Chapter 14 Aviation, Radar and Other Issues

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14 Aviation, Radar and Other Issues

14.1 Introduction

14.1.1 This chapter assess the potential effects of the Proposed Development in relation to:

- Aviation, Radar & Defence;
- Shadow Flicker; and
- Carbon Balance

14.1.2 The aviation and shadow flicker assessments have been undertaken by the Applicant. The Climate Change Assessment has been undertaken by ITPEnergised.

14.1.3 Elements relating to Major Accidents and Disasters have been addressed in the individual technical discipline chapters where relevant.

14.1.4 Impacts on Population and Human Health have been addressed in the individual Environmental Impact Assessment (EIA) topic chapters where relevant.

14.1.5 Assessment of the effects on telecommunications has been scoped out within the Scoping Report (refer to **Technical Appendix 4.1**). The turbine layout has been designed to avoid direct impact on telecommunication links.

14.2 Aviation, Radar and Defence

Introduction

14.2.1 This section of the chapter considers the potential effects on aviation, radar and defence associated with the construction, operation and decommissioning of the Proposed Development.

14.2.2 The assessment of potential effects on aviation, radar and defence considers technical acceptability, based on air navigation safety, rather than following a strict EIA process of assessing the significance of effects. Such effects often require the implementation of technical mitigation solutions to ensure continued safe operation in the presence of a wind farm. The assessment of effects on these receptors is therefore one of technical analysis and consultation and seeks to identify whether the effect is likely to be 'acceptable' or 'not acceptable' to air navigation services provision.

Statement of Competence

14.2.3 The aviation, radar and defence assessment was conducted by Sam Johnson of RES. Sam is the Senior Aviation Manager at RES, with an MMath in Mathematics. Sam has over 20 years' experience in the radar industry with over 15 years specifically in the area of wind farms. Sam is a member of the Renewable UK Aviation Working Group and is Chair of Aviation Investment Fund Company Limited (AIFCL).

Guidance

14.2.4 This assessment has been prepared with reference to Civil Aviation Authority (CAA) Publication (CAP) 764, Policy and Guidelines on Wind turbines (CAA, 2016). This is the primary guidance in relation to the assessment of wind turbines on aviation in the UK.

Scope of Assessment

Effects Scoped Out

14.2.5 Interference with surveillance systems and radar can occur when wind turbine blades are moving, therefore potential effects during construction are not assessed.

14.2.6 Upon decommissioning, the Defence Geographic Centre (DGC) will be informed of the removal of wind turbines. Following this, no decommissioning effects are expected and are not considered further.

Effects Assessed in Full

14.2.7 The assessment identifies and considers the potential effects that the Proposed Development may have on civilian and military aviation, air safeguarding and, if required, the mitigation measures proposed to prevent, reduce or offset any potential adverse effects where possible.

14.2.8 In relation to military and civil aviation assets it considers potential impacts on the military Air Defence (AD) Radar at Brizlee Wood, the military Air Traffic Control (ATC) Radars at RAF Spadeadam (Deadwater Fell and Berry Hill), RAF Leuchars Radars, NATS En Route Ltd (NERL) radars at Lowther Hill, and Edinburgh Airport, and the potential mitigation measures identified to address these. The potential impact on the Edinburgh Air Traffic Control Surveillance Minimum Altitude chart (ATCSMAC) is also considered.

14.2.9 In relation to military assets, it considers potential impacts on the Eskdalemuir Seismic Array (EKA).

14.2.10 The assessment is based on an evaluation of existing data sources and desk studies, and consultation with key stakeholders.

14.2.11 The effects of wind turbines on aviation interests are well known but the primary concern is one of safety. The two principal scenarios that can lead to effects on the operations of aviation stakeholders are:

- physical obstruction: wind turbines can present a physical obstruction at or close to an aerodrome or in the military low flying environment, which itself presents a health and safety risk or otherwise requires changes to flight routes in the area which brings about other operational effects; and
- radar/air traffic services (ATS): wind turbine clutter appearing on a radar display can affect the safe provision of ATS as it can mask unidentified aircrafts from the air traffic controller and/or prevent them from accurately identifying aircrafts under control. In some cases, radar reflections from wind turbines can affect the performance of the radar system itself.

14.2.12 In this context the scope of the assessment is to consider the impact of the Proposed Development on aviation stakeholders, including military, en route, airports and other airfields, radar systems and air space users. This assessment also considers civil and military stakeholder aviation obstruction lighting requirements.

