Appendix 14.1: Carbon Balance Assessment

14.1 Carbon Balance Assessment

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14 Carbon Balance Assessment

14.1 Executive Summary

14.1.1 This assessment uses the Scottish Government's Carbon Calculator for wind farms on peat to assess the benefit of displacing electricity from fossil fuels with renewable generated electricity, compared to the emissions of carbon required for the construction and operation of An Càrr Dubh Wind Farm (the Proposed Development) over its 40 year lifetime, including losses of stored carbon from disturbed peatland and forestry felling. The Carbon Calculator provides an estimate of the carbon payback time for the Proposed Development.

14.1.2 The results of the Carbon Calculator show that from the start of operation the wind turbines in the Proposed Development are estimated to produce annual carbon savings in the region of 40,000 tonnes of CO_2e per year through the displacement of grid electricity, based on the current average grid mix.

14.1.3 The assessment of the carbon losses and gains has estimated an overall loss of just over 116,000 tonnes of CO_2e; these are mainly from embodied emissions resulting from the manufacture of the turbines, and provision of backup power to the grid, which should be minimised through the provision of on-site energy storage. Ecological carbon losses account for 43 % of the total emissions resulting from the Proposed Development construction and operation; these are more than compensated for by the estimated gains of 90,000 tonnes of CO_2e from the large area of bog habitat that will be restored.

14.1.4 The estimated payback time of the Proposed Development, using the Scottish Government Carbon Calculator, is estimated at around 8 months (0.7 years), with a minimum/maximum range of -2.2 years to 6.5 years. The negative value for the minimum represents the best-case scenario that the benefit of restoring a large area of degraded bog to stop it oxidising outweighs the minimum losses produced by the construction activities, whereas the maximum value is the worst-case scenario of highest losses and no restoration gains. The carbon intensity of the electricity produced by the Proposed Development is estimated at 0.003 $kgCO_2e/kWh$. This is well below the outcome indicator for the electricity grid carbon intensity of 0.05 $kgCO_2e/kWh$ required by the Scottish Government in the Climate Change Plan update (Scottish Government, 2020) and therefore the Proposed Development is evaluated to have an overall beneficial effect on climate change mitigation.

14.2 Introduction

14.2.1 The Carbon Balance Assessment has been undertaken by Clare Wharmby on behalf of Fluid Environmental Consulting. Clare is a Full member of IEMA and a Chartered Environmentalist with over 15 years of experience undertaking carbon balance assessments for wind farms on peat across the UK.

14.2.2 Increasing atmospheric concentrations of greenhouse gases (GHGs), also called carbon emissions, are resulting in global heating which will cause catastrophic changes to our climate. A major contributor to this increase in GHG emissions is the burning of fossil fuels for primary energy or electricity generation. With concern growing over climate change, reducing its cause is of utmost 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.

14.2.3 However, no form of electricity generation is completely carbon free; for onshore wind farms, there will be emissions resulting from the manufacture of turbines, as well as emissions from both construction and decommissioning activities and transport.

14.2.4 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 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, including forestry. Conversely, restoration activities undertaken post-construction or post-decommissioning could have a beneficial effect on stored carbon 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.

14.2.5 The aim of this Appendix Report is to provide clear information about the whole life carbon balance of the Proposed Development. 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 web-based Carbon Calculator. This Report explains the policy basis for assessing carbon balance, explains the Scottish Government Carbon Calculator methodology used, details all the inputs into the model and provides an estimate of the expected net carbon savings over the lifetime of the Proposed Development, once carbon losses from materials and ecological disturbance have been taken into account, and includes a sensitivity analysis for key parameters.

14.3 Legislation, Policy and Guidelines

This assessment has been carried out in accordance with the principles contained within the following legislation and policy.

Legislation

14.3.1 One of the key drivers for the development of renewable energy is the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019, which sets a net-zero target for the Scottish emissions account by 2045 and challenging interim targets for emission reductions compared to the baseline.

Policy

14.3.2 The update to the Climate Change Plan (Scottish Government, 2020) recognises the need to continue the process of decarbonising the electricity grid and increasing generation capacity to support the delivery of electric heating and transport. However, the Climate Change Plan Update also recognises the importance of maintaining and restoring carbon storage in peat.

14.3.3 The Scottish Energy Strategy (Scottish Government, 2017) set a whole-system target to supply the equivalent of 50% by 2030 of all the energy for Scotland's heat, transport, and electricity consumption from renewable sources. The new Draft Energy Strategy and Just Transition Plan was published 10 January 2023 and is currently under consultation. The draft strategy recognises that the peatland impacts of onshore wind farms can be significant and Scotland needs to balance the benefits from onshore wind deployment and the impact on carbon rich habitats. The draft strategy commits to convening an expert group, including representatives from industry, agencies, and academia to provide advice to the Scottish Government on how guidance could be developed to support both peatland and onshore wind aims. Furthermore, the strategy states that the Scottish Government will ensure that adequate tools and guidance are available to inform the assessment of net carbon impacts of development proposals on peatlands and other carbon-rich soils.

14.3.4 National Planning Framework 4 (Scottish Government, 2023) sets the national spatial strategy for Scotland, including spatial principles, regional priorities, national developments, and national planning policy. Policy 5 states that:

c) Development proposals on peatland, carbon rich soils and priority peatland habitat will only be supported for:

ii. The generation of energy from renewable sources that optimises the contribution of the area to greenhouse gas emissions reductions targets;

d) Where development on peatland, carbon-rich soils or priority peatland habitat is proposed, a detailed site specific assessment will be required to identify:

iii. the likely net effects of the development on climate emissions and loss of carbon.

14.3.5 Onshore wind turbines: Planning Advice (Scottish Government, updated 2014) which under the heading of Securing Sufficient Information to Determine Planning Applications, for wind turbines proposed on peatland, refers to guidance on carbon calculations.

Guidance

14.3.6 The Environmental Impact Assessment Guide to Assessing Greenhouse Gas Emissions and Evaluating their Significance (IEMA, 2022) provides guidance for assessing the baseline against which the impact of a new project can be compared against, how to set an appropriate study boundary and how to communicate the impacts. This guidance has been considered in the content of this Appendix.

14.4 Consultation

14.4.1 A consultation on the scoping report was undertaken by the Scottish Ministers and this commenced on 11 May 2021. Scoping options were sought from the list of consultees and the following organisations responded in relation to the carbon balance assessment.

Table 14.1 Scoping opinions relating the carbon balance assessment

Organisation	Scoping opinion
Argyll and Bute Council	**Under Forestry** *"Any felling required will be taken into account in calculating the carbon balance of the proposed development, and consideration will be given to any required replanting under the Scottish Government's Policy on Control of Woodland Removal."* **Under Climate Change, including carbon balance** *"It is noted that climate change, including carbon balance will be dealt with in the 'Other Issues' chapter of the EIA Report. It is noted from the Scoping Report that a carbon balance assessment will be undertaken using the most up to date version of the Scottish Government Windfarm Carbon Calculator Tool."*
RSPB Scotland	**Under Habitats & habitat management/mitigation** *"Particular attention should be given to peatland, Figure 6.1 highlights that the majority of the site falls into Class 2 on NatureScot's Carbon and Peatland map, all proposed turbines would be situated on Class 2 peat. A full assessment of the carbon implications of this proposal should be undertaken by using the latest version of the Scottish Government's Carbon Calculator."*

14.4.2 These comments have been addressed within this Appendix.

14.5 Assessment Methodology

14.5.1 The assessment has used the following methodologies to estimate the overall impact of the Proposed Development on the carbon balance at the site:

- the baseline assessment of carbon stored in soils at the site has been calculated using desk and field data and standard conversion factors; and
- the carbon payback of the wind turbine component of the Proposed Development has been estimated using the Scottish Government's Carbon Calculator, (online version 1.7.0).

