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 Loch Liath Wind Farm (the Proposed Development) over its 35-year lifetime, including losses of stored carbon from disturbed peatland and reduction of carbon fixing vegetation cover. 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 96,000 tonnes of CO_2e; these are largely from the predicted requirement of provision of backup power to the grid and embodied emissions from the manufacture of the turbines. Ecological carbon losses account for only 6 % of the total emissions resulting from the Proposed Development construction and operation; these are partially compensated for by the estimated gains of 1,200 tonnes of CO_2e from the 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 2.4 years, with a minimum/maximum range of 1.9 to 3.0 years. There are no current guidelines about what payback time constitutes a significant impact, but 2.4 years is around 6.9% of the anticipated lifespan of the Proposed Development; 94% of this payback period is due to turbine lifecycle and grid backup power for intermittent power generation, which are not under the direct control of the Applicant. The carbon intensity of the electricity produced by the Proposed Development is estimated at 0.013 kgCO2e/kWh. This is well below the outcome indicator for the electricity grid carbon intensity of 0.05 kgCO2e/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.

14.2 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. 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 4 December 2020. Scoping opinions 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 to the carbon balance assessment

Organisation	Scoping opinion
The Highland Council	Carbon balance calculations should be undertaken and included within the EIAR with a summary of the results provided focussing on the carbon payback period for the wind farm.
The Highland Council Forestry Team	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 Governments Policy on Control of Woodland Removal. *It should be noted that no felling is required for the Proposed Development.*
RSPB Scotland	RSPB Scotland recommends that a carbon calculation in line with current best practice is undertaken to determine the 'carbon payback period' over the operational life of the development. Recommend that the carbon calculator is used as early as possible in the planning process, to inform siting and micrositing of both turbines and tracks and other infrastructure, and not simply undertaken after the site layout has been determined. RSPB Scotland considers that the payback period should be as close to zero as possible.

14.4.2 These comments have been addressed within this Appendix report.

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 (the 'Site') 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 Site 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 carbon ('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)	1,605	1,525	1,685
Average peat depth across site (m)	0.60	0.54	0.66
Carbon content of dry peat (% by weight)	56%	49%	62%
Dry soil bulk density (g/cm^3)	0.11	0.08	0.14

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 14.4 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 14.3 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 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.
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.	Carbon removals resulting from the creation or restoration of active carbon-absorbing habitat. 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.	

Project phase	Included in assessment	Excluded from assessment
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., 35 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 Proposed Development 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: CJIN-M077-ZQJ5					
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 13 wind turbines (three with tip heights of up to 180 m and ten with tip heights of up to 200m).	None.
Lifetime of wind farm (years)	35	35	35	Chapter 4 states that the Proposed Development has been designed to have an operational lifespan of up to 35 years.	None.
Performance					
Turbine capacity (MW)	6.6	6.6	6.6	Chapter 4 states that the candidate turbine has a maximum capacity of 6.6MW.	None.
Capacity factor – using direct input of capacity factor (percentage efficiency)	27.2	25.6	28.9	The capacity factor has been estimated at a five-year average wind load factor for Scotland, 2017 to 2021 (BEIS, December 2022, Table 6.1 Renewable electricity capacity and generation). Mean: 27.2 Count: 5 Standard error: 0.8	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: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Backup					
Extra capacity required for backup (%)	5	5	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).	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 efficiency of the reserve generation (%)	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 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 available for similar turbine model (SG 6.6-170) (Siemens Gamesa, 2022) and this has been used to estimate the turbine lifecycle emissions. The units are embodied GHG emission per kWh produced.	
Total CO_2 emission from turbine life (tCO2 MW-1	1,432	1,289	1,575	Units of gCO_2e/kWh of electricity over a standard 25 lifespan have been converted to tCO_2e per MWh and scaled down for electricity generation over 35 years to not	A range of +/- 10% has been used to calculate the likely minimum and maximum.