14.2.13 As standard, the DGC (AIS Information Centre) will be provided with the following information for incorporation on to aeronautical charts and documentation:

- the date of commencement of the Proposed Development;
- the exact position of the wind turbine towers in latitude and longitude;
- a description of all structures over 300 feet high;
- the maximum extension height of all construction equipment;
- the height above ground level of the tallest structure; and
- details of a visible and/or infrared aviation lighting scheme.

Baseline Characterisation

Study Area

14.2.14 Consideration is given to aviation infrastructure that is within operational range of the Proposed Development. Operational range varies with the type of infrastructure but broadly includes regional airports operating radar up to 50 km of the Proposed Development, non-radar aerodromes within 17 km, parachute drops zones within 3 km, and military radar and en route radar systems up to 100 km from the Proposed Development (dependent on operational range).

14.2.15 Consideration is given to EKA within a 50 km range.

Desk Study

14.2.16 The Applicant has a dedicated aviation manager who has provided input to the Proposed Development since its inception. This has included:

- civil and military radar line of sight (LoS) analysis;
- review of relevant aviation charts;
- review of military low flying charts;
- general aviation advice based on prevailing civil and aviation issues; and
- review of AKA impact.

Significance Criteria

14.2.17 Significance criteria for aviation impacts are typically difficult to establish; they are not strictly based on the sensitivity of the receptor or magnitude of change but on whether the industry regulations for safe obstacle avoidance or radar separation (from radar clutter) can be maintained in the presence of the wind turbines.

14.2.18 Any anticipated impact upon aviation stakeholders which results in restricted operations is therefore considered to be of significance.

Assessment Limitations

14.2.19 No limitations have been identified that would affect the findings of the assessment, based on the information available at the time of writing (September 2023).

Consultation

Table Error! No text of specified style in document.**-14.1: Consultation relating to Aviation, Radar and Defence**

Consultee and Date	Scoping / Other Consultation	Issue Raised	Response / Action
Edinburgh Airport, February 2023	Scoping	This proposal has been examined from an aerodrome safeguarding perspective and conflicts with safeguarding criteria.	An independent assessment was commissioned that satisfied the Airport's Safeguarding Team that there was no impact on the

Consultee and Date	Scoping / Other Consultation	Issue Raised	Response / Action
			Instrument Flight Procedures (IFPs).
MOD, February 2023	Scoping	Physical Obstruction The development falls within Low Flying Area 14 (LFA 14), an area within which fixed wing aircraft may operate as low as 250 feet or 76.2 metres above ground level to conduct low level flight training. The addition of turbines in this location has the potential to introduce a physical obstruction to low flying aircraft operating in the area.	A lighting scheme will be agreed with the MOD to ensure the development is fitted with MOD accredited in accordance with the Air Navigation Order 2016.
		Eskdalemuir Seismological Recording Station The proposed application site falls within the statutory consultation zone of the seismological recording station at Eskdalemuir (the array), a UK asset that contributes to the Comprehensive Nuclear Test Ban Treaty. Research has confirmed that wind turbines of current design generate seismic noise which can interfere with the operational functionality of the array. In order to ensure the United Kingdom can continue to implement its obligations in maintaining the Comprehensive Nuclear Test Ban Treaty a noise budget, based on the findings of research for the 50km radius surrounding the array, is managed by the MOD.	Currently there is no noise budget available but guidance is being prepared by the MOD and Scottish Government via the Eskdalemuir Working Group (EWG), which is hoped to unlock available noise budget to allow the Proposed Development an allocation.

Consultee and Date	Scoping / Other Consultation	Issue Raised	Response / Action
NATS, February 2023	Scoping	None	None

Baseline

CAA and Airports

14.2.20 The only civil airport to respond to Scoping was Edinburgh Airport with concerns of impacts on their IFPs.

14.2.21 The Civil Aviation Authority will require the Proposed Development to have visible lighting in accordance with the Air Navigation Order 2016, Article 222, to assist with air safety.

NERL

14.2.22 The Proposed Development is approximately 59 km north-east of the Lowther Hill radar.

14.2.23 NERL has indicated that the Proposed Development does not pose any impact on any of their NERL radars.

Military Aviation

14.2.24 The Proposed Development is approximately 89 km north-west of the Brizlee Wood radar. The Defence Infrastructure Organisation (DIO) has indicated that the Proposed Development will have no impact on any of its AD or ATC radars.