14.5.2 GHG emissions are measured in tonnes of carbon dioxide equivalents (tCO_2e) which is a quantity that describes, for a given mixture and amount of GHG, the amount of carbon dioxide (CO_2) that would have the same global warming potential (GWP), when measured over a 100 year timescale. These units therefore enable comparison of different GHGs emitted, or saved, at different project stages.

Baseline Assessment Methodology

14.5.3 The stored carbon within the Proposed Development red line boundary was estimated from the average depth of peat at the site (calculated from the 100m peat grid peat probes across the site to reduce the sampling bias from detailed peat probing for infrastructure) and the total red line boundary area, multiplied by the estimated percentage of carbon content and dry soil bulk density. Tonnes of carbon were converted to carbon dioxide (tCO_2) by multiplying with the factor of 3.67, which converts from the atomic weight of C to the molecular weight of CO_2. Table 14.2 shows the parameters used to estimate the baseline of stored carbon.

Table 14.2 Parameters used to estimate baseline stored carbon within red line boundary

Parameter	Expected	Minimum	Maximum
Size of site based on red line boundary (ha)	1,659	1,659	1,659
Average peat depth across site (m)	0.95	0.93	0.98
Carbon content of dry peat (% by weight)	56%	49%	62%
Dry soil bulk density (g/cm^3)	0.13	0.10	0.16

The Scottish Government's Carbon Calculator for Wind Farms on Peat Lands

14.5.4 The Scottish Government methodology, titled 'Calculating potential carbon losses and savings from wind farms on Scottish Peat lands: a new approach (Nayak, et al, 2008), was designed in response to concerns on the reliability of methods used to calculate reductions in GHG emissions arising from large scale wind farm developments on peat land. The calculator looks at the benefit of displacing conventionally generated electricity in the grid compared to the predicted direct and indirect emissions of carbon from construction, operation and decommissioning of a wind farm. It provides an estimate of the carbon payback time for the Proposed Development based on predicted emissions from construction materials and grid backup and losses and gains of stored carbon on site but does excludes minor sources such as result of traffic generated during construction or operation.

14.5.5 This method built further on the Technical Guidance note produced by Scottish Natural Heritage (SNH) in 2003 for calculating carbon 'payback' times for wind farms. However, this guidance did not take account of the wider impacts on the hydrology and stability of peat lands. The current methodology provides a straightforward way to model the impacts of installation and operation of wind farms on peat soils, considering the wider potential impacts on peat land hydrology and decomposition of organic matter.

14.5.6 The most recent version of the Carbon Calculator (v1.7.0) is a web-based application and central database, where all the data entered is stored in a structured manner. This web-based tool replaces all earlier versions of the Excel-based calculator and incorporates high-level automated checking, detailed user guidance and cells for identification of data sources and relevant data calculations. Table 13.3 at the end of this section outlines the input parameters used in the Carbon Calculator. Individual aspects of the methodology will be discussed further within this report, in the context of actual inputs and outputs of the model.

14.6 Scope of Carbon Calculator

14.6.1 Table 13.2 shows the following potential emission sources, and savings, of carbon emissions from the three key project stages that are covered by the Carbon Balance Assessment.

Table 14.3 – Carbon emissions and savings included in the assessment

Project phase	Included in assessment	Excluded from assessment
Construction	Carbon emissions resulting from the extraction, production and manufacture of turbine components and concrete required for foundations.	Carbon emissions resulting from manufacture and transport of other materials required for foundations and tracks e.g. steel, sand, rock and geotextile. These materials are not explicitly included in the Scottish Government Carbon Calculator for wind farms on peat. Carbon emissions from the production of energy storage infrastructure are not included in the Carbon Calculator.
	Carbon emissions resulting from the direct excavation of peat on-site for building tracks, hardstanding, turbine foundations and other infrastructure.	Carbon emissions resulting from the transport of labour to the construction-site. This element is not included in the Scottish Government Carbon Calculator for wind farms on peat.
		Carbon emissions resulting from the use of plant and equipment during construction, including for forestry felling. This element is only included in the Scottish Government Carbon Calculator if the detailed forestry felling calculations are used; the simple data was used for this site.
Operation	Carbon emissions from the indirect impact of drainage on peat surrounding the Proposed Development infrastructure.	Carbon emissions resulting from manufacture and transport of spare parts and materials for repair or transport of labour required throughout the lifetime of the Proposed Development. These elements are not explicitly included in the Scottish Government Carbon Calculator for wind farms on peat.
	Carbon savings resulting from the generation of electricity by wind turbines and displacement of grid electricity generated by fossil fuels.	
	Carbon emissions resulting from the provision of back up generation	
	Carbon emissions during the lifetime of the Proposed Development resulting from the loss of active carbon-absorbing habitat, including forestry.	Carbon removals resulting from the creation or restoration of active carbon-absorbing habitat, including forestry. The Scottish Government Carbon Calculator does not estimate future sequestration from restored vegetation, only the change to the existing carbon balance of soils in restored areas.
	Changes to the methane/CO_2 balance resulting from the restoration of degraded bog habitat.	
Decommissioning	-	No explicit assessment of decommissioning emissions has been carried out as these are not included within the Carbon Calculator.

Temporal Scope

.1.1 The temporal scope for savings is set as the same period as the lifespan of the consent for the operation of the Proposed Development, i.e., 40 years but, unless it is specified that the Proposed Development site will be restored with respect to hydrology and habitat upon decommissioning, the losses through the indirect effects on peat will continue until the Carbon Calculator estimates that there is no more oxidisable peat within the vicinity of the infrastructure.

Study Area

14.6.2 The baseline assessment looks at the estimated stored soil carbon within the site boundary under existing conditions, as this will enable the percentage loss of this carbon through the project development to be estimated.

14.6.3 For the carbon payback assessment, since GHG emissions and savings are both ultimately a global ‘pool’, this assessment is not restricted solely to those emissions or savings that occur within the site boundary. Land-based emissions from peat and habitat losses are based on the site footprint, but other activities, for example, emissions resulting from the extraction and production of steel for turbines, are still attributable to the Proposed Development even though they are likely to occur in other parts of the world.

14.7 Significance Criteria

14.7.1 In determining whether an application to build and operate a wind farm should be consented, the assessment of potential carbon losses and savings is a material consideration for Scottish Ministers. It is one important consideration among many, and currently there are no official guidelines about what constitutes an acceptable or unacceptable payback time, therefore this assessment looks at a range of metrics, including the payback, the carbon intensity of electricity produced and the ratio of soil carbon losses to gain, to evaluate the impact of the Proposed Development on carbon emissions. This information has informed a high-level assessment of climate change mitigation effects in Chapter 14: Other Issues of the EIA Report.