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				overestimate the emissions for the longer lifetime of the site. A correction factor was used to negate the impact of a known error in the carbon calculator (correspondence with Scottish Government, January 2023). To correct the error of the estimated tCO_2/MW being incorrectly multiplied by the site capacity factor, the input parameter has been divided by this factor.	
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.
Average air temperature at site (^oC)	7.5	7.3	7.7	Based on average annual temperature data for North Scotland for the time period 2003 – 2022. The data is sourced from the Meteorological Office (2023). 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.

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average depth of peat at the Site (m)	0.60	0.54	0.66	The peat depth distribution from the Outline Peat Management Plan (OPMP) (EIA Report Appendix 7.3) was used to estimate the average peat depth across the Site, using the mid-point of the peat depth ranges and the areas of peat depth distribution across the survey area.	A range of +/- 10 % has been used to calculate the likely minimum and maximum.
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 drainage features at site (m)	30	20	41	The average extent of drainage has been estimated using Von Post data from 52 cores on-site. Von Post scores were as a range for each peat core – it has assumed that the low 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 14.8.	The minimum and maximum values are based on an estimated input range of +/-25% for the bulk density. The wide range of values reflects the difficulty in measuring this parameter with accuracy.
Average water table depth at site (m)	0.10	0.07	0.14	The minimum annual water table depth is estimated at the mid-depth of the acrotelm/catotelm boundary, assumingthis boundary represents the maximum, although this varied significantly across the site. The expected value is the midpoint of the minimum and maximum.	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.

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Dry soil bulk density (g/cm^3)	0.11	0.08	0.14	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) and detailed in Section 14.8. The estimated bulk density of 0.11 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 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 overall Proposed Development site payback is not particularly sensitive to this parameter due to the slow rate of carbon fixation by bogs. 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,

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
					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)	0	0	0	No forestry felling is required for the construction of the Proposed Development.	None.
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 greenhouse gas 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 (tCO_2 MWh^{-1})	0.432	0.432	0.432		
Borrow Pits					

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Number of borrow pits	1	1	1	Chapter 4 states that the construction of the Proposed Development will also require the creation of one temporary borrow pit for the extraction of stone.	None.
Average length of pits (m)	200	190	210	The dimensions of the borrow pit are estimated as a length of 200 m as stated in Chapter 4. This is used to divide the total area from the OPMP which includes slopes and drains.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Average width of pits (m)	45	43	48		
Average depth of peat removed from pit (m)	0.09	0.08	0.10	The volume of peat excavated from the borrow pit is taken from the OPMP excavation calculations (total volume of peat excavated, including slopes and drains). The volume of peat was divided by the infrastructure area to get an average peat depth removed from these excavations.	A range of +/- 10 % has been used to calculate the likely minimum and maximum.
Foundations and hard-standing area associated with each turbine					
Method used to calculate CO_2 loss from foundations and hardstanding	Rectangular, with vertical sides			The simple method of calculation for turbine foundations was used for this application because there is no clear groups of turbines in terms of different peat depths, structures or use of piling.	None.
Average length of turbine foundations (m)	19.5	18.5	20.5	Chapter 4 states that these typically measure approximately 22m diameter. Although the 13 turbine foundations are circular in shape, in order to be able to	A range of + 5% has been used to calculate the likely expected and