14.2.25 The DIO has a requirement for the Proposed Development to agree a suitable scheme of visible and/or infrared lighting.

EKA

14.2.26 The Proposed Development is approximately 40 km north of the EKA and eleven of the turbines are within the 50 km safeguarded zone.

14.2.27 The DIO has indicated that the Proposed Development will have an unacceptable impact upon the EKA as it lies within the 50 km protection range.

Mitigation and Residual Effects

Predicted Operational Effects

14.2.28 Wind turbines have the potential to impact the performance of air traffic control radars. These impacts include:

- The creation of "false" targets, whereby the wind turbines present on the radar display. Multiple false targets can lead to the radar initiating false aircraft tracks.
- False returns can also cause track seduction, i.e. real aircraft tracks are 'seduced' away from the true position as the radar updates the aircraft track with the false return. This can lead to actual aircraft not being detected.
- Shadowing whereby the aircraft is not detected by the radar as it is flying within the physical 'shadow' of the wind turbine.

Aviation & Radar and Defence

CAA and Airports

14.2.29 Following an independent assessment, there is no impact on the Edinburgh IFPs.

EKA

14.2.30 There is a potential impact on the EKA, albeit the Proposed Development is on the outer edge of the 50 km consultation range and only 11 of the 18 turbines are inside it.

Proposed Mitigation

EKA

14.2.31 The MOD maintains that the Eskdalemuir 'noise budget' within the 50 km zone has been fully allocated to other wind farm sites and there are numerous other sites in the queue. This restriction will therefore apply to the Proposed Development.

CAA

14.2.32 A reduced visible aviation lighting scheme has been agreed with the CAA. The reduced scheme means only seven wind turbine needs to be lit and no tower lights are required provided an infrared scheme is agreed with the DIO.

14.2.33 Under provisions given in the Air Navigation Order (ANO) Article 222 section 6, the CAA provides for the following variation:

- medium intensity steady red (2000 candela) lights on the nacelles of turbines T01, T03, T09, T10, T13, T16 and T18;
- a second 2000 candela light on the nacelles of the above turbines to act as alternate in the event of a failure of the main light (note that both lights should not be lit at the same time);

- lights capable of being dimmed to 10% of peak intensity when the lowest visibility (as measured at suitable points around the wind farm by visibility measuring devices) exceeds 5 km;
- a scheme of infrared lighting to be agreed with the MOD to account for operators who carry night vision device capability (note that dimming permission is applicable only to visible lights, not infra-red lighting); and
- intermediate level 32 candela lights are not required to be fitted on the turbine towers.

14.2.34 The results of the assessment for night-time lighting are contained in **Chapter 6: Landscape & Visual Impact Assessment**. An infrared lighting scheme will be agreed with the DIO prior to the Proposed Development becoming fully operational.

Summary

14.2.35 The Proposed Development will impact the EKA. It is expected that the impact can be mitigated once the MOD and Scottish Government has agreed on the updated technical 'noise budget' and allocation policy. This mitigation could be secured through an appropriately worded suspensive planning condition.

14.2.36 Infrared lighting will be agreed with the DIO for the MOD low flying requirements and a visible lighting scheme has been agreed with the CAA.

14.3 Shadow Flicker

Introduction

14.3.1 This section of the chapter summarises the potential effect of shadow flicker associated with the Proposed Development.

14.3.2 In sunny conditions, any shadow cast by a wind turbine will mirror the movement of the rotor. When the sun is high, any shadows will be confined to the wind farm area but when the sun sinks to a lower azimuth moving shadows can be cast further afield and potentially over adjacent properties. Shadow flicker is generally not a disturbance in the open as light outdoors is reflected from all directions. The possibility of disturbance is greater for occupants of buildings when the moving shadow is cast over an open door or window, since the light source is more directional.

14.3.3 Whether shadow flicker is a disturbance depends upon the observer's distance from the turbine, the direction of the dwelling and the orientation of its windows and doors from the wind farm, the frequency of the flicker and the duration of the effect, either on any one occasion or averaged over a year.

14.3.4 In any event and irrespective of distance from the turbines, the flickering frequency will depend upon the rate of rotation and the number of blades. It has been recommended (Clarke, 1991) that the critical frequency should not be above 2.5 Hz, which for a three-bladed turbine is equivalent to a rotational speed of 50 rpm. The proposed turbines at the Proposed Development would rotate at a maximum of approximately 13 rpm, well below this threshold.

