turbines (who will typically be viewing them from below) and for population centres located at lower altitude.

4.1.7 For the proposed Kirkan Wind Farm, receptors on and close to the A835 road (for example, at Viewpoint 1, the Aultguish Inn), will observe the aviation lights from angles of 3 or more degrees below the horizontal plane, and thus observe the lights to be suppressed by around a factor of 10 relative to the illuminances calculated in Figure 1.

4.1.8 Receptors for the Kirkan Wind Farm located in moderately distant population centres (for example Marybank; viewpoint 7) will observe the aviation lights from around 1 degree below the horizontal plane, corresponding to a suppression of the illuminance by about a factor of about 2.5.

4.1.9 Table 2 provides the calculated illuminance of the brightest turbine light for the approved lighting scheme, as seen from each of 16 viewpoints from which they may be visible. The calculation of these values takes into account both the propagation of light (Figure 1) and the suppression of light relative to the horizontal plane (Figure 2). Values are given for both average 'clear' conditions (with a 200cd light) and for the limit of 'poor visibility' conditions (with a 2000cd light). Table 1 provides every-day visual comparators to the calculated illuminances.

4.1.10

Viewpoint	Brightest Turbine			Illuminance (lumens per square metre)	
	Number	Distance (km)	Vertical suppression factor	200 cd average conditions	2000 cd poor visibility
1	3	2.31	0.09	2.9×10^{-6}	9.72×10^{-6}
2	16	0.76	0.09	29.0×10^{-6}	202.4×10^{-6}
5	17	7.52	1.26	3.17×10^{-6}	0.89×10^{-6}
6	10	9.20	0.43	0.67×10^{-6}	0.08×10^{-6}
7	17	17.53	0.40	0.12×10^{-6}	$< 0.01 \times 10^{-6}$
8	7	14.87	1.13	0.53×10^{-6}	$< 0.01 \times 10^{-6}$
9	17	23.21	1.25	0.16×10^{-6}	$< 0.01 \times 10^{-6}$
10	17	26.47	1.19	0.10×10^{-6}	$< 0.01 \times 10^{-6}$
11	1	30.72	1.26	0.07×10^{-6}	$< 0.01 \times 10^{-6}$
13	1	11.28	0.82	0.78×10^{-6}	0.04×10^{-6}
14	1	16.38	0.86	0.31×10^{-6}	$< 0.01 \times 10^{-6}$
15	3	9.83	1.11	1.48×10^{-6}	0.14×10^{-6}
16	10	15.73	1.23	0.49×10^{-6}	$< 0.01 \times 10^{-6}$
17	3	7.37	0.39	1.04×10^{-6}	0.31×10^{-6}
18	1	33.02	1.25	0.05×10^{-6}	$< 0.01 \times 10^{-6}$
19	1	8.20	0.99	2.03×10^{-6}	0.41×10^{-6}

Table 2: Calculated illuminances of the brightest turbine aviation light as seen from the 16 viewpoints from which they may be visible. Table 1 provides every-day comparisons to the illuminances quoted. Calculations are provided for both a 200 cd light under average 'clear' atmospheric conditions and a 2000 cd light at the limit of the poor visibility conditions (visibility=5km) when such a light is required. Calculations take into account the vertical suppression of light away from the horizontal plane, assuming the LED specifications of a commercially-available aviation light from CEL (see Figure 2).

4.1.11 Under typical 'clear' conditions, for nearby receptors on the A835 (Viewpoint 1), the aviation lighting will appear of comparable brightness to some of the brightest stars in the sky, or to car brake lights at distances of about 6 km. When the visibility is sufficiently poor as to require 2000cd lighting, these lights will appear up to a factor of ~3 brighter, although still fainter than the brightest star in the sky.

4.1.12 From the nearby Wild Land Areas (WLA-28: Fisherfield – Letterewe – Fannichs, Viewpoint 13, and WLA-29: Rhiddoroch – Beinn Dearg – Ben Wyvis, Viewpoints 6, 14, 15, 16, 19), the aviation lighting will be observed to be comparable in brightness to typical bright stars such as those in Orion, or to car brake lights at distances of about 10km. From these viewpoints the 2000cd lights in poor visibility will be fainter than the 200cd lights in clear conditions, and either barely observable or unobservable.

4.2 Additional considerations

4.2.1 The total illuminance from all turbine lights within the wind farm (calculated in Appendix C7) is comparable to, or below that, produced by starlight in a moonless sky, beyond an average distance of about 3km from the turbines. Thus, other than the individual points of light visible from individual turbines, outside of the wind farm there will be no significant change to the ambient light levels, and hence on the nature of 'dark skies'.

4.2.2 A common concern is that, during the hours of darkness, when turbine blades pass in front of the aviation lights they will appear to flicker. Although this is true, it should be noted that lights in the night sky naturally flicker (stars 'twinkle') due to atmospheric refraction effects. When seen from viewpoints at which the illuminances of the turbine lights are comparable to those of stars, any such flickering will therefore be consistent with other similar brightness lights in the night sky, and so is unlikely to be any cause of concern.

5. Summary

5.1 This report has considered the observability of the aviation lighting for proposed Kirkan Wind Farm. The report takes into account the brightness of the lights, geometric dilution of light, atmospheric attenuation, and the response of the human eye.

5.2 At distances of 5-15 km, 200 candela lights, which will be lit on the turbines under typical atmospheric conditions, will have an apparent brightness comparable to that of bright stars in the night sky, or to car brake lights at a distance of 3-10km. They will thus be visible to observers with a degree of dark adaptation, but will not be prominent. The lights will remain visible to fully dark-adapted eyes out to distances of 30-40km, but their prominence falls further still.

5.3 When the visibility is sufficiently poor as to require 2000 candela lighting, then the visual impact of these beyond 5km distance will be less than that of the 200 candela lights, and these lights will be invisible beyond about 10km distances.