Table 14.4 Input parameters used in the Carbon Calculator

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Wind Farm Characteristics					
Dimensions					
No. of turbines	13	13	13	Chapter 4: Project Description states that the Proposed Development comprises of up to 13 wind turbines (including internal transformers), each with a maximum tip height of up to 180m.	None
Life time of wind farm (years)	40	40	40	Chapter 4 states that the Proposed Development has been designed to have an operational lifespan of up to 40 years.	None
Performance					
Turbine capacity (MW)	6.6	6.6	6.6	Chapter 4 states that the currently considered candidate turbine has a rated capacity of 6.6MW	None
Capacity factor – using direct input of capacity factor (percentage efficiency)	27.2	25.6	28.9	There is no direct mast data for the site of the Proposed Development so the capacity factor has been estimated from the five-year average wind load factor for Scotland (2017 to 2021) (BEIS, December 2022, Table 6.1 Renewable electricity capacity and generation). The initial modelling for the site indicates that it will have a higher capacity factor than the Scottish average due to good wind resources but in the absence of data, the more conservative Scottish average has been used in the model.	A 95% confidence level has been calculated as the mean +/- 2 SE to estimate the likely minimum and maximum values of the range.

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				Mean: 27.2 Count: 5 Standard error: 0.8	
Backup					
Extra capacity required for backup (%)	2.5	2.5	2.5	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. SEPA has indicated that, for this parameter, the electricity generation capacity of Scotland, rather than the UK, should be considered. In 2020, Scotland generated about 60% of gross electricity consumption via onshore wind (Scottish Renewables Statistics, 2021). However, Chapter 4 states that there is a national requirement to balance the peaks and troughs associated with electricity supply and demand to avoid strains on transmission and distribution networks, and to keep the electricity system stable. Therefore, there will be an energy storage facility with a capacity of up to 20MW in total as part of the Proposed Development to support the flexible operation and further decarbonisation of the electricity supply. Therefore, this parameter has been reduced by 50% from 5% to 2.5% to represent this onsite balancing.	This input parameter assumes no improvement in external grid management techniques, including demand side management or smart metering over the lifetime of the wind farm.
Additional emissions due to reduced thermal	10	10	10	Fixed value within the Carbon Calculator for scenario where extra capacity for backup is required.	Extra emissions due to reduced thermal efficiency of the reserve

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
efficiency of the reserve generation (%)					power generation ≈ 10% (Dale et al 2004 referenced by the Carbon Calculator).
Carbon dioxide emissions from turbine life - (e.g. manufacture, construction, decommissioning)	Direct input of total emissions			Chapter 4 states that the candidate turbine is the Siemens Gamesa 6.6-155. There is an Environmental Product Declaration (EPD) available for similar turbine model (SG 6.6-170) (Siemens Gamesa, 2022) and this has been used to estimate the turbine lifecycle emissions.	
Total CO2 emission from turbine life (tCO_2 MW-1	1,432	1,288	1,575	Units of gCO_2e/kWh of electricity over lifespan have been converted to tCO_2e per MW. The EPD is based on a 25 year life span so the total emissions per installed MW have been scaled to a 40 year lifespan. A correction factor has been used to negate the impact of a known error in the carbon calculator (correspondence with SG, January 2023). To correct the error that the estimated tCO_2/MW is incorrectly multiplied by the site capacity factor, the input parameter has been divided by this factor.	A range of +/- 10% has been used to calculate the likely minimum and maximum.
Characteristics of peat land before wind farm development					
Type of peat land	Acid Bog	Acid Bog	Acid Bog	There are only two options, of which one has to be selected within the Carbon Calculator; acid bog and fen. Based on Chapter 8 Ecology, blanket bog and wet modified bogs are extensive within the site, whereas fen is a less prevalent.	None

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average air temperature at site (°C)	7.5	7.3	7.7	Based on average annual temperature data for North Scotland for the time period 2002 – 2021. The data is sourced from the Meteorological Office (2022). Mean: 7.5 Count: 20 Standard Error: 0.09	A 95% confidence level has been calculated as the mean +/- 2 SE to estimate the likely minimum and maximum values of the range. Although, it is probable that average site temperatures are rising due to impacts of global climate change, the overall payback is not sensitive to temperature and therefore this parameter is not included in the sensitivity analysis.
Average depth of peat at the site (m)	0.95	0.93	0.98	Red Line Application area - using only 100 m grid peat depths to avoid sampling bias of specific locational peat probing. Mean: 0.95 Count: 5,231 Standard Error: 1.33	A 95% confidence level has been calculated as the mean +/- 2 SE to estimate the likely minimum and maximum values of the average.
Carbon (C) Content of dry peat (% by weight)	56	49	62	The default values for carbon content of peat 49% and 62% is provided in the Carbon Calculator.	Upper and lower range provided as default. Midpoint used as expected value.
Average extent of drainage around	23	13	36	The average extent of drainage has been estimated using Von Post data from 18 cores on-site. Von Post scores were as a range for each peat core – it has assumed that the low	The minimum and maximum values are based on an estimated input range of +/-25% for the bulk density.

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
drainage features at site (m)				scores are representative of the acrotelm and the high scores, of the catotelm. The average score for acrotelm and catotelm was calculated and used to estimate the bulk density of the peat on the site, which was then used to estimate hydraulic conductivity and consequently estimated drainage distance using equations from Nayak et al (2008). More detail is provided in Section 17.5	The wide range of values reflects the difficulty in measuring this parameter with accuracy.
Average water table depth at site (m)	0.29	0.20	0.39	The expected and minimum annual water table depth is estimated at the mid-depth of the acrotelm/catotelm boundary as measured by the peat cores taken across the site, assuming that this boundary represents the maximum, although this varied significantly across the site.	A range of between the surface and the acrotelm/catotelm boundary has been used, with the minimum being mid-depth and the maximum being the boundary. The expected depth is the average of these two values.
Dry soil bulk density (g/cm^3)	0.13	0.10	0.16	The bulk density for the site has been estimated from the Von Post scores of peat cores on-site using the equation described by Päiväinen (1969). The estimated bulk density of 0.13 g/cm^3 sits within the estimated range provided by SEPA for blanket peat.	A range of +/- 25% has been used to calculate the likely minimum and maximum.
Characteristics of bog plants					
Time required for regeneration of bog plants after restoration (years)	22.5	15	30	This parameter needs to be estimated and there are relatively few studies available on the average time taken for bog plant communities to regeneration following restoration. Rochefort *et al* (2003) estimate that a significant number of characteristic bog species can be	The overall Proposed Development site payback is not particularly sensitive to this parameter due to the slow rate of carbon fixation by bogs.