Reflected Light

14.3.5 A related visual effect to shadow flicker is that of reflected light. Theoretically, should light be reflected off a rotating turbine blade onto an observer then a stroboscopic effect would be experienced. In practice a number of factors limit the severity of the phenomenon and there are no known reports of reflected light being a significant problem at wind farms.

14.3.6 A limiting factor is that wind turbines have a semi-matt surface finish which means that they do not reflect light as strongly as materials such as glass or polished vehicle bodies.

14.3.7 Secondly, due to the convex surfaces found on a turbine, light will generally be reflected in a divergent manner.

14.3.8 Thirdly, as with shadow flicker, certain weather conditions and solar positions are required before an observer would experience this phenomenon.

14.3.9 It is therefore concluded that the Proposed Development will not cause a material reduction to amenity owing to reflected light.

Policy and Guidance

14.3.10 The following policy document has been referred to in undertaking the assessments:

- National Planning Framework 4[1]

14.3.11 The following guidance documents have been referred to in undertaking the assessments:

- Scottish Government - Onshore wind turbines: planning advice[2]

[1] *Available online:* https://www.gov.scot/publications/national-planning-framework-4/, (last accessed 26/09/2023)

[2] *Available online:* https://www.gov.scot/publications/onshore-wind-turbines-planning-advice/, (last accessed 25/08/2023)

- Department of Energy & Climate Change (DECC) guidelines3

14.3.12 The update to Shadow Flicker Evidence Base (2011), published by the then Department for Energy and Climate Change (DECC), states that assessing shadow flicker effects within ten times the rotor diameter of wind turbines has been widely accepted across different European countries, and is deemed to be an appropriate area.

14.3.13 Scottish Government guidance advocates that beyond this distance, shadow flicker should not be a problem.

Methodology

14.3.14 Properties have been assessed within a radius of ten rotor diameters distance of any turbine as per DECC guidelines.

14.3.15 This shadow flicker assessment is based on turbines with a 150 m rotor diameter and the planning application includes a 50 m micro-siting distance for infrastructure. As such, this 50 m distance is added to the ten-rotor diameter (150m = 150 * 10) m distance to give a total distance of 1,550 m (= 1,500 m + 50 m) from any turbine.

14.3.16 Analysis was undertaken for shadow flicker at all properties within 1,550m from any wind turbine.

14.3.17 This analysis takes into account the motion of the Earth around the Sun, the local topography and the turbine locations and dimensions. The analysis was performed using a layout of 18 turbines, each with a maximum tip height of 180m using the WindPRO Shadow Flicker software package.

14.3.18 The assessment does not include the cumulative impact of any nearby developments.

Assessment Results

14.3.19 **Figure 16.1** details the locations of affected properties relative to the Proposed Development.

14.3.20 With due reference to the DECC report, and allowance for 50 m micro-siting, the potential duration of shadow flicker effects is given in **Table 16.2**.

[3] *Available online:* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48052/1416-update-uk-shadow-flicker-evidence-base.pdf, p12, (*last accessed* 25/08/2023)

16.2 Shadow Flicker Assessment Summary of Results

RES Property ID	Property Address	Distance to nearest turbine (km)	Total hours per year
H50	Esperston Farm, Temple EH23 4SA	1.5	17.5
H55	Whitelaw, North Middleton EH23 4RG	1.2	73.9
H63	4 Esperston Farm Cottages, Temple EH23 4SA	1.5	38.3
H64	2 Esperston Farm Cottages, Temple EH23 4SA	1.4	38.6
H80*	Outerston Hill, Temple EH23 4SD	1.0	101.0
H170	1 Esperston Farm Cottages, Temple EH23 4SA	1.4	38.3
H191*	Mauldslie West Cottage, Temple EH23 4TB	1.3	38.0
H263	3 Esperston Farm Cottages, Temple EH23 4SA	1.4	38.6
H271	Mauldslie Farm, Temple EH23 4TB	1.4	42.0
H288*	Mauldslie Hill Cottage, Temple EH23 4TB	1.2	39.1

14.3.21 The above impacts represent a worst-case scenario for the following reasons:

14.3.22 The analysis assumes that the wind turbines rotors are always turning (in reality this only occurs when there is sufficient wind to turn the rotor blades and the wind turbines are not undergoing maintenance);

14.3.23 The analysis assumes that the orientation of the wind turbines is always aligned so as to cast a sufficient shadow towards the property (in reality the wind turbines automatically turn to face the prevailing wind which may, or may not, create this condition)

14.3.24 The analysis assumes that sunshine is always of sufficient intensity to cause shadow flicker (in cloudy skies it is unlikely to do so);

14.3.25 The analysis assumes that all receptors have relevantly orientated windows (in reality this may not be true); and

14.3.26 The analysis assumes that no trees or walls obscure the view of the wind turbines and hence block any potential shadow flicker (in reality many properties have trees or bushes near to the property that may obscure the view to the proposed development).