5.4 The reduction of light intensity below the horizontal plane for aviation lighting means that, in reality, from most nearby locations any impact would be even further reduced, by up to a factor of 10.

5.5 The impact of the aviation lighting is illustrated through consideration of the illuminance of the brightest turbine light from 16 viewpoints. Except for the very closest viewpoint, in all cases the illuminance of the aviation lighting is calculated to be comparable to, or fainter than, that of typical bright stars.

5.6 The calculations provided here are based on the aviation lighting being switched on. A radar-activated lighting scheme for the Kirkan Wind Farm, whereby the lights are only switched on when aircraft are in the vicinity, would still further reduce the impact of the lighting.

Appendix A: Terminology and propagation of light

A.1 The measure of how intrinsically powerful a light source is (its *power*, or *radiant flux*) is the amount of energy that it emits each second. This is measured in *Watts.* A familiar example will be a standard domestic light bulb (e.g. a 60 Watt light bulb).

A.2 This energy emitted by a light can be spread across a wide range of wavelengths (colours); some of these are not detectable by the human eye (see Appendix B for a technical discussion of the eye's sensitivity). The amount of energy per second emitted, weighted by the (daytime) sensitivity of the human eye at different wavelengths, is known as *luminous flux* and is measured in *lumens.*

A.3 Another commonly used measure of the intrinsic brightness of a light source is the *luminous intensity.* This is defined as the luminous flux emitted per unit solid angle in a given direction. Solid angle is a measure of angular area, measured in *steradians*. The solid angle of the full surface of a sphere is 4π steradians (thus 1 steradian is approximately 3283 square degrees).

A.4 For an isotropic light source (i.e. one that emits light equally in all directions) the luminous intensity is simply the luminous flux scaled down by the factor of 4π. If a light emits anisotropically (i.e. different amounts of light in different directions) then the luminous intensity will vary with direction.

A.5 Luminous intensity is measured in *candelas.* Aviation warning light regulations are expressed in terms of candela requirements.

A.6 More distant light sources appear fainter, because the light emission spreads out over a larger area. The observability of light depends upon the *illuminance* of the light, which measures the luminous intensity of light that passes through a unit area of surface at that distance. Illuminance is measured in *lumens per square metre* (also known as *lux*). It is the illuminance of the light that determines how bright it appears to the observer.

A.7 For perfect transmission of light (i.e. no light absorbed or scattered by the medium through which it is passing), the illuminance (I) is related to the luminous intensity (L) by:

$$I = \frac{L}{D^2}$$

where D is the distance between the light source and the observer in metres.

A.8 Figure A1 shows examples of illuminance as a function of distance for lights of 200 and 2000 candela luminous intensities, in the absence of any attenuation effects (see Appendix C).

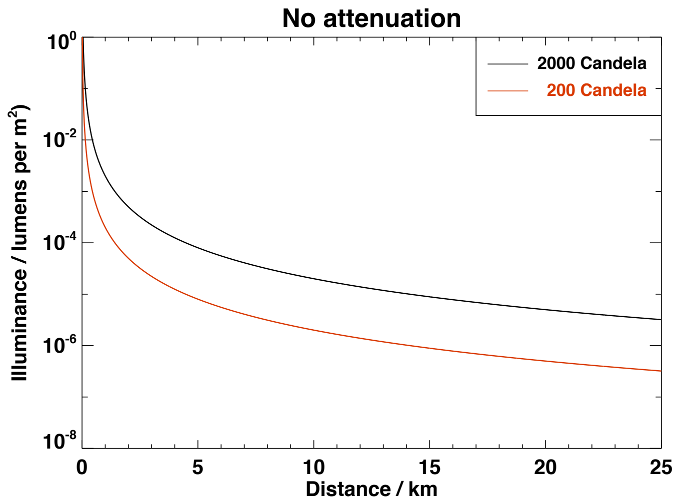

Figure A1: The illuminance of 2000 candela and 200 candela luminous intensity lights as a function of distance, in the absence of any atmospheric attenuation (i.e. considering geometric effects only).

Appendix B: The response of the human eye to light

B.1 Optical sensors in the eye

B1.1 The human eye is composed of two different types of optical sensors, known as *cones* and *rods*.

B1.2 Cones are concentrated in the central portion of the retina, and provide the sharpest vision. Cones come in three types adapted to detect different wavelengths of light (approximately, blue, green and red light respectively). The combination of light detected by these three types of cone cells provides the ability for humans to discern colour. Cones are adapted to work at high ambient light levels, (above a few candela/m^2), which is known as the *photopic* regime.

B1.3 Rods are more distributed around retina. Rods have a much higher sensitivity than cones, allowing fainter levels of light to be detected. Rods mediate vision in the *scotopic* regime, corresponding to ambient light levels below about 0.003 candela/m^2. Rods have no colour response, and so in these low light levels the eye loses the ability to distinguish colour and objects appear grey.

B1.4 Because rods are spread across the eye, and largely absent from the (cone-dominated) central region, this gives rise to the well-known effect that in low ambient light levels, faint light sources appear clearer in peripheral vision than when looked at directly.

B1.5 The eye's sensitivity function has been formalised by the International Commission on Illumination (CIE). In the photopic regime, the widely used standard is the CIE 1978 V(λ) function, based on data by Judd (1951) and Vos (1979): this is shown in Figure B1 and has maximum sensitivity at a wavelength of 555nm (green).

B1.6 Figure B1 also shows the CIE 1951 V'(λ) sensitivity function of the eye in the scotopic regime, which is based on measurements by Wald (1945) and Crawford (1949). Here it can be seen that the peak sensitivity is at significantly shorter wavelength than the photopic curve (507nm), and that the sensitivity at longer (redder) wavelengths is dramatically lower in the scotopic regime. In particular, at the wavelength of standard red aviation LEDs (633nm) it is nearly a factor 100 lower.