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average width of turbine foundations (m)	19.5	18.5	20.5	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.	maximum values of both length and width.
Average depth of peat removed from turbine foundations (m)	0.24	0.23	0.25	The volume of peat at each turbine/hardstanding location was taken from the OPMP excavation calculations (total volume of peat excavated, including slopes and drains). The volume of peat was divided by the total infrastructure area (temporary and permanent hardstandings, which includes the turbine foundations) to get an average peat depth removed from these excavations.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Average length of hardstanding (m)	74	70	77	The hardstanding area is made up of both permanent and temporary excavated areas, both of which have been included in this calculation. The total area of all the 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 minimum and maximum.
Average width of hardstanding (m)	74	70	77		
Average depth of peat removed from hardstanding (m)	0.24	0.23	0.25	The volume of peat at each turbine/hardstanding location was taken from the OPMP excavation calculations (total volume of peat excavated, including slopes and drains). The volume of peat was divided by the total infrastructure area (temporary and permanent hardstandings, which includes the turbine foundations) to get an average peat depth removed from these excavations.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Volume of concrete used in entire area	13,000	11,700	14,300	Chapter 4 states that each foundation will require approximately 1,000 cubic metres (m^3) of concrete.	A range of +/- 10% has been used to calculate the minimum and maximum.
Access tracks					
Total length of access track (m)	26,650	25,318	27,982	Chapter 4 states that the Proposed Development will comprise 17,325 m of existing track and approximately 9,325 m of new access tracks	A range of +/- 5% has been used to calculate the minimum and maximum.
Existing track length (m)	17,325	16,459	18,191	Chapter 4 states that approximately 17,325 m of existing will be upgraded which is likely to require only scraping of the top layer of material to ensure the turbine blade tips do not strike the earthworks embankment and possible improvements to the running surface prior to use.	A range of +/- 5% has been used to calculate the minimum and maximum.
Length of access track that is floating road (m)	1,140	1,083	1,197	Chapter 4 states that 1,140 m of floating track.	A range of +/- 5% has been used to calculate the minimum and maximum.
Floating road width (m)	7.9	7.6	8.3	The total width of the track (including verges and drains) has been estimated from the length of track and the total infrastructure area for floating track estimated in the OPMP.	A range of +/- 5% has been used to calculate the minimum and maximum.
Floating road depth (m)	0.0	0.0	0.50	This parameter accounts for sinking of floating road. The Carbon Calculator states that it should be entered as the	Zero value for expected and minimum values. The maximum is

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				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 set as zero for the expected and minimum values. The average peat depth for the floating track has been taken from the OPMP excavation calculations.	estimated at 50% of the average peat depth for all the floating track locations on-site.
Length of floating road that is drained (m)	1,140	1,083	1,197	Chapter 4 states the tracks will have adequate crown or cross-slope to allow rainwater to be shed and, where gradients are present, lateral drainage will intercept flow. A drainage ditch will be formed on the upslope side of the track, dependent on a detailed drainage design, therefore it has been assumed that all floating track is drained.	A range of +/- 5% 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 +/- 5% has been used to calculate the minimum and maximum.
Length of access track that is excavated road (m)	8,185	7,776	8,594	Chapter 4 states that 8,185 m will be standard track.	A range of +/- 5% has been used to calculate the likely minimum and maximum.
Excavated road width (m)	7.3	6.9	7.7	The total width of the track (including verges and drains) has been estimated from the length of track and the total infrastructure area for excavated track estimated in the OPMP.	A range of +/- 5% has been used to calculate the likely minimum and maximum.

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average depth of peat excavated for road (m)	0.23	0.21	0.25	The volume of peat from excavated track has been taken from OPMP excavation calculations (total volume of peat excavated, including slopes and drains). The volume of peat was divided by the infrastructure area to get an average peat depth removed.	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 (m3)	1,957	1,859	2,055	The volume of additional excavated peat has been calculated from the OPMP excavation calculations for the three additional infrastructure components listed below: • Construction compound • Met mast • Substation	A range of +/- 5% has been used to calculate the likely minimum and maximum.
Area of additional peat covered by infrastructure (m^2)	11,317	10,751	11,883	The area of additional peat covered by additional infrastructure has been calculated from the OPMP	A range of +/- 5% has been used to calculate the likely minimum and maximum