Mitigation

14.3.27 Mitigation measures can be incorporated into the operation of the Wind Farm to reduce the instance of shadow flicker. Mitigation measures include planting tree belts between the affected dwelling and the responsible turbine(s) and shutting down individual turbines during periods when shadow flicker could theoretically occur. Any complaints received can be considered against the worst-case scenario as a first check. If found necessary, any mitigation measures will be specifically designed to minimise adverse effects at affected properties.

Summary

14.3.28 Shadow flicker modelling was carried out for a radius of 1550 m around all turbine locations using the WindPRO Shadow Flicker software package.

14.3.29 Based on the worst-case scenario, 10 inhabited properties were identified that could theoretically experience shadow flicker. Seven of these properties are not financially involved.

14.3.30 Any complaints received during operation can be investigated against the worst-case scenario and mitigation measures can be implemented if necessary. Mitigation measures include the planting of tree belts or the shutting down of individual turbines during periods when shadow flicker could theoretically occur.

14.4 Climate Change Assessment

Introduction

14.4.1 Increasing atmospheric concentrations of greenhouse gases (GHGs), including carbon dioxide (CO_2) – also referred to as carbon emissions – are resulting in climate change. A major contributor to this increase in GHG emissions is the burning of fossil fuels. With concern growing over climate change, reducing its cause is of upmost importance. The replacement of traditional fossil fuel power generation with renewable energy sources provides high potential for the reduction of GHG emissions. This is reflected in UK and Scottish Governments' climate change and renewable energy policy and commitments. The relevant aspects of such policies are summarised in **Chapter 5: Statutory and Policy Framework**.

14.4.2 Whilst the Proposed Development will reduce carbon emissions by replacing the need to burn fossil fuels for power, no form of electricity generation is completely carbon free; for onshore wind farms, there will be emissions as a result of component manufacturing, transportation and installation processes associated with the Proposed Development.

14.4.3 In addition to the lifecycle emissions from the turbines and associated wind farm infrastructure, where a wind farm is located on carbon rich soils such as peat, there are potential emissions resulting from direct action of excavating peat for construction and also the indirect changes to hydrology that can result in losses of soil carbon. The footprint of a wind farm's infrastructure will also decrease the area covered by carbon-fixing vegetation.

14.4.4 Conversely, restoration activities undertaken post-construction or post-decommissioning could have a beneficial effect on carbon uptake through the restoration of modified bog habitat. Carbon losses and gains during the construction and lifetime of a wind farm, and the long-term impacts on the peatlands on which they are sited, need to be evaluated to understand the consequences of permitting such developments.

14.4.5 A technical review of energy displacement by the UK Energy Research Centre (UKERC) considered over two hundred studies and papers from all round the world for the UK Government and concluded that "*it is unambiguously the case that wind energy can displace fossil fuel-based generation, reducing both fuel use and carbon dioxide emissions*" (UKERC, 2006). Whilst the wind turbines will reduce carbon emissions by replacing the need to burn fossil fuels for power, there is the potential for carbon fixers and sinks to be lost through the clearing of vegetation and materials for construction. There must therefore be a sufficient balance between the carbon reduced and that which is produced and lost through associated processes.

Methodology

14.4.6 All applications that are over 50 MW are dealt with through the Scottish Government's Energy Consents Unit in accordance with Section 36 of the Electricity Act 1989 and require a carbon balance assessment using the Scottish Government's online 'Carbon Calculator' tool, that can be used to calculate the greenhouse gas emissions and carbon payback times for wind farm developments on Scottish peatlands. This online tool is supported by two documents published by the Scottish Government and Scottish Renewables, and Scottish Environment Protection Agency (SEPA) to aid in calculating the potential carbon losses and savings.