B1.7 At intermediate light levels both cones and rods are activated; this is known as *mesopic* vision. It is not as sensitive as scotopic vision, but does allow perception of colour. The eye sensitivity in mesopic vision depends upon the relative stimulation of the cones and rods. As indicated on Figure B1 there is a gradual change of the sensitivity function as we move down the mesopic regime. At all points, the sensitivity to red LEDs will be dominated by whatever component of photopic vision remains.

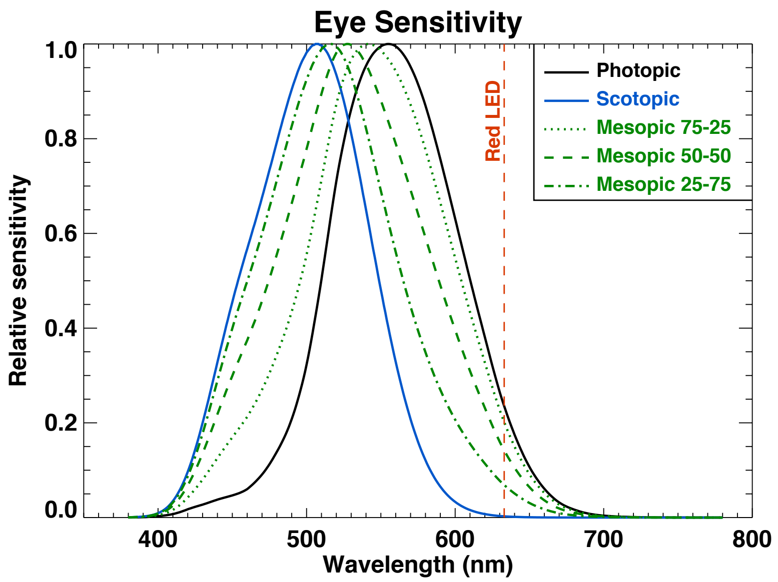

Figure B1: The relative sensitivity of the eye as a function of wavelength, in the photopic regime (black line; vision mediated by cones, at high light levels) and the scotopic regime (blue line; vision mediated by rods, at low light levels). The data are the accepted CIE 1978 and CIE 1951 standard values (see text for details). At low light levels the eye sensitivity function shifts towards bluer wavelengths, with significantly lower relative sensitivity to red light. Also shown in green lines are intermediate stages of mesopic vision, where both cones and rods are activated (dotted, dashed and dot-dashed lines show respectively a 75%-25% split, a 50%-50% split, and a 25%-75% split between photopic and scotopic vision).

B1.8 The conversion of radiant flux to luminous flux is normally derived by weighting the radiant flux by the photopic sensitivity function. Thus, in the photopic regime, a light of given luminous intensity viewed from a given distance will appear to deliver the same illuminance irrespective of its colour: in other words, from a given distance, a blue light and a red light emitting the same candela of light would appear equally bright.

B1.9 However, if the light level is sufficiently low that the eye enters the mesopic or scotopic regime, then the shift of the eye's sensitivity function towards shorter wavelengths would result in a redder light appearing fainter than a bluer one.

B.2 Eye detection thresholds

B2.1 Studies of the detection threshold of the eye (that is, the faintest detectable illuminance for a single fixed light) have a long history; for example, it is of wide interest in astronomy to understand the faintest star visible under different light pollution conditions, and that analysis is directly relevant here.

B2.2 The most authoritative and extensive data samples were taken by Blackwell (1946), supplemented by the work of Knoll et al. (1946), who studied the detectability of point sources of light by the eye in different ambient lighting conditions. Specifically, they considered background illumination levels (B), and tested the ability of observers to detect point source lights of incremental illuminance (ΔI) above this background. The primary results are shown in Figure B2 and have largely been supported by later studies.

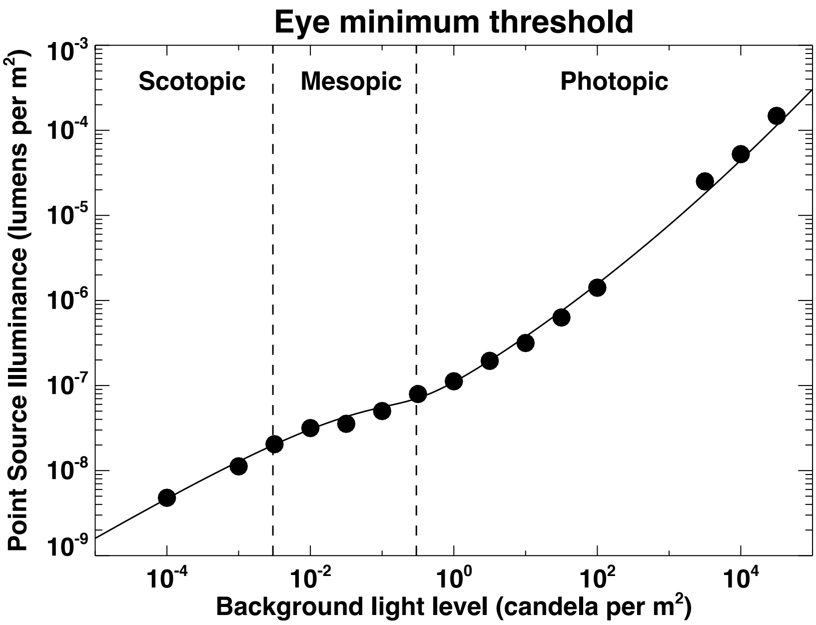

Figure B2: The minimum point source illuminance, which is detectable by the eye, as a function of the background ambient light level. Plotted data points are from Knoll et al. (1946), and the fitting function comes from Crumey (2014).

B2.3 There have been many attempts to provide functional fits to these data. The best of these consider separate functional forms in the photopic and scotopic regimes, as it is clear from Figure B2 that the detectability of light is non-linear due to the changes between the different vision regimes. The fit shown in Figure B2 comes from Crumey (2014), and is the one adopted for the current analysis.