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				excavation calculations for the three additional infrastructure components.	
Improvement of C sequestration at site by blocking drains, restoration of habitat etc.					
Improvement of degraded bog					
Area of degraded bog to be improved (ha)	5.65	5.1	6.2	This includes degraded bog areas for backfill from excavated peat of 36,500 m^2 and degraded bog areas for reprofiling and potentially some damming structures of 20,000 m^2.	A range of +/- 10% has been used to calculate the likely minimum and maximum
Water table depth in degraded bog before improvement (m)	0.35	0.26	0.44	This parameter has not been directly measured but from experience in other similar environments, in peat that is degraded, the water table to be down between 30-40 cm.	A range of +/- 25% has been used to calculate the likely minimum and maximum.
Water table depth in degraded bog after improvement (m)	0.10	0.09	0.11	Target optimum water table depth for restoring peat is around 0.1m.	A range of +/- 10% has been used to calculate the likely minimum and maximum
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	12.5	10	15	The restoration is coming from a combination of replacement and re-profiling and damming; estimated time for restoration of hydrology and habitat would be a minimum of 10 years.	The minimum has been set at 10 years and a range of + 25% & +50% has been used to calculate the likely expected and maximum.
Period of time when effectiveness of the improvement in	35	35	35	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	None

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
degraded bog can be guaranteed (years)				lifetime of the Proposed Development (35 years), the period of time when the improvement can be guaranteed should be entered as 35 years.	
Restoration of peat removed from borrow pits					
Area of borrow pits to be restored (ha)	0.9	0.81	0.99	The peat restoration calculation in the OPMP estimate that the borrow pit could be reinstated with 1m depth of peat.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
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.	A range of +/- 25% has been used to calculate the likely minimum and maximum.
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.10	0.09	0.11	To restore the bog habitat in the borrow pits, it is expected that the average annual water table depth needs to be restored to around 0.1 m from the surface.	A range of +/- 10% has been used to calculate the likely minimum and maximum.
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.

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	35	35	35	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 (35 years), the period of time when the improvement can be guaranteed should be entered as 35 years.	
Removal of drainage from foundations and hardstanding				Chapter 4 states the during operation, hard-standing areas at each turbine location will be retained for use during operation and decommissioning. 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 a decommissioning method statement will be prepared and agreed with the relevant statutory consultees prior to decommissioning of the Site, 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	No	No	No	See above.	

Online calculator reference: CJIN-M077-ZQJ5					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
site be restored on decommissioning?					
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 52 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 = 2.4, count 49)

Calculate the average Von Post scores for catotelm layer (mean = 6.6, count 63)

Calculate an average weighted Von Post score, using the average depth of acrotelm and catotelm to weight the score (weighted average score = 5.9)

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 Site. 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)	9,665,000	8,263,000	11,163,000
Estimated amount of carbon in soils (tC)	590,000	324,000	969,000
Estimated equivalent emissions of CO_2 (tCO_2)	2,165,000	1,189,000	3,556,000

14.9.4 Table 14.5 shows that there are approximately 0.6 million tonnes of stored carbon on-site and if this were fully oxidised, this would equate to approximately 2.2 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 will negatively affect this store of carbon, even in the absence of development.

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, 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	28,313	39,054	34.8%
CO_2 loss from excavated peat	1,912	-286	6,336	2.0%
Subtotal of emissions during construction	**35,331**	**28,027**	**45,390**	**36.8%**

14.9.7 Table 14.6 shows that 37 % of the total losses occur during the Proposed Development construction phase. The majority of these come from the manufacture of the turbines, with a small proportion due to other materials used in construction (for example concrete for foundations). The potential oxidation of peat excavated for infrastructure construction only contributes 2% to the overall losses.