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				established in 3–5 years, a stable high water-table in about a decade, and a functional ecosystem that accumulates peat in perhaps 30 years.	The maximum value has been set at the limit of 30 years. The estimated value has been estimated at -25% of the maximum and the minimum at -50%.
Carbon accumulation due to C fixation by bog plants in un-drained peats ($t\ C\ ha^{-1}\ yr^{-1}$)	0.215	0.12	0.31	Suggested acceptable literature values from Carbon Calculator. The overall result is not very sensitive to this input, so the default value can be used if measurements are not available.	The range suggested in the methodology from the literature for apparent C accumulation rate in peatland is 0.12 to 0.31 $t\ C\ ha^{-1}\ yr^{-1}$ (Turunen et al., 2001, Global Biogeochemical Cycles, 15, 285-296; Botch et al., 1995, Global Biogeochemical Cycles, 9, 37-46, referenced by the Carbon Calculator). The SNH guidance uses a value of 0.25 $t\ C\ ha^{-1}\ yr^{-1}$. Range of 0.12 to 0.31 $t\ C\ ha^{-1}\ yr^{-1}$.
Forestry Plantation Characteristics					
Area of forestry plantation to be felled (ha)	3.77	3.39	4.15	Chapter 4 states that the felling of approximately 3.77 hectares (ha) of forestry to facilitate access will be required during construction.	A range of +/- 10 % has been used to calculate the likely minimum and maximum.
Average rate of carbon sequestration in timber ($tC\ ha^{-1}\ yr^{-1}$)	3.0	2.25	3.75	Chapter 4 states that the age and species of the tree crops to be felled is variable, the estimated area of felling	A range of +/- 25 % has been used to calculate the likely minimum and maximum.

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				required is 0.96 ha of broadleaved trees and 2.81 ha of coniferous plantation. The Woodland Carbon Calculation Spreadsheet (UK Woodland Carbon Code, 2021) provides an estimate of total carbon sequestered (in tCO_2e/ha/year) for each 5 year age period. The average rate of sequestration has been calculated for mixed conifer and mixed broadleaf based on an estimated mix of age classes for the 40 year life span of the Proposed Development. The average annual sequestration rate for each species group/age class has been multiplied by the area to be felled and then the total calculated annual sequestration has been divided by the total felled area to get an estimated average sequestration rate. The CO_2e is converted to C by dividing by 3.67.	
Counterfactual emission factors					
Coal-fired plant emission factor (tCO_2 MWh^{-1})	1.002	1.002	1.002	Fixed counterfactual emission factors are provided 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 GHG emissions by UK organisations published by BEIS.	
Grid-mix emission factor (tCO_2 MWh^{-1})	0.19338	0.19338	0.19338		
Fossil fuel- mix emission factor	0.432	0.432	0.432		

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
(tCO_2 MWh^{-1})					
Borrow Pits					
Number of borrow pits	1	1	1	While there are three proposed borrow pit search areas, the two which are located at roadsides within the commercial forestry to the southeast of the Proposed Development are existing and do not contain peat. The PMP states that the third is located adjacent to proposed Turbine 11 with an average soil depth of c. 0.48 m and although this corresponds to organic soil, the excavation volume is treated as peat for the purposes of impact assessment. Therefore, for the purposes of this assessment only the third borrow pit is included.	None
Average length of pits (m)	100	95	105	Chapter 4 provides the expected dimensions of borrow pit 3 as 100 x 70m	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Average width of pits (m)	70	67	74		
Average depth of peat removed from pit (m)	1.00	0.75	1.24	Calculated from peat probe depths from the borrow pit area and a buffer of 50m in order to capture sufficient sample points. Mean: 1.00 Count: 74 Standard Error: 0.123	A 95% confidence level has been calculated as the mean +/- 2 SE to estimate the likely minimum and maximum values of the average.

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Foundations and hard-standing area associated with each turbine					
Method used to calculate CO_2 loss from foundations and hard-standing	Rectangular, with vertical sides			The simple method of calculation for turbine foundations was used for this application because this is no clear groups of turbines in terms of different peat depths, structures or use of piling.	None
Average length of turbine foundations (m)	20.2	19.2	21.2	Chapter 4 states that these typically measure approximately 22.8m diameter. Although the 13 turbine foundations are circular in shape, in order to be able to enter an average value for length and width, the square root of the area of the foundations was calculated to get an average length and width.	A range of + 5% has been used to calculate the likely expected and maximum values of both length and width.
Average width of turbine foundations (m)	20.2	19.2	21.2		
Average depth of peat removed from turbine foundations (m)	1.06	0.66	1.45	The volume of peat at each turbine/hardstanding location was calculated from the turbine area multiplied by the average peat depth for each location (averaged from all the peat probes within a 50 m buffer of each turbine/hardstanding location). The total volume of peat was divided by the total area to provide an average peat depth across all 13 turbine locations. Mean: 1.06 Count: 13 Standard Error: 0.20	A 95 % CI has been calculated as mean +/- 2 SE based on a sample of 13 turbine locations.

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average length of hard-standing (m)	75	71	79	The hardstanding area is made up of both permanent and temporary excavated areas. All of these areas were included to estimate the worst case scenario. The total area of a typical hardstanding was measured in GIS and the square root used to estimate length and width (although the actual shapes are irregular).	A range of +5 % has been used to calculate the likely expected and maximum values of both length and width.
Average width of hard-standing (m)	75	71	79		
Average depth of peat removed from hard-standing (m)	1.06	0.66	1.45	The volume of peat at each turbine/hardstanding location was calculated from the turbine area multiplied by the average peat depth for each location (averaged from all the peat probes within a 50 m buffer of each turbine/hardstanding location). The total volume of peat was divided by the total area to provide an average peat depth across all 13 turbine locations. Mean: 1.06 Count: 13 Standard Error: 0.20	A 95 % CI has been calculated as mean +/- 2 SE based on a sample of 13 turbine locations.
Volume of concrete used in entire area	21,216	20,155	22,277	Chapter 4 states that each turbine foundation will require approximately 1,632 cubic metres (m^3) of concrete and 200 tonnes of reinforcement	A range of +/- 10% has been used to calculate the minimum and maximum.
Access tracks					

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Total length of access track (m)	23,100	20,790	25,410	Chapter 4 states that a network of onsite access tracks of approximately 23.1km (of which 6.6km will be upgraded existing track and 16.5km will be new track).	A range of +/- 10% has been used to calculate the minimum and maximum.
Existing track length (m)	6,600	5,400	7,260	Chapter 4 states that nominal track running width will be approximately 6m and existing tracks will be upgraded to this width. Using the shapefile of the infrastructure of the peat depths shows that there is little to no peat around the upgraded track areas and therefore, only the new track has been assessed below.	A range of +/- 10% has been used to calculate the likely minimum and maximum
Length of access track that is floating road (m)	5,640	5,076	6,204	Floating track is estimated to be used on 5.46km of the new track length.	
Floating road width (m)	8.0	8.0	8.8	Chapter 4 states that nominal track running width will be approximately 6m and adjacent to this track will be an assumed 1m wide verge at either side (8m track width in total) for cabling and appropriate drainage. The total width of track and verge has been included in the carbon calculator.	A range of + 10% has been used to calculate the likely maximum.
Floating road depth (m)	0.0	0.0	0.63	This parameter accounts for sinking of floating road. The Carbon Calculator states that it should be entered as the average depth of the road expected over the lifetime of the Proposed Development. If no sinking is expected, enter as zero. It is anticipated that sinking of the floating track would be minimal and therefore this parameter has been	Zero value for expected and minimum values. The maximum is estimated at 50% of the average peat depth for all the floating track locations on-site.