14.4.7 The Carbon Calculator compares an estimate of the carbon emissions from the construction, operation, and decommissioning of the Proposed Development to those emissions estimated from other electricity generation sources. Input parameters are based on the proposed site design, infrastructure dimensions, results from peat depth surveys and laboratory testing of peat, and other information gained from site survey work, desk study and, where applicable, assumptions relating to groundwater, drainage, and habitat regeneration. As no infrastructure is yet to be constructed for the Proposed Development, the assumptions relating to infrastructure have been based on information for the Proposed Development or from standard, default representative information.

14.4.8 This report and assessment should be read in conjunction with the online carbon calculator inputs and outputs (**Technical Appendix 14.1**), and the project description contained in **Chapter 3: Project Description**.

Input Parameters

14.4.9 Information relating to the Proposed Development (including consideration of design, operation, and construction) has been collated, and includes details of the proposed infrastructure, local ecology, and restoration proposals associated with the Proposed Development. This collated information has been entered into the online carbon calculator and is outlined below.

Windfarm Characteristics

14.4.10 The Proposed Development will comprise 18 turbines up to 180 m tip height when vertical with a power rating of 6 MW. The operational life of the Proposed Development is expected to be 50 years.

Capacity Factor

14.4.11 The capacity factor is 43.5% from energy yield assessments undertaken by the Applicant, with a minimum of 41.3% and a maximum of 45.7% (calculated from +/- 5%).

Back Up

14.4.12 The Carbon Calculator indicates that if over 20% of national electricity is generated by wind energy, the extra capacity required for backup is 5% of the rated capacity of the wind plant. The values for 'fraction of output to backup' are therefore input as expected 5% and maximum 5% to represent full requirement for backup, and a minimum of 0% to represent no backup required (Nayak *et al.*, 2008). SEPA indicates that for this parameter, the electricity generation capacity of Scotland, rather than the UK, should be considered. In 2022, Scotland generated about 66% of gross electricity consumption via onshore wind (Scottish Renewables Statistics, 2023). Where the balancing capacity is obtained from fossil fuel generating stations, emissions will increase by 10% due to reduced thermal efficiency of the reserve generation stations (*Dale et al.*, 2004). This value is fixed in the Carbon Calculator.

CO_2 Emissions from Turbine Life (tCO2/MW)

14.4.13 CO_2 emissions during the life of a turbine include emissions that occur during the manufacturing, transportation, erection, operation, dismantling and removal of the structures. As there is no direct Life Cycle Assessment for the Proposed Development available at this point in time, the inbuilt Carbon Calculator option which allows for emissions to be calculated according to turbine capacity has been selected.

Characteristics of Peatland Before Wind Farm Development

Type of Peatland

14.4.14 The best habitat description available on the Carbon Calculator is Acid bog (refer to **Chapter 8: Ecology** and **Technical Appendix 8.1** for further information on habitats found within the site boundary).

Average Annual Air Temperature at Site

14.4.15 The average annual air temperature of 12.96°C is based on average annual temperature data from the Met Office UK climate averages (Met Office, 2023). The nearest climate station to the Proposed Development is located at the Royal Botanic Garden, Edinburgh, approximately 21.7 km north-west of the Proposed Development site.

Average Depth of Peat at Site

14.4.16 The average peat depth of 0.20 m was calculated based on peat probe data from within the site boundary of the Proposed Development (refer to **Technical Appendix 10.1 and 10.2**)

Carbon Content of Dry Peat

14.4.17 Site specific values are not available, so the standard values from the 'Windfarm Carbon Calculator Web Tool, User Guidance' have been used.

Average Extent of Drainage around Drainage Features at Site

14.4.18 Site specific values are not available, so the standard values from the 'Windfarm Carbon Calculator Web Tool, User Guidance' have been used. The expected value is 10 m, with a minimum of 5 m and maximum of 50 m.

Average Water Table Depth at Site

14.4.19 Site specific values are not available, so the values for 'intact peat' from 'Windfarm Carbon Calculator Web Tool, User Guidance' have been used as a worst-case scenario. The expected value is 0.1 m, with a minimum 0.05 m, and a maximum 0.3 m.

Dry Soil Bulk Density

14.4.20 Given the difficulty of collecting sufficient samples to derive a representative site-specific value for this parameter, Scottish generic values for peat from 'Windfarm Carbon Calculator Web Tool, User Guidance' have been used. The expected value is 0.132 g/cm^3, with a minimum of 0.072 g/cm^3 and a maximum of 0.293 g/cm^3.