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	56,822	56,822	56,822	59.2%
Losses due to reduced carbon fixing potential	4,346	1,417	9,883	4.5%
Losses due to Dissolved Organic Carbon (DOC) & Particulate Organic Carbon (POC) leaching	9	2	18	0.0%
CO_2 loss from drained peat	-526	-5,336	-	-0.5%
Subtotal of emissions during operation	**60,651**	**52,905**	**66,723**	**63.2%**

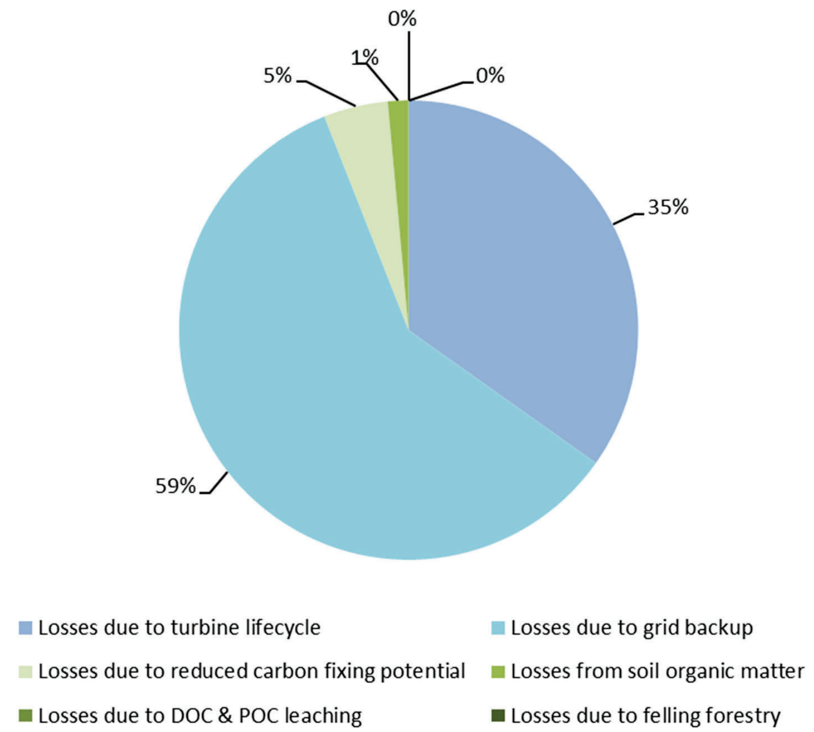
14.9.8 Table 14.7 shows that a further 63 % of the emissions occur during the operational phase of the Proposed Development. The most significant of these is the requirement for back-up power in the grid, which is assumed to come from a fossil fuel source. Losses due to reduced carbon fixing potential of bog vegetation account for 4.5%, whereas there is predicted to be a very small gain from drained peat, which is a function of the ratio of methane to carbon dioxide emissions in drained peat that is automatically calculated using the site-specific methodology within the Carbon Calculator.

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 categories; the majority of emissions result from activities largely outside of the control of the Applicant (shown in blue); the largest emission source is from back-up power required for intermittent generation and this depends on both the grid mix and future grid management policies and is not under the control of the Applicant. Lifecycle emissions from the turbines also contributes a significant proportion of the total emissions and while these can be potentially reduced through consideration at the procurement phase, availability and delivery timescales of appropriate turbines are usually a more important factors in selection.

14.9.11 Emissions under the control of the Applicant are shown in green. These include minimal losses of carbon fixing potential in bog plants and extraction of peat for infrastructure. Therefore, mitigation measures for climate change include micrositing infrastructure further away from peat areas during construction where possible; this has occurred because the average peat depth under infrastructure is significantly lower than the average peat depth across the Site.

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 and restoring peat in borrow pits. The gains from restored bog 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. There is a very small increase in emissions predicted from the restoration of the borrow pit – this is due to the initial minimal average peat depth estimated for the borrow pit. 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	-1,255	-610	-2,018	102.5%
Change in emissions due to restoration of peat from borrow pits	31	34	28	-2.5%

Source of gains	Estimated gains (tCO_2e)			% of overall gains (expected scenario)
	Expected	Minimum	Maximum	
Total estimated gains	**-1,224**	**-576**	**-1,990**	**100%**