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				set as zero for the expected and minimum values. The average peat depth for the floating sections has been estimated from GIS. Mean: 1.26 Count: 440	
Length of floating road that is drained (m)	5,640	5,076	6,204	Chapter 4 states access tracks have been designed to have a camber of 2.5% to ensure they are free draining Adjacent to this track will be a 0.5m wide verge at either site (8m (max width in total) for cabling and drainage, subject to local ground conditions. Therefore, it has been assumed that all the floating track will be drained.	A range of +/- 10% has been used to calculate the likely minimum and maximum.
Average depth of drains associated with floating roads (m)	0.43	0.39	0.47	It is assumed that the drainage would be a V shape of around 0.5m which equates to a depth of around 0.43m.	A range of +/- 10% has been used to calculate the likely minimum and maximum.
Length of access track that is excavated road (m)	10,860	9,774	11,946	Chapter 4 states that the length of new access track is 16.5km, of which 5.64km is floating and the remainder is excavated.	A range of +/- 10% has been used to calculate the likely minimum and maximum
Excavated road width (m)	8.0	8.0	8.8	Chapter 4 states that nominal track running width will be approximately 6m and adjacent to this track will be an assumed 1m wide verge at either side (8m track width in total) for cabling and appropriate drainage. The total width of track and verge has been included in the carbon calculator.	A range of + 10% has been used to calculate the likely maximum.

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average depth of peat excavated for road (m)	0.88	0.79	0.93	The average peat depth across the excavated track was calculated as the average of all the peat probes within the track shape, including a buffer of 25m either side. Mean: 0.88 Count: 1,003 Standard Error: 0.03	A 95 % CI has been calculated as mean +/- 2 SE of the peat probes within the calculated boundary of the track.
Cable Trenches					
Length of any cable trench on peat that does not follow access tracks and is lined with a permeable membrane (e.g. sand) (m)	0	0	0	Chapter 4 states that to minimise ground disturbance, cables will be routed along the side of the access tracks where practicable.	Assume all cable trenches follow access track routes.
Additional peat excavated (not accounted for above)					
Volume of additional peat excavated (m^3)	16,219	14,597	17,841	The volume of additional excavated peat has been calculated using the area of the three additional infrastructure components listed below, multiplied by the average peat depth at each component (calculated from the GIS shape file with a 50m buffer around each shape). • Temporary construction compound • Met mast • Permanent construction compound & substation	A range of +/- 10% has been used to calculate the likely minimum and maximum

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Area of additional peat covered by infrastructure (m^2)	22,035	19,832	24,239	Chapter 4 states the area of the additional infrastructure components.	A range of +/- 10% has been used to calculate the likely minimum and maximum
Improvement of C sequestration at site by blocking drains, restoration of habitat etc.					
<u>Improvement of degraded bog</u>					
Area of degraded bog to be improved (ha)	443	421	465	The PMP details the area of restoration (using the area when the overlap between activities is removed). This includes direct areas where hagged peat is restored with emplaced peat or by reprofiling, and areas within 30m of hagged or drained peat where restoration is planned.	A range of +/- 5% has been used to calculate the likely minimum and maximum
Water table depth in degraded bog before improvement (m)	0.29	0.20	0.39	The same method for estimating the water table depth for the whole site has been used to estimate the current depth in the areas to be restored. Although it could be expected that the water table would be lower in the degraded areas, in order to not overestimate the gains from restoration, the site average has been used here.	A range of between the surface and the acrotelm/catotelm boundary has been used, with the minimum being mid-depth and the maximum being the boundary. The expected depth is the average of these two values.
Water table depth in degraded bog after improvement (m)	0.15	0.10	0.30	Target optimum water table depth for restoring peat is around 0.1m but discussions with the hydrology team have led to using more conservative values in order to not overestimate the gains from restoration.	The maximum has been set at 0.3m, with a minimum of 0.1m to reflect the uncertainty in this parameter.
Time required for hydrology and habitat of	12.5	10	15	The restoration is coming from a combination of hag emplacement and re-profiling and ditch blocking; estimated	The minimum has been set at 10 years and a range of + 25% & +50%

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
bog to return to its previous state on improvement (years)				time for restoration of hydrology and habitat would be a minimum of 10 years.	has been used to calculate the likely expected and maximum.
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	40	40	40	The Carbon Calculator states that if the time required for hydrology and habitat to return to its previous state is 10 years and the restoration can be guaranteed over the lifetime of the Proposed Development (40 years), the period of time when the improvement can be guaranteed should be entered as 40 years.	None
<u>Improvement of felled plantation land</u>					
Area of felled plantation to be improved (ha)	0	0	0	Chapter 4 states that permanent felling is restricted to an area of 3.77 ha which would not be replanted because the infrastructure footprint associated with the swept path design for the access to the construction and operation of the Proposed Development. This area will not be improved or restored as peat bog after construction as track and swept path would be maintained for future access for abnormal loads should it necessary.	A range of +/- 10% has been used to calculate the likely minimum and maximum
<u>Restoration of peat removed from borrow pits</u>					
Area of borrow pits to be restored (ha)	0.70	0.63	0.77	The PMP states that the borrow pit in the main infrastructure area will be reinstated using acrotelmic and catotelmic peat excavated from the pit and stored locally.	A range of +/- 5% has been used to calculate the likely minimum and maximum

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	0.50	0.38	0.62	This is a difficult parameter to estimate; however, it is assumed that the water table would be significantly lowered by drainage prior to restoration. It is estimated that the water table would be around halfway up the depth of peat to be restored, which should be the same as the amount removed.	Same methodology as initial peat depth in borrow pit 3.
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.15	0.10	0.30	Target optimum water table depth for restoring peat is around 0.1m but discussions with the hydrology team have led to using more conservative values in order to not overestimate the gains from restoration.	The maximum has been set at 0.3m, with a minimum of 0.1m to reflect the uncertainty in this parameter.
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	10	7.5	12.5	It is estimated that due to the relatively small restoration areas and use of acrotelm layers with intact vegetation to restore these areas, the process should be relatively quick to restore hydrology and plant communities.	A range of +/- 25% has been used to calculate the likely minimum and maximum.
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	40	40	40	The Carbon Calculator states that if the time required for hydrology and habitat to return to its previous state is 10 years and the restoration can be guaranteed over the lifetime of the Proposed Development (40 years), the period of time when the improvement can be guaranteed should be entered as 40 years.	None

Online calculator reference: **9778-ZJBG-J4D5**					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Removal of drainage from foundations and hardstanding				Chapter 4 states the during operation, the hardstanding provides safe access for maintenance and repairs which may also require the use of a crane. The crane hardstanding will therefore be permanent infrastructure. It is therefore assumed that drainage around foundations and hardstandings will be maintained. It should be noted that there is no significant improvement to the payback by completing this section.	
Restoration of Application Site after decommissioning					
Will hydrology of the Proposed Development site be restored on decommissioning?	No	No	No	Chapter 4 states that the proposals for refurbishment / decommissioning are not known at this stage, therefore the response to this question has been marked as 'no' as a worst-case scenario. However, it should be noted, this response has no impact on the overall carbon payback at this site.	
Will habitat of the Proposed Development site be restored on decommissioning?	No	No	No	See above.	
Choice of methodology for calculating emission factors	Site specific			As required for planning applications.	

14.8 Detailed Methodology Statements

14.8.1 Table 14.2 details the site-based parameters and conversion factors used for the baseline assessment and Table 14.4 details all the input parameters and assumptions used within the carbon calculator. Two of the parameters have been estimated using data collected from peat cores and published equations in the literature. Detailed methodology describing the data and equations are provided below.