Characteristics of Bog Plants

Regeneration of Bog Plants

14.4.21 This parameter needs to be estimated and there are relatively few studies available on the average time taken for bog plant communities to regenerate following restoration. The time for regeneration of bog plants can vary widely depending on the location of the site, the target plants, and ground condition. Rochefort *et al* (2003) estimate that a significant number of characteristic bog species can be established in 3-5 years, a stable high water-table in about a decade, and a functional ecosystem that accumulates peat in around 30 years.

14.4.22 As such, five years has been stated as a reasonable precautionary estimate for the regeneration time needed for most bog species, with a minimum of two years and a longer establishment time of 30 years.

Carbon Accumulation

14.4.23 The Carbon Calculator Guidance (Technical Note, Version 2.10.0, Scottish Government) suggests a mid-range value of 0.25 tC ha-1 yr^{-1} and a range of 0.12 to 0.31 t C ha-1yr^{-1}.

Forestry Plantation Characteristics

Area of Forestry Plantation to be Felled

14.4.24 There is only one area of forestry (9.8 ha) that would be felled on site to accommodate Turbine 1 and its associated infrastructure. The minimum and maximum extent has been calculated as +/- 10%.

Average Rate of Carbon Sequestration in Timber

14.4.25 Standard values informed by 'Windfarm Carbon Calculator Web Tool, User Guidance' have been used to inform the average rate of carbon sequestration in timber.

Counterfactual Emission Factors

14.4.26 The counterfactual emission factors for three methods of energy generation are fixed in the carbon calculator. Values for both coal-fired and fossil fuel-mix emission factors are updated from DUKES data for the UK which is published annually. The source for the grid-mix emission factor is the list of emission factors used to report on greenhouse gas emissions by UK organisations published by BEIS.

Borrow Pits

14.4.27 Two borrow pits are planned for the Proposed Development (refer to **Chapter 3**). The borrow pit search areas are of different sizes and shapes and as such the area of the borrow pits was divided by their total number and then the square root of this value was calculated to get an average length and width. The average peat depth in the two borrow pit areas is 0.11 m, with a minimum of 0.10 m and a maximum of 0.12 m.

Foundations and Hardstanding Areas

14.4.28 The turbine foundations for the Proposed Development are expected to be 27 m in diameter. As outlined in **Chapter 3**, a full ground investigation will be completed prior to construction which will inform final foundation and crane hardstanding design. As such, final dimensions may be subject to minor variations.

14.4.29 The average peat depth in the foundation areas is 0.11 m, with a minimum of 0.10 m and a maximum of 0.12 m, and the average peat depth in the hardstand areas is 0.11 m, with a minimum of 0.10 m and a maximum of 0.12 m.

Volume of Concrete

14.4.30 It is expected that the Proposed Development would require a total of 8,775 m^3 of concrete.

Access Tracks

14.4.31 There are no existing tracks within the Proposed Development site. The total length of new access tracks proposed is approximately 17 km. Small changes to the access track layout may occur post consent (e.g., as a result of micrositing) leading to minor variations to the overall track length. There are no floating tracks proposed.

14.4.32 The average peat depth on the route of the proposed access track is 0.22 m, with a minimum of 0.21 and a maximum of 0.23 m.

Cable Trenches

14.4.33 **Chapter 3** states that the wind farm array cables on site will be laid in trenches, typically approximately 0.5 m deep and 1 m wide, laid on a sand bed and backfilled using suitably graded material, and will mainly be located adjacent to the access tracks within the Proposed Development.

Additional Peat Excavated

14.4.34 The volume of additional peat predicted to be excavated is 3,413 m^3. Further information can be found in **Technical Appendix 9.2 Draft Peat Management Plan**.

Peat Landslide Hazard

14.4.35 The peat landslide hazard is a fixed value automatically defined by the Carbon Calculator and is shown to be 'negligible'.

Improvement of Carbon Sequestration at the Site

Improvement of Degraded Bog

14.4.36 The Outline Biodiversity Enhancement Management Plan (oBEMP) (**Technical Appendix 8.6**) outlines the objective to deliver peatland restoration within the site boundary. The area of degraded bog to be improved is 36.69 ha.

Improvement of Felled Plantation Land

14.4.37 The felled area will not be improved for peatland.

Restoration of Peat Removed from Borrow Pits

14.4.38 **Chapter 3** outlines that all borrow pits will be restored following the completion of construction. This is a total area of 12.57 ha.