B2.4 These results are based on a white light source (i.e. one that emits across a very wide range of wavelengths); the colour temperature of the white light (that is, the exact distribution of radiant flux across wavelength) will have an effect on the derived threshold in the mesopic and scotopic regime, but this will typically be well below a factor of 2.

B2.5 Note that these data are based on the average results from young adults (less than 30 years old) in fully dark-adapted conditions. Those who have not taken the time to dark-adapt their eye in low lighting conditions, will have significantly higher detectable limits.

B2.6 Dark adaptation is a relatively slow process associated with chemical changes in the eye. Dark adaptation of the cones to lower light levels takes between 5 and 10 minutes. Rods are nearly fully activated after about 30 minutes, although the sensitivity of rods to low light levels continues to improve marginally even after hours of darkness. Even a short exposure to bright light resets this process. An observer in a partially lit environment (e.g. street lighting) never becomes fully dark adapted.

B2.7 Older people typically take longer to dark-adapt, and generally have significantly higher detectable limits. Blackwell & Blackwell (1971) estimate a factor approximately 3 higher threshold on average at age 65.

B.3 Ambient background lighting levels and limiting sensitivities

B3.1 Figure B2 indicates that the detectable limit of light depends strongly on the background ambient light level. This can vary considerably, depending on location and on moon phase.

B3.2 In a street-lit area, the ambient light level is about 10 candela/m^2. From Figure B2, this gives a faintest detectable illuminance of a (white) point-source light of around $5x10^{-7}$ lumens/m^2. To put this value into context, this is about the same apparent brightness as typical bright stars in the night sky, such as the main stars in the constellation of Orion, or of a car brake light seen from a distance of about 10 km.

B3.3 The darkest night-time conditions are found for a new moon, and away from any source of light pollution. For this, the ambient light level due to starlight from all of the stars in the sky is around $2x10^{-4}$ candela/m^2. The corresponding faintest detectable illuminance is around $6x10^{-9}$ lumens/m^2.

B3.4 Falchi et al. (2016) studied the sky brightness as a function of location in Europe; their data indicate that the background light level away from towns in the region of the Kirkan Wind Farm is very close to the dark sky background (less than 10% higher). Cinzano et al. (2001) found a similar result for the increased sky brightness due to airglow. Their limiting brightness in that region of Scotland corresponds to an illuminance of fractionally below 10^{-8} lumens/m^2. This value provides a more realistic estimate of the limit of the detectability of a white light source in optimal new moon conditions.

B3.5 For red LED aviation lighting at 633nm, the sensitivity of rods is a factor approximately 100 below that of the cones (see Figure B1). Thus, if the ambient light level were to be sufficiently low as to be fully in the scotopic regime, then faint red lights become largely undetectable. A realistic detectable limit for faint red lights is at the bottom of the mesopic regime, at an illuminance of around $2x10^{-8}$ lumens/m^2.

Appendix C: Attenuation of light

C.1 Overview

C1.1 Light is attenuated by scattering and absorption processes as it travels through the atmosphere. The attenuation is described by the *optical depth* of the attenuating medium, τ, such that the un-attenuated fraction of light (f) is given by:

$$f = \exp(-\tau)$$

where exp is the exponential function.

C1.2 The optical depth depends upon the amount of attenuating material that the light passes through. This can be written as

$$\tau = \sigma \int n \, dl$$

where σ is the cross-section of the absorber or scatterer, *n* is the number density of the scatters, and the integral over *dl* is an integral along the path from the source to the observer.

C1.3 In the case of light travelling horizontally through the atmosphere near the surface of the Earth, the number density of scatterers can be estimated to be constant along the line of sight, and so the optical depth scales proportionally to the distance (D). This can be written as

$$\tau = \tau_0 \left(\frac{D}{1\text{km}}\right)$$

where τ_0 is the optical depth for a characteristic distance of 1km.

C1.4 The value of τ_0 depends on the properties of the atmosphere, and also depends on the wavelength of the light that is being observed.

C1.5 The value of τ_0 is also dependent upon altitude, since the density of scatterers depends upon altitude.

C1.6 If the observer and the light source are at different altitudes then a full integral of the equation in C1.2 is formally required, rather than the simplification in C1.3. However, differences in calculated illuminance are small. Furthermore, where different altitudes are involved, the suppression of the beam of the aviation light away from the horizontal plane has a far more significant effect on the resultant illuminance of the light, meaning that a more detailed calculation is unwarranted.

C1.7 Atmospheric optical depth has been widely studied, by measuring the attenuation of light as it passes vertically through the atmosphere from the edge of space to the surface of the planet (i.e. the attenuation of incoming light from the Sun or stars, or equivalently of out-going light from Earth as measured by satellites).

C1.8 The attenuation is made up of two[1] primary components. These are: (i) Rayleigh scattering by air molecules; and (ii) scattering and absorption by microscopic solid or liquid particles suspended in the atmosphere (aerosols). These are discussed in the next two sections.

C.2 Rayleigh scattering

C2.1 Scattering by particles whose size is much smaller than the wavelength of the light, such as air molecules in the atmosphere, is known as Rayleigh scattering. Rayleigh scattering has a characteristic wavelength dependence as roughly

$$\tau \propto \lambda^{-4}$$

where λ is the wavelength of the light (e.g. Penndorf 1957). Thus, bluer wavelengths are more strongly scattered (this is why the sky appears blue).

C2.2 The total optical depth for Rayleigh scattering vertically through the atmosphere has been well-established. It is given by (e.g. Hayes & Latham 1975; Buton et al. 2013):

$$\tau_{Rayleigh,atmos} \approx 0.14 \left(\frac{\lambda}{500\text{ nm}}\right)^{-4} e^{(-h/h_0)}$$

where the numerical value corresponds to a wavelength λ of 500nm ($5\text{x}10^{-7}$m) which is appropriate for white light detected by the eye at low light levels (see Appendix B). In this equation, h is the height of the observer above sea-level, and h_0 is the scale-height of the atmosphere, set by the rate at which atmospheric pressure falls off with altitude.