Methodology for Estimating Dry Soil Bulk Density

14.8.2 Within Lindsay's Peatbogs and Carbon; A critical synthesis (2010), several studies document the relationship between bulk density and Von Post scale of humification. Work by Päiväinen in 1969 documented linear relationships for different types of peat. The relationship for Sphagnum-based peat is described as Y = 0.045 + 0.011 x, where x is the Von Post score for humification.

14.8.3 Cores were taken at 18 locations and the range of Von Post scores for both humification (H score) was recorded for the peat column. It was assumed that the low range represented the acrotelm and the high range, the catotelm. The coverage of Von Post data across the Proposed Development site meant that it was possible to use this equation to estimate the overall bulk density at the site. The methodology used was:

Calculate the average Von Post scores for acrotelm layer (mean = 3.6, count 18);

Calculate the average Von Post scores for catotelm layer (mean = 8.7, count 18);

Calculate an average weighted Von Post score, using the average depth of acrotelm and catotelm to weight the score (weighted average score = 7.5)

Use this weighted average score to estimate bulk density using Päiväinen's equation, calculating a minimum and maximum range as +/-25%

Estimating Average Drainage Distance from Drainage Features

14.8.4 The calculated estimate of dry soil bulk density has been used to estimate the hydraulic conductivity of the peat, according to the relationship curve described within Peatbogs and Carbon (Lindsey, 2010). Hydraulic conductivity describes the ease with which a fluid can move through pore spaces and fractures in soils. There are two equations for hydraulic conductivity, where y is hydraulic conductivity in m/day and x is bulk density:

If the bulk density if less than 0.13 g/cm^3, the equation is y = 7683.3*(exp(-74.981*x))

If the bulk density is greater than 0.13 g/cm^3, the equation is y = 10^-8*(x^-8.643)

14.8.5 The value of hydraulic conductivity given by this equation is then used to estimate the average drainage distance, using the equation given in Nayak et al (2008). This equation is given as y=11.958x – 9.361, where x is the log value of hydraulic conductivity measured in millimetres per day (mm/day).

14.8.6 It should be noted that the minimum value for bulk density produces the highest estimate for hydraulic conductivity (the less densely packed material allows freer movement of water) and therefore drainage distance. Therefore, the Carbon Calculator is modelling a worst case scenario, as it is highly unlikely that the maximum bulk density of peat (with the greatest amount of stored carbon) would also have the maximum average drainage distance.

14.9 Results of Carbon Balance Assessment

Baseline Conditions

14.9.1 It is not easy to set a simple baseline for climate change impacts because the impact is due to a global atmospheric pool of GHG emissions – each individual project has a very small overall impact

on this pool, but there are many small projects and therefore effective climate change mitigation relies on reducing the impacts of all of these.

14.9.2 However, the key carbon balance impact of constructing a wind farm on peat land is the potential release of stored carbon and therefore the baseline looks at the estimated stored soil carbon on-site under existing conditions, as this will enable the percentage loss of this carbon through the Proposed Development to be estimated.

14.9.3 Table 14.5 shows the estimate of stored carbon in peat within the red line boundary. Estimated volume and emissions have been rounded up to the nearest thousand cubic metres/tonnes.

Table 14.5 – Estimated Stored Carbon in Peat at the Proposed Development Site (Based on Red Line Boundary)

Parameter	Expected	Minimum	Maximum
Estimated volume of peat (m^3)	15,797,000	15,356,000	16,237,000
Estimated amount of carbon in soils (tC)	1,140,000	752,000	1,611,000
Estimated equivalent emissions of CO_2 (tCO_2)	4,183,000	2,761,000	5,911,000

14.9.4 Table 14.5 shows that there are approximately 1.14 million tonnes of stored carbon on-site and if this was fully oxidised, this would equate to approximately 4.2 million tonnes of CO_2 emissions. It is hard to assess the future of this stored carbon on-site in the absence of the Proposed Development but it is probable that future climate change impacts would affect this store – there is already some evidence of peat hagging and erosion so it is likely that without restoration, this carbon store will naturally reduce and this loss could be accelerated by climate change.

Carbon Balance Assessment - Emissions

14.9.5 The results from the Carbon Balance Assessment have been divided into losses from activities resulting in the emission of carbon, savings from the avoidance of carbon emissions by displacing grid electricity from other fuel sources and gains from site restoration activities that should result in uptake of atmospheric carbon.

14.9.6 This section looks at the two key project stages of construction and operation (specific decommissioning activities are not included in the Carbon Calculator) and allocates emissions to those two stages. However, it should be noted that for some of the key sources of emissions such as oxidation of soil carbon or losses from future forestry sequestration, it is hard to be precise about when they will occur in the Proposed Development life cycle.

Table 144.6 – Estimated Carbon Emissions during the Construction Phase

Emission source	Estimated emissions (tCO_2e)			% of overall emissions (expected scenario)
	Expected	Minimum	Maximum	
Losses due to turbine life + construction materials	33,419	28,291	39,054	28.8%
CO_2 loss from excavated peat	29,659	5,959	80,463	25.5%

Emission source	Estimated emissions (tCO_2e)			% of overall emissions (expected scenario)
	Expected	Minimum	Maximum	
Subtotal of emissions during construction	**63,078**	**34,250**	**119,517**	**54.3%**

14.9.7 Table 14.6 shows that 54 % of the total losses occur during the Proposed Development construction phase. These are split between the manufacture of the turbines, with a small proportion due to other materials used in construction (for example concrete for foundations) and the potential oxidation of peat excavated for infrastructure construction.

Table 144.7 – Estimated Carbon Emissions during the Operational Phase

Emission source	Estimated emissions (tCO_2e)			% of overall emissions (expected scenario)
	Expected	Minimum	Maximum	
Losses due to backup	32,469	32,469	32,469	28.0%
Losses due to reduced carbon fixing potential	5,955	1,753	15,405	5.1%
Losses due to Dissolved Organic Carbon (DOC) & Particulate Organic Carbon (POC) leaching	380	-	1,275	0.3%
Losses due to felling forestry	1,659	1,122	2,255	1.4%
CO_2 loss from drained peat	12,602	-	71,072	10.9%
Subtotal of emissions during operation	**53,065**	**35,344**	**122,476**	**45.7%**

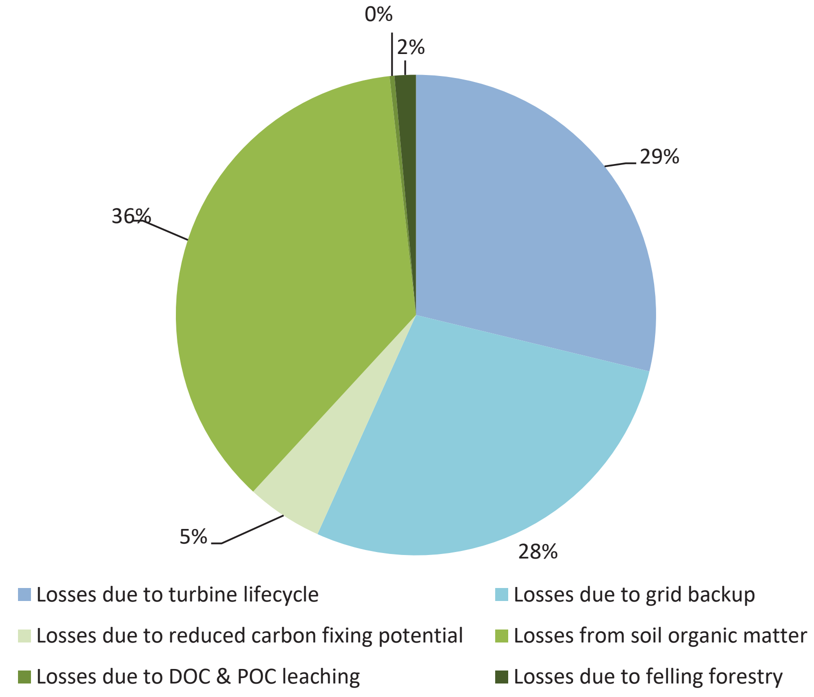
14.9.8 Table 14.7 shows that a further 46% of the emissions occur during the operational phase of the Proposed Development. The most significant of these is the requirement for back-up power in the grid, which is assumed to come from a fossil fuel source. Losses from drained peat account for around 11% and reduced carbon sequestering potential over the project lifetime from felling of forestry and loss of carbon fixing vegetation account for a further 6.5%.