Early Removal of Drainage from foundations and hardstanding

14.4.39 The crane hardstandings will remain in place during the lifetime of the Proposed Development to facilitate maintenance works (refer to **Chapter 3**). It is assumed that drainage around the hardstandings will be maintained.

Restoration of Site after Decommissioning

Hydrology & Habitats

14.4.40 The oBEMP (**Technical Appendix 8.6**) outlines the proposed habitat and conservation management measures in relation to the Proposed Development. The management recommendations include the aim of drain blocking to promote restoration of the hydrological conditions within the site and managing areas to favour the reintroduction of species. It is also proposed that controlled grazing will be implemented to facilitate grassland management. It has been assumed that this will continue to form part of a decommissioning and restoration plan for the Proposed Development in the future.

Methodology for Calculating Emission Factors

14.4.41 Site specific values have been used as required for a planning or S36 application.

Output

14.4.42 The output from the Carbon Calculator indicates the expected total carbon dioxide loss for the Proposed Development (from manufacture of turbines, construction, decommissioning, and carbon sink losses, also taking account of gains due to restoration of borrow bits) is 207,360 tonnes of carbon dioxide (tCO_2 eq). Input and output parameters are detailed in **Technical Appendix 14.1**.

14.4.43 Scottish Government guidance on wind farm carbon savings (Scottish Government, 2018), states: "*carbon emission savings from wind farms should be calculated using the fossil fuel sourced grid mix as the counterfactual, rather than the grid mix*." Taking account of the expected total CO2 loss from the Carbon Calculator result, the Proposed Development would be expected to result in a saving of approximately 177,787 tonnes of carbon dioxide (tCO_2) per annum, meaning a total of over 8.8 million tonnes over the 50-year operational lifetime of the Proposed Development, through displacement of carbon-emitting generation.

14.4.44 The expected carbon payback time of the Proposed Development is 1.1 years. This is the period of time for which a wind farm needs to be in operation before it has, by displacing generation from fossil-fuelled power stations, avoided as much carbon dioxide as was released in its lifecycle.

14.4.45 As recommended in current guidance estimated savings are for replacement of fossil fuel electricity generation but, while this could be the case in the short term, it is not the most probable scenario in the longer-term. The grid-mix of electricity generation represents the overall carbon emissions from the grid per unit of electricity and includes nuclear and renewables as well as fossil fuels. Based on the grid-mix results, the Proposed Development is expected to result in a saving of approximately 79,585 tCO_2 per annum with an expected carbon payback time of 2.5 years.

14.5 References

Clarke A.D (1991), A case of shadow flicker/flashing: assessment and solution, Open University, Milton Keynes

Dale, L, Millborrow, D, Slark, R and Strbac, G (2004) Total Cost Estimates for Large-Scale Wind Scenarios in UK, Energy Policy, 32, 1949-56

Meteorological Office (2023). UK Climate Averages. Available at: https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages. Accessed 01/11/23

Nayak D.R., Miller D., Nolan A., Smith P., Smith J.U. (2008). Calculating Carbon Savings from Windfarms on Scottish Peatlands - Revision of Guidelines. October 2007 to January 2008. Final Report

Parsons Brinckerhoff (2011) 'Update of UK Shadow Flicker Evidence Base', Department of Energy and Climate Change, UK Government

Rochefort, Quinty, Campeau, Johnson & Malterer (2003). North American approach to the restoration of Sphagnum dominated peatlands. Wetlands Ecology and Management 11: 3–20

Scottish Government (2016). Calculating Potential carbon losses and savings from wind farms on Scottish peatlands. Technical Note – Version 2.10.0. Available at: https://www.gov.scot/publications/carbon-calculator-for-wind-farms-on-scottish-peatlandsfactsheet/

Scottish Government Online Carbon Calculator Tool V1.7.0. Available at: https://informatics.sepa.org.uk/CarbonCalculator/

Scottish Government (2018). Carbon Calculator: Technical Guidance. Available at: https://www.gov.scot/publications/carboncalculator-technical-guidance/

SEPA. Windfarm Carbon Calculator Web Tool, User Guidance.

Scottish Renewable (2023). Statistics. Available at: https://www.scottishrenewables.com/our-industry/statistics Accessed on 30/10/2023

UKERC – United Kingdom Energy Research Council (2006). The Costs and Impacts of Intermittency: An assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network. Available at: http://www.ukerc.ac.uk/support/Intermittency