C2.3 The atmospheric scale-height depends upon temperature, but for a temperature of 280K (around 7°C) it is typically $h_0 \approx$ 8km.

C2.4 Optical depth is proportional to the number of scattering molecules, and therefore to the density of the air. Atmospheric density (ρ) largely follows pressure (apart from small effects of temperature variations with altitude) in falling off exponentially with altitude, $\rho \propto \exp(-h/h_0)$. Since

$$\int_0^\infty \exp\left(\frac{-h}{h_0}\right) = h_0$$

the optical depth of the atmosphere, viewed vertically to space from sea level, is equivalent to looking through a distance h_0 of atmosphere horizontally at sea-level.

C2.5 Given the large scale-height of the atmosphere, the density at an altitude of 450m above sea-level (the average hub altitude of the 6 turbines in the Kirkan Wind Farm which carry visible lighting) is around 95% of that at sea-level. Thus, when looking horizontally at any altitude close to the Earth's surface, the optical depth due to

[1] A third component of atmospheric attenuation, due to Ozone, is small ($\tau_{ozone} \approx 0.016$ along a vertical path from Earth to space) and in any case it can be ignored for the current analysis of horizontal attenuation near the Earth's surface, as the ozone is located at high altitude.

Rayleigh scattering can be treated as a constant, depending only on the distance (D) between the light source and the observer,

$$\tau_{Rayleigh} \approx 0.14\ \frac{D}{h_0}\left(\frac{\lambda}{500\ \text{nm}}\right)^{-4}$$

Thus the optical depth produced by air molecules in 1 km of atmosphere close to sea level is

$$\tau_{0,Rayleigh} \approx 0.018\ \left(\frac{\lambda}{500\ \text{nm}}\right)^{-4}$$

C.3 Scattering by aerosols

C3.1 In addition to the normal molecular composition of air, air can contain additional components which restrict the passage of light. Common examples include dust and pollen, or man-made pollutants such as smoke or vehicle emissions. In maritime environments, sea salt is prevalent. Another common aerosol is liquid water droplets suspended in the air, as is the case for cloud or fog.

C3.2 It is common experience that under foggy conditions lights are visible for considerably shorter distances. For other aerosols, at typically much lower concentrations, the effect is less stark than for fog, but these still attenuate light, through scattering processes.

C3.3 For most aerosols the dominant scattering process is known as Mie scattering. The wavelength dependence of Mie scattering depends upon the nature of the scattering aerosol. Mie scattering is often expressed as a power law,

$$\tau \propto \lambda^{-\alpha}$$

where α is known as the Ångström exponent. Broadly speaking, the smaller the particle, the larger the value of α. For very small particles, Mie scattering tends towards Rayleigh scattering (α ~ 4). For large particles such as water droplets, which are very much larger than the wavelength of the light, the scattering become geometric, with no wavelength dependence (α = 0).

C3.4 Since for typical aerosols α is significantly below 4, the importance of Mie scattering compared to Rayleigh scattering increases for redder light. Mie scattering also differs from Rayleigh scattering in its directionality: Mie scattering tends to deflect light by relatively small angles.

C3.5 To model the attenuation due to aerosols, both the Ångström exponent and the density of aerosols are required. Like Rayleigh Scattering, the aerosol optical depth is generally measured along a vertical path between the surface of the Earth and space, either by ground-based instruments such as a LIDAR (Light Detection and Ranging) or from space, for example by MODIS (the Moderate Resolution Imaging Spectroradiometer) on NASA's Terra satellite. The total optical depth for aerosol scattering vertically through the atmosphere can be written as

$$\tau_{aerosol,atmos} \approx A_0 \left(\frac{\lambda}{500\text{ nm}}\right)^{-\alpha} e^{(-h/h_{aerosol})}$$

where A_0 is the aerosol optical depth from sea-level to space at 500 nm, h is the height of the observer above sea-level, and $h_{aerosol}$ is the scale-height of aerosols in the atmosphere.

C3.6 The scale-height of aerosols is significantly smaller than that of the molecular content of the atmosphere. The precise value depends upon local conditions – both topology and weather. Hayes & Latham (1975) draw on data from many sets of measurements and argue for a typical scale-height of 1.5 km, while noting that it can vary by a factor of two from day to day. This value is widely adopted by many researchers. Matthias et al. (2004) analyse a significant dataset obtained from the European Aerosol Research Lidar Network in Aberystwyth and derive a typical scale height of 1.2km, again with significant variations. Other UK locations can be expected to be similar. In this report, a conservative value of $h_{aerosol}$ =1.5km is adopted.

C3.7 The aerosol optical depth is found to vary considerably with location on the Earth, being particularly high in polluted areas. In any given location, it also varies significantly with time.

C3.8 Estellés et al. (2002) measured A_0 over an 8-year period at a coastal location of the UK (Plymouth) and determined that it varied around a mean of 0.18 (median 0.19), with an (asymmetric) standard deviation of 0.08. The lowest observed value of the observed aerosol optical depth over this period was about 0.08. Matthias et al. (2004) found a median A_0 of 0.14 (after converting their data from 350 to 500nm), with a lower limit of around 0.06. Data available from the Aerosol Robotic Network (AERONET; see https://aeronet.gsfc.nasa.gov) found a median A_0 of 0.08 for Edinburgh.

C3.9 The proposed Kirkan Wind Farm is in an isolated location (away from large amounts of man-made pollutants), and away from the coast (sea-salt pollutants), and so hence the aerosol density might be expected to be relatively low. For the analysis in this report, the effect of a range of different A_0 values from 0.05 to 0.14 is therefore considered.