Comparison with the Baseline

14.9.13 The soil carbon losses from the Proposed Development are estimated at around 6,000 tonnes of CO_2e. This represents 0.3 % of the estimated total stored carbon on-site (as set out in Table 14.5) 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	1,912	Change in emissions due to improvement of degraded bogs	-1,255
CO_2 loss from drained peat	-526	Change in emissions due to restoration of peat from borrow pits	31
Losses due to reduced carbon fixing potential	4,346	-	
Losses due to Dissolved Organic Carbon (DOC) & Particulate Organic Carbon (POC) leaching	9	-	
Total soil carbon losses	**5,742**	**Total restoration gains**	**-1,224**

14.9.15 Table 14.9 shows that the ratio between soil carbon loss and restoration gains is 4.7; there are nearly five times more losses than gains, but this is mainly due to predicted losses from carbon fixing vegetation rather than losses of existing peat and overall, the scale of losses of carbon from the site is very low for this Site.

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	7,169,610	6,747,860	7,617,715
Grid-mix of electricity generation	1,383,690	1,302,315	1,470,175
Fossil fuel - mix of electricity generation	3,091,095	2,909,270	3,284,295

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 generated units of electricity. 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	0.5	0.4	0.6
Grid-mix of electricity generation	2.4	1.9	3.0

Counterfactual emission factor	Estimated time to payback (years)		
	Expected	Minimum	Maximum
Fossil fuel - mix of electricity generation	1.1	0.8	1.3
Carbon intensity (kgCO_2e/kWh)	0.013	0.010	0.017

14.9.19 Table 14.11 shows that the Proposed Development is estimated to have a payback of 2.4 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.

Limitations to Assessment

14.9.20 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 significant 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 five 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) – 30m, impact of decreasing and increasing by 50%	2.4	2.4	2.4
Average water table depth at site (m) – 0.10m, impact of decreasing and increasing by 50%	2.4	2.3	2.4
Water table depth in degraded bog (m) before improvement – 0.35m, impact of decreasing and increasing by 50%	2.4	2.4	2.4
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%	2.4	2.4	2.4

Sensitivity analysis	Estimated time to payback (years) (based on expected scenario, grid mix electricity factor)		
	As assessed: Expected	Reduce parameter	Increase parameter
Extra capacity required for backup (%) – 5%, impact of decreasing and increasing by 50%	2.4	1.7	3.1

14.9.21 Table 14.12 shows that varying the site-based parameters by 50% has virtually no impact on the overall expected payback. This is due to the low average peat depth at the Site (estimated at 0.6 m across the whole site and lower at the majority of infrastructure locations); since the site-based carbon losses are very low compared to the turbine lifecycle and backup power supplied to the grid, changing these parameters does not significantly affect the payback.

14.9.22 The most influential input parameter for this Site is the extra capacity required for backup; the Carbon Calculator methodology suggests that '*If 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 (Dale et al 2004). We suggest this should be 5% of the actual output*'. However, this is an area of uncertainty, both in terms of current and future grid requirements and is not under the control of the Applicant when designing the site.

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 (2027 to 2061) of approximately 0.028 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 2.4 years to 16.6 years. However, this would not affect the carbon intensity of the project, estimated at 0.013 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 96,000 tonnes of CO_2e, mainly due to non-site losses including provision of backup power to the grid and embodied emissions from the manufacture of the turbines. Ecological carbon losses only account for 6 % of the total emissions resulting from the Proposed Development construction and operation, and the baseline assessment demonstrated that less than 0.3 % of the soil carbon within the site boundary would be lost. Restoration of an area of degraded bog on the site is estimated to produce gains over the lifetime of the windfarm through blocking of drains and re-wetting of peat; these gains are estimated at around 1,200 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 2.4 years, with a minimum/maximum range of 1.9 to 3.0 years. There are no current guidelines about what payback time constitutes a significant impact, but 2.4 years is around 6.9% of the anticipated lifespan of the Proposed Development; the majority of this payback is due to turbine lifecycle and grid backup, which are not under the direct control of the Applicant. 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 low carbon footprint, and after 2.4 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 0.013 $kgCO_2e$/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.

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