14.9.9 Emissions produced during the decommissioning phase are not included separately in the Carbon Calculator assessment, although some estimate of these are included within the lifecycle assessment of the turbines. Calculating emissions from this phase is difficult because the exact activities are not known but they are unlikely to be significant compared to the emission sources during construction and operation.

14.9.10 Graph 14.1 shows how the emissions are split between sources; the majority of emissions result from activities largely outside of the control of the Applicant (shown in blue); lifecycle emissions from the turbines can be potentially reduced through consideration at the procurement phase but availability and delivery timescales of appropriate turbines are usually more important factors in selection. The second largest emission source is from back-up power and this depends on both the grid mix and future grid management policies and is not under the control of the Applicant.

14.9.11 Emissions under the control of the Applicant are shown in green. These include the losses of carbon due to the forestry felling, loss of carbon fixing potential in bog plants and extraction and drainage of peat for infrastructure. Therefore, mitigation measures for climate change include micrositing infrastructure further away from peat areas during construction where possible.

Graph 144.1 – Breakdown of Emission Sources for the Proposed Development



Carbon Balance Assessment – Gains

14.9.12 Table 14.8 shows the estimated carbon gains over the lifetime of the Proposed Development from improvements through restoration of degraded bog, restoring felled forestry to bog and restoring peat in borrow pits. The gains are negative because they are atmospheric removals or avoided emissions. It should be noted that the Carbon Calculator is conservative about estimating the gains from restoration, only accounting for changes in the balance of methane to carbon dioxide emissions from the restoration of degraded bogs and the borrow pit and not accounting for any additional carbon sequestration that might occur from restored areas, such as compensatory tree planting as is proposed in Chapter 4. The gains from restoration are not apportioned between construction and operational phases of the development because of the uncertainty about when they will occur.

Table 14.8 – Estimated Carbon Gains

Source of gains	Estimated gains (tCO_2e)			% of overall gains (expected scenario)
	Expected	Minimum	Maximum	
Change in emissions due to improvement of degraded bogs	-89,314	-	-159,507	99.7%

Source of gains	Estimated gains (tCO_2e)			% of overall gains (expected scenario)
	Expected	Minimum	Maximum	
Change in emissions due to restoration of peat from borrow pits	-312	-149	-432	0.3%
Total estimated gains	**-89,626**	**-149**	**-159,939**	**100%**

Comparison with the Baseline

14.9.13 The soil carbon losses from the Proposed Development are estimated at around 49,000 tonnes of CO_2e. This represents 1.2 % of the estimated total stored carbon on-site (as set out in Table 13.4) and includes anticipated losses from excavated and drained peat, losses due to leaching and losses from reduced carbon fixing potential. In reality, this percentage is likely to be lower because the method used by the Carbon Calculator tool assumes that all excavated peat will be oxidised, whereas good management and re-use at site is likely to prevent at least a proportion of this oxidation.

Comparison of Soil Carbon Losses with Carbon Gains from Restoration

14.9.14 Table 14.9 shows a comparison of soil carbon losses with the estimated carbon gains from restoration. The estimated carbon is shown for the expected value within the carbon calculator.

Table 14.9 – Comparison of soil carbon losses with restoration gains

Soil carbon loss category	Expected tCO_2e	Restoration gain category	Expected tCO_2e
CO_2 loss from removed peat	29,659	Change in emissions due to improvement of degraded bogs	-89,314
CO_2 loss from drained peat	12,602	Change in emissions due to restoration of peat from borrow pits	-312
Losses due to reduced carbon fixing potential	5,955	-	
Losses due to Dissolved Organic Carbon (DOC) & Particulate Organic Carbon (POC) leaching	380	-	
Total soil carbon losses	**48,596**	**Total restoration gains**	**-89,626**

14.9.15 Table 14.9 shows that the ratio between soil carbon loss and restoration gains is 0.48; there are nearly two times more gains than losses. The calculation of the estimated losses assumes a worst-case scenario that all excavated peat is oxidised and conversely the restoration gains do not include future carbon sequestration from restoring carbon fixing vegetation in the degraded bog. The calculation of restoration gains is dependent on two very uncertain parameters (average water table

before and after restoration). Since the restoration gains over a large area have a significant impact on the payback, the impact of these parameters is explored in the sensitivity analysis.

Carbon Balance Assessment – Savings

14.9.16 Table 14.10 shows the estimated annual and lifetime CO_2 savings, based on the three different counterfactual emission factors. The highest estimated savings are for replacement of coal-fired electricity generation but there is minimal coal-fired generation remaining in the UK to be displaced. The average 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. This average grid mix is likely to over-estimate lifetime savings due to decarbonisation of the electricity grid and Section 14.10 looks at the impact of grid decarbonisation on the payback period of the Proposed Development.

Table 144.10 – Estimated Annual and Lifetime Carbon Savings from the Operation of the Proposed Development from the Displacement of Grid Electricity

Counterfactual emission factor – annual savings	Estimated savings (tCO_2e per year)		
	Expected	Minimum	Maximum
Coal-fired electricity generation	204,846	192,796	217,649
Grid-mix of electricity generation	39,534	37,209	42,005
Fossil fuel - mix of electricity generation	88,317	83,122	93,837
Counterfactual emission factor – lifetime savings	**Estimated savings (tCO_2e over lifetime)**		
Coal-fired electricity generation	8,193,840	7,711,840	8,705,960
Grid-mix of electricity generation	1,581,360	1,488,360	1,680,200
Fossil fuel - mix of electricity generation	3,532,680	3,324,880	3,753,480

Payback Time and Carbon Intensity

14.9.17 There are two useful metrics for comparing different projects and different technologies. The Carbon Calculator tool calculates an estimated payback time, which is the net emissions of carbon (total of carbon losses and gains) divided by the annual estimated carbon savings. However, an alternative metric is the carbon intensity of the units of electricity that will be produced. This calculation divides the net emissions by the total units of electricity expected to be produced over the lifetime of the Proposed Development. This calculation is useful as it is independent of the grid emission factor of displaced electricity.

14.9.18 Table 14.11 shows the estimated payback time, if the electricity generated by the Proposed Development is assumed to displace electricity generated by the grid for a range of different displaced fuels, and also the carbon intensity of the units produced.