C3.10 Observed values of the Ångström exponent are typically in the range 0 to 1.5 (see discussion in Hayes & Latham 1975). Smirnov et al. (2002) argue that the exponent in maritime environments is α=0.3-0.7, while Estellés et al. (2012) found α =1.03±0.21 for their data taken at Plymouth. The Edinburgh AERONET data find a median α = 1.1. Larger values of α lead to lower values of attenuation for red lights, and so here a conservative value of α=1.2 is adopted. It should be stressed that the adoption of other reasonable values of α would not have a significant influence on the results (the effect of varying α is smaller than the effect of the range of A_0 values considered above).

C3.11 As for Rayleigh scattering (C2.4), the aerosol optical depth as viewed vertically to space from sea level, is equivalent to looking through a distance of $h_{aerosol}$ of atmosphere horizontally at sea-level.

C3.12 Unlike Rayleigh scattering, the aerosol scale-height is low, and so the altitude above sea-level needs to be taken into account when considering the attenuation. For an altitude of 450m, and a scale-height of 1.5km, the aerosol density is around 74% of that at sea-level.

C3.13 Thus, following the arguments in C2.5, when looking horizontally at an altitude h, the optical depth due to aerosol scattering depends on the distance (D) between the light source and the observer as

$$\tau_{aerosol} = A_0 \frac{D}{h_0} \left(\frac{\lambda}{500\text{ nm}}\right)^{-\alpha} \exp\left(\frac{-h}{h_0}\right)$$

Thus for typical conditions, using our best estimate parameters and assuming 530m altitude, we find an optical depth for 1 km distances of

$$\tau_{0,aerosol} = [0.025\ to\ 0.07] \left(\frac{\lambda}{500\text{ nm}}\right)^{-1.2}$$

where the term in square brackets represents the range, due to the range of values to be adopted for A_0.

C.4 Resultant total attenuation under typical conditions

C4.1 Combining the optical depth for Rayleigh scattering with that from aerosols gives the total optical depth:

$$\tau = \tau_{Rayleigh} + \tau_{aerosol}$$

C4.2 At distance D, this is thus:

$$\tau \approx \left(0.017\left(\frac{\lambda}{500\text{ nm}}\right)^{-4} + [0.025\ to\ 0.07]\left(\frac{\lambda}{500\text{ nm}}\right)^{-1.2}\right)\left(\frac{D}{1\text{km}}\right)$$

C4.3 From C1.1, the un-attenuated fraction of light is then f = exp(-τ). Figure C1 shows this attenuation both for white light (500nm) and for red light (633nm). The solid and dashed lines show, respectively, the fractions of remaining light given by the equation in C4.2, for the upper and lower ends of the range of A_0 values. The dotted lines show the contribution from Rayleigh scattering only.

C4.4 It can be seen that atmospheric attenuation has a significant effect, reducing light levels by factor of approximately 2 at 10km distance (depending on colour) in poorer aerosol conditions, with shorter (bluer) wavelengths of light being more strongly attenuated than longer (redder) wavelengths.

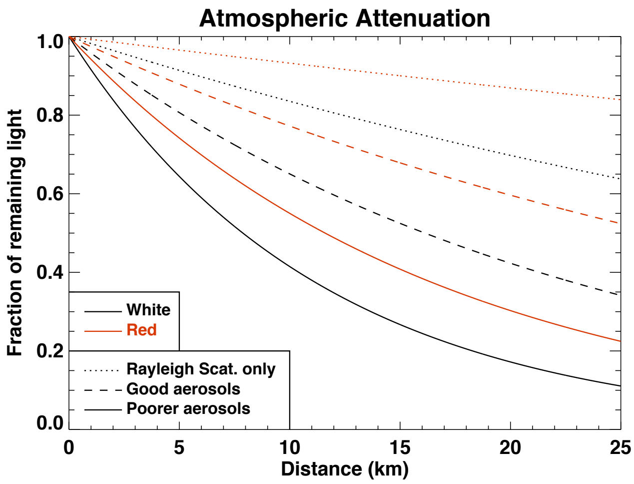

Figure C1: The attenuation of light as it passes horizontally through the atmosphere at an altitude of 450m. Results are shown for both white light (500nm) and red light (633nm). The dotted lines show the contribution from Rayleigh scattering by air molecules, in the absence of aerosols. The dashed and solid lines include aerosol attenuation under a range of realistic 'clear sky' condition. It can be seen that atmospheric attenuation has a significant effect, particularly at larger distances. There is a dependence on colour, with redder light being less strongly attenuated.

C4.5 Combining this atmospheric attenuation with the geometric dilation of light discussed in Appendix A (Figure A1) then allows the total illuminance of a light as a function of distance to be derived, by multiplying the geometically-calculated illuminance by the un-attenuated fraction. This is shown for a 200 candela light in Figure C2.

C4.6 Figure C2 also compares the derived illuminance against other objects in the night sky, in particular the brightest star in the northern hemisphere, and typical bright stars in the constellation of Orion. It can be seen that at a distance of around 10km, the illuminance of a 200 candela red light is comparable to those of bright stars in the night sky.

C4.7 Figure C2 further shows that the choice of aerosol attenuation factor makes little qualitative difference to the perceived brightness of the lights, at least out to distances of 10km.

C.5 Reduction of illuminance of aviation lighting below the horizontal plane

C5.1 It is important to note that the calculations of Figure C2 assume the quoted candela value for the lights. Turbine lighting is highly directional, with the CAA candela requirements relating to the horizontal plane. At angles well below the horizontal plane, the luminous intensity of the aviation lighting is strongly suppressed, resulting in significantly lower illuminance. This will be relevant both for observers close to the turbines (who will typically be viewing them from below) and for population centres located at lower altitude.

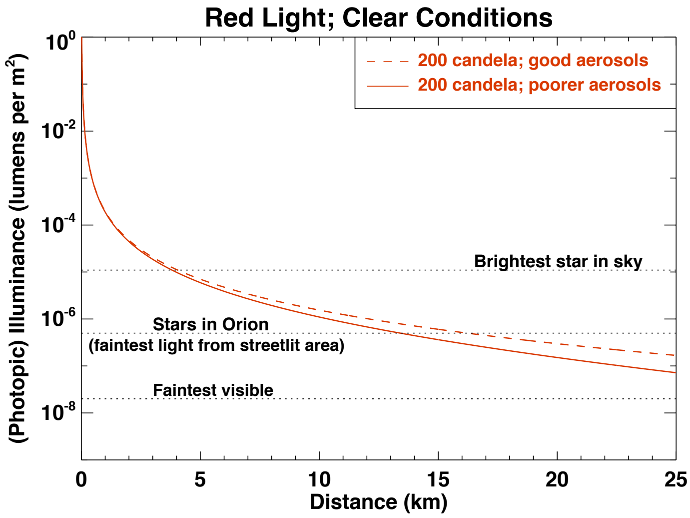

Figure C2: The illuminance of a single 200 candela red light (633nm) as a function of distance, viewed horizontally at an altitude of 450m. The results are shown considering the upper (solid line) and lower (dashed line) end of the realistic range of aerosol optical depth for typical clear conditions. For comparison, the illuminance provided by the brightest star in the northern sky is shown, along with those of typical bright stars such as those in the constellation of Orion. The latter also represent the approximate visual limit of the eye from street-lit areas (see Appendix B). Also indicated is the approximate visible limit to red light under perfect conditions (away from street lighting and other light pollution; new moon; dark-adapted eyes).

C5.2 To illustrate this effect, Figure 2 in the main report shows the vertical distribution of light using the technical specifications of a 2000 candela or 200 candela aviation LED currently available on the market, supplied by Contarnax Europe Ltd (CEL). This shows the strong suppression below the horizontal plane.

C5.3 If an aviation light is installed at a hub height of 110m then an observer at a distance of 2 km, at the same altitude as the base of the wind turbine, will be at an angle of -3 degrees relative to the light's horizontal plane. For an aviation LED with CEL's specifications, this corresponds to a factor 10 suppression in candela rating, thus effectively converting a 200 candela light into a 20 candela light. At 4km the observer will be at an angle of -1.5 degrees, with about a factor of 3 suppression of light. Where the observer is on lower ground than the turbines, these suppression factors will be even greater.

C.6 Visibility

C6.1 An important factor for aviation lighting on wind turbines is the *visibility*. According to The Air Navigation Order regulations (Article 222) and Civil Aviation Authority CAP764 guidance, when the visibility is better than 5km the luminous intensity of the aviation warning lights may be reduced from 2000 to 200 candela.

C6.2 Visibility relates to the attenuation of light. It is defined by the World Meteorological Organisation as the distance at which the intrinsic brightness of a light is reduced to 5% of its initial value due to light attenuation (i.e. excluding the $1/D^2$ geometric dilution discussed in Appendix A). It is usually defined at 550nm.

C6.3 Visibility and optical depth are directly related. At the 5% visibility threshold,

$$\exp(-\tau) = 0.05.$$

This corresponds to τ=3.0.

C6.4 As discussed in C2.5, the contribution of Rayleigh scattering at 550nm to the optical depth at a distance of 5km is only $\tau_{Rayleigh}$ = 0.06, and thus aerosol scattering completely dominates the opacity in poor visibility conditions.

C6.5 In such poor visibility conditions, the opacity is generally associated with larger particles such as liquid water droplets (cloud or fog), and hence a lower value of the Ångström exponent is appropriate. Here a value of α=0.6 is assumed, but again the results are not critically dependent upon the choice. For α=0.6, the opacity at 633nm at the visibility threshold is τ = 2.6 at 5km, corresponding to an optical depth per km of τ_0 = 0.52.

C6.6 In such poor visibility conditions, a 2000 candela light is required. Figure C3 shows the illuminance of such a light as a function of distance, accounting for atmospheric attenuation at the threshold value. This represents a worst-case scenario for 2000 candela lighting: in better conditions the luminous intensity of the lighting can be reduced, while in poorer conditions the atmospheric attenuation effects will be increased.

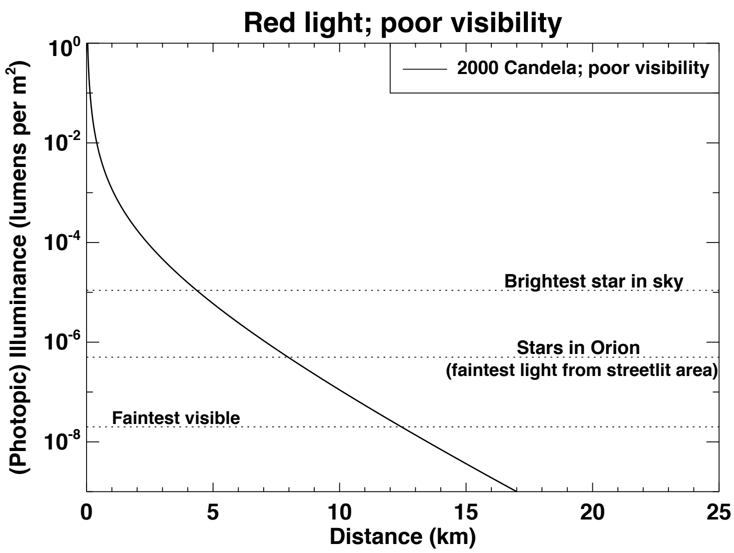

Figure C3: The illuminance of a 2000 candela light as a function of distance, as observed when the visibility conditions for the wind farm are at the threshold limit for requirement of such lights (visibility = 5%). This is compared against the illuminance provided by bright stars in the night sky.

C6.7 Figure C3 shows that, beyond about 5km from the wind turbine, the illuminance of this light drops below that of the brightest stars in the night sky.