Table 14.11 – Estimated Payback Time in Years and Carbon Intensity of the Units of Electricity Produced

Counterfactual emission factor	Estimated time to payback (years)		
	Expected	Minimum	Maximum
Coal-fired electricity generation	0.1	-0.4	1.3
Grid-mix of electricity generation	0.7	-2.2	6.5
Fossil fuel - mix of electricity generation	0.3	-1.0	2.9
Carbon intensity (kgCO_2e/kWh)	0.003	-0.010	0.031

14.9.19 Table 14.11 shows that the Proposed Development is estimated to have a payback of 0.7 years based on the current grid mix and the carbon intensity of units produced would be significantly lower than the current grid mix (the value of 0.19338 kgCO_2e/kWh is currently used in the Carbon Calculator). It should also be noted that the assessment boundary of the carbon intensity of electricity generated by the Proposed Development is far wider than the direct operational emissions included in the measurement of carbon intensity of the grid mix; if these were included, the impact of the Proposed Development would be shown to be even more beneficial.

14.9.20 The negative value for the minimum represents the best-case scenario that the benefit of restoring a large area of degraded bog to stop it oxidising outweighs the lowest estimate of losses produced by the construction activities, whereas the maximum value is the worst case where no restoration gains are produced and the losses from construction are at the upper end.

Limitations to Assessment

14.9.21 The assessment of the payback of the Proposed Development is limited by both the Carbon Calculator and the parameters used to estimate the site characteristics. Within the Carbon Calculator there are several parameters known to have a potentially large impact on overall estimated payback time; for some of these parameters there is also a degree of uncertainty over the inputs due to data collection restraints. To demonstrate the robustness of the estimated payback, the sensitivity analysis below shows the impact of varying four of the key parameters on the payback time under a grid mix counterfactual emission factor, whilst holding all other parameters constant, as shown in Table 14.12.

Table 14.12– Impact of changing individual parameters on expected payback in years

Sensitivity analysis	Estimated time to payback (years) (based on expected scenario, grid mix electricity factor)		
	As assessed: Expected	Reduce parameter	Increase parameter
Average extent of drainage around drainage features at site (m) – 23m, impact of decreasing and increasing by 50%	0.7	0.4	0.9
Average water table depth at site (m) – 0.29m, impact of decreasing and increasing by 50%	0.7	1.1	0.2
Area of degraded bog to be improved (ha) - impact of removing the area of restoration associated with infill which is a non-standard technique and therefore has a higher level of uncertainty around success – decreasing restoration area by 44 ha	0.7	0.9	
Water table depth in degraded bog (m) before improvement – 0.29m, impact of decreasing and increasing by 50%	0.7	2.9	-1.1
Time required for hydrology and habitat of bog to return to its previous state on improvement (years) – 12.5 years, impact of decreasing and increasing by 50%	0.7	0.2	1.2

14.9.22 Table 14.12 shows that the average drainage distance around drainage features on-site is a potentially important parameter in terms of the area of peat that would be drained by the Proposed Development infrastructure, however, increasing this parameter by 50% adds only around a fifth of a year to the payback.

14.9.23 Changing the average water table depth across the site is slightly more influential, adding or removing around 0.4 years to the payback.

14.9.24 The most influential input parameters for this site are the water table in the restored bog (both before and after restoration because it is the difference in the amount of peat that is re-wetted through restoration activity) and the time taken to achieve restored state. In particular, reducing the estimated water table depth in the degraded bog by 50% increases the payback by over 2 years. Therefore, the input parameters used should be considered the best estimate given the information available but it should be noted that the actual payback of this site is largely dependent on successful restoration of a large area of degraded bog. In order to check that the non-standard restoration technique of infilling is not disproportionally affecting the site payback, the impact of removing this area (44 ha in total) has also been modelled. This shows that removing this area from the restoration calculations only increases the payback by 0.2 years.

14.10 Impact of Electricity Grid Decarbonisation

14.10.1 The most significant cumulative effect of the Proposed Development is on the long-term grid electricity carbon factor. As the supply of renewable electricity increases, the overall average national grid carbon factor is predicted to decrease. The cumulative effect of these projects would be to reduce the projected emissions savings of an individual project as each unit of grid electricity would be worth less carbon. This effect will be higher as renewable energy develops further into the future; however, at the same time the exact generation composition of the grid and therefore the carbon emissions per unit of electricity is less predictable.

14.10.2 Although there is a great deal of uncertainty surrounding the future grid factor, the Department for Business, Energy and Industrial Strategy produce grid projections as part of the supplementary guidance for valuing energy usage and GHG emissions. The projections predict an average grid factor over the expected lifetime of the Proposed Development (2026 to 2065) of approximately 0.029 $kgCO_2e/kWh$ (BEIS, 2022). The impact of applying this average grid factor to the Proposed Development would be to reduce the overall average annual saving and therefore increase the expected payback period from 0.7 years to 4.5 years. However, this would not affect the carbon intensity of the project, estimated at 0.003 $kgCO_2e/kWh$, which would be well below the projected average of the grid for the lifetime of the Proposed Development and would therefore contribute towards this grid decarbonisation.

14.11 Summary

14.11.1 The results of the Carbon Calculator show that the wind farm component of the Proposed Development is estimated to produce annual carbon savings of nearly 40,000 tonnes of CO_2e per year, through the displacement of grid electricity, based on the current average grid mix. Displacement of existing sources of generating capacity depends on the time of day and how the grid needs to be balanced.

14.11.2 The assessment of the carbon losses and gains during construction and operation has estimated an overall loss of just over 116,000 tonnes of CO_2e, mainly due to non site-based losses including embodied emissions from the manufacture of the turbines and provision of backup power to the grid. The requirement for backup power should be minimised through the provision of onsite energy storage. Ecological carbon losses account for 43 % of the total emissions resulting from the Proposed Development construction and operation and the baseline assessment demonstrated that less than 1.2 % of the soil carbon within the site boundary would be lost. Restoration of a large area of degraded bog on the site is estimated to produce significant gains over the lifetime of the windfarm through blocking of drains and re-wetting of peat; these gains are estimated at around 90,000 tonnes of CO_2e.

14.11.3 The estimated payback time of the Proposed Development, using the Scottish Government Carbon Calculator, is estimated at around 8 months (0.7 years), with a minimum/maximum range of -2.2 to 6.5 years. The negative value for the minimum represents the best-case scenario that the benefit of restoring a large area of degraded bog to stop it oxidising outweighs the minimum losses produced by the construction activities, whereas the maximum value is the worst case scenario of highest losses and no restoration gains. There are no current guidelines about what payback time constitutes a significant impact, but 0.7 years is only 1.8% of the anticipated lifespan of the Proposed Development. Compared to fossil fuel electricity generation projects, which also produce embodied emissions during the construction phase and then significant emissions during operation due to combustion of fossil fuels, the Proposed Development has a very low carbon footprint, and after 0.7 years the electricity generated is estimated to be carbon neutral and will displace grid electricity generated from fossil fuel sources. The carbon intensity of the electricity produced by the Proposed Development is estimated at 0.003 $kgCO_2e/kWh$. This is well below the outcome indicator for the electricity grid carbon intensity of 0.05 $kgCO_2e/kWh$ required by the Scottish Government in the Climate Change Plan update (Scottish Government, 2020) and therefore the Proposed Development is evaluated to have an overall beneficial effect on the carbon balance.

14.12 References

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