C6.8 Zhang et al. (2020) give an overview of different techniques for measuring visibility. As locally-derived data are not available for the distribution of visibilities on the proposed Kirkan Wind Farm site, an estimate can be made using the public data on visibility measurements available in other locations around Scotland.

C6.9 A dataset is available from the Leuchars air base in Fife, that stretches back for 60 years (Singh et al. 2017). Leuchars is subject to broadly the same weather conditions and prevailing wind direction as the Scottish Borders area, and therefore can be expected to provide similar results. The visibility distribution for Leuchars for the past two decades is shown in the upper panel of Figure C4. Based on these data, the visibility at Leuchars drops below 5km for between 3 and 4% of the time.

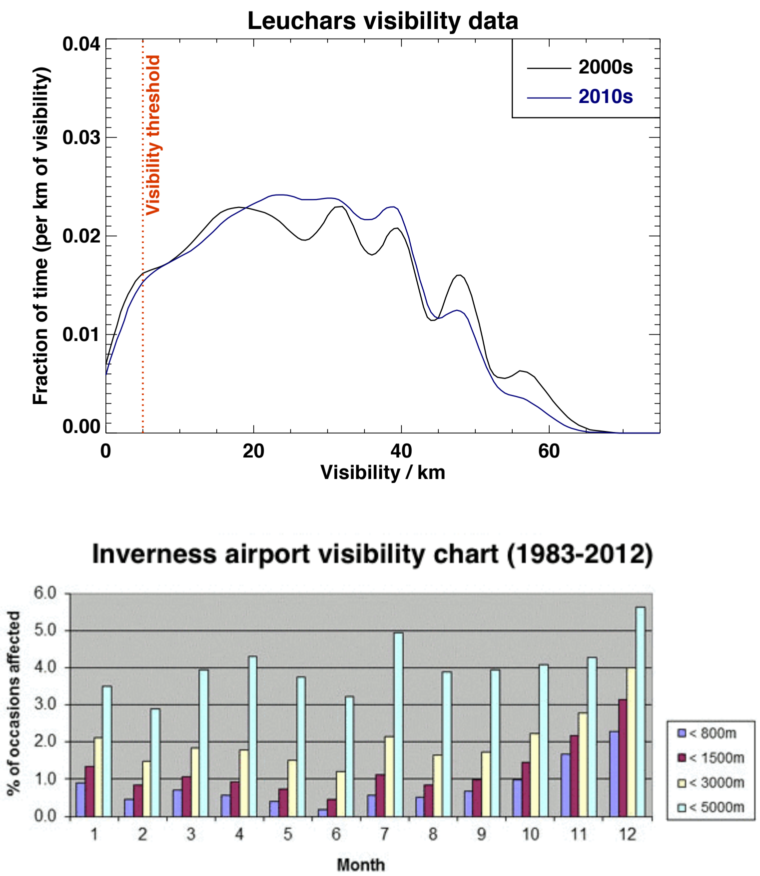

Figure C4: Top: the distribution of visibilities measured at the Leuchars air base over the past two decades (data from Singh et al. 2017). Bottom: the published visibility chart for Inverness Airport (credit: Met Office).

C6.10 Data published by the Met Office for Inverness Airport (43km from the Kirkan Wind Farm) is shown in the lower panel of Figure C4. This similarly shows that visibility drops below 5km for about 4% of the time. Similar data from other Scottish airports indicate poor visibility for fractions of between 4% and 7% of the time, with the higher values associated with airports closer to large population centres, where man-made pollutants will be higher.

C6.11 Leuchars and Inverness Airport are both located close to sea level. Although aerosol densities decrease with increasing altitude, higher altitude sites like the Kirkan Wind Farm are more likely to be affected by cloud or mist. For this reason, a conservative estimate is that the Kirkan Wind Farm may be affected by poor visibility for at most 10% of the time.

C.7 Total ambient light level of the wind farm

C7.1 The CAA-agreed lighting scheme for the Kirkan Wind Farm includes 6 turbines with visible lighting. In Figure C5, the total illuminance provided by the sum total of all of these turbine hub lights is assessed as a function of distance, and compared to natural ambient light levels. The analysis assumes that all turbines are located at the same distance from the observer. Results are shown for distances of 3km to 25km, as at smaller distances the overall extent of the wind farm means that the assumption of equal distance to all turbines is poor.

C7.2 The analysis also assumes that the maximum luminous intensity of the turbines is seen which, as discussed above, will over-estimate the effect below the horizontal plane due to the directionality of the light.

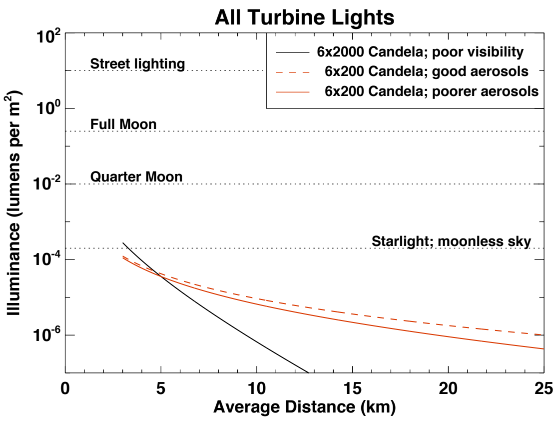

Figure C5: The total illuminance provided by all turbine hub lights as a function of distance, compared to natural and man-made ambient light backgrounds. The red solid and dashed lines show respectively the upper and lower end of the range of aerosol optical depths considered for 'clear' conditions. The black line shows poor visibility conditions when 2000 candela lights are mandated. In all cases, the assumption is made that all turbines are visible, and all are located at the same distance (this will not be valid for small distances). As is evident, for all distances beyond 3 km the total ambient light level produced by the wind farm is below that of the starlit moonless sky.

C7.3 The results indicate that, even in the worst-case scenario, the contribution of the whole wind farm development is comparable to, or below, the ambient background levels produced by starlight in a moonless sky, at all distances beyond 3 km.

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