Appendix 12.1: Carbon Balance Assessment

12.1 Carbon Balance Assessment

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12 Carbon Balance Assessment

12.1 Executive Summary

12.1.1 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 Dunside 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.

12.1.2 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 50,000 tonnes of CO_2e per year, through the displacement of grid electricity.

12.1.3 The assessment of the Proposed Development estimates losses of around 90,000 tonnes of CO_2e, nearly all of which come from the lifecycle emissions of the turbines and the batteries. Ecological carbon losses account for only 1% of the total losses resulting from the Proposed Development due to the site only having shallow deposits of peat and the infrastructure having been designed to avoid these where possible. Re-wetting of degraded peat bogs on the Site are estimated to produce gains over the lifetime of the wind farm of around 5,700 tonnes of CO_2e.

12.1.4 The payback time of the Proposed Development, using the Scottish Government Carbon Calculator, is estimated at 1.8 years, with a minimum/maximum range of 1.3 to 2.5 years. There are no current guidelines about what payback time constitutes a significant impact, but 1.8 years is around 5% of the anticipated lifespan of the Proposed Development. The carbon intensity of the electricity produced by the Proposed Development is estimated at 0.01 kgCO_2e/kWh. This is well below the outcome indicator for maintaining the electricity grid carbon intensity below 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.

12.2 Introduction

12.2.1 This Carbon Balance Assessment has been undertaken by Clare Wharmby on behalf of East Point Geo. 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.

12.2.2 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; in the UK, 40.8% of electricity was generated from fossil fuels in 2022 (Department for Energy Security and Net Zero, 2023). 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' delivery plans for climate targets (Carbon Budget Delivery Plan (Department for Energy Security and Net Zero, March 2023) and the update to the Climate Change Plan (Scottish Government, 2020)).

12.2.3 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.

12.2.4 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.

12.2.5 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 Appendix 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 considered, and includes a sensitivity analysis for key parameters.

12.3 Legislation, Policy and Guidelines

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

Legislation

12.3.1 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 1990 baseline.

Policy

12.3.2 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.

12.3.3 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 undergoing post-consultation review. 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.

12.3.4 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.

12.3.5 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

12.3.6 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 Report.

12.4 Consultation

12.4.1 Consultation on the scoping report was undertaken by the Scottish Ministers and this commenced on 17 March 2022. Scoping opinions were sought from the list of consultees and SEPA and East Lothian Council responded in relation to the carbon balance assessment; see Table 12.1 below.

Table 12.1 Scoping opinions relating to the carbon balance assessment

Organisation	Scoping opinion
SEPA	*The planning submission must a) demonstrate how the layout has been designed to minimise disturbance of peat and consequential release of CO_2.* *Please note we do not validate carbon balance assessments except where requested to by Scottish Government in exceptional circumstances*
East Lothian Council	*The Scoping Report notes (para 12.10) that the applicant will carry out a carbon balance assessment for the proposal using Scottish Government guidance produced by Aberdeen University and the Macaulay Land Use Research Institute and the latest version of the carbon calculator spreadsheet produced by the Scottish Government (currently version 1.6.1). This is supported.*

12.4.2 This Appendix Report forms the response to this opinion and the payback period has been assessed in Section 12.9.

12.5 Assessment Methodology

12.5.1 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 values for carbon content of peat; 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).

12.5.2 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

12.5.3 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 12.2 shows the parameters used to estimate the baseline of stored carbon. The source and references for these parameters are provided in Table 12.4.

Table 12.2 Parameters used to estimate baseline stored carbon within red line boundary

Parameter	Expected	Minimum	Maximum
Size of site based on red line boundary (ha)	1,298	1,233	1,363
Average peat depth across site (m)	0.32	0.31	0.33
Carbon content of dry peat (% by weight)	56%	49%	62%
Dry soil bulk density (g/cm^3)	0.09	0.07	0.11

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

12.5.4 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. Accompanying this methodology was an excel spreadsheet tool called the 'Carbon Calculator for wind farms on peat' which estimates 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.

12.5.5 This method built further on the Technical Guidance note produced by Scottish Natural Heritage (SNH, now NatureScot) 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.

12.5.6 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 12.4 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 Appendix Report, in the context of actual inputs and outputs of the model.

12.6 Scope of Carbon Calculator

12.6.1 Table 12.3 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 12.3 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, and for the manufacture and end of life processing of the lithium-ion batteries. The turbine and battery Lifecycle Carbon Assessment (LCA) values are taken from the literature and put into the carbon calculator as direct input of values.	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 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 and are also not included within the boundary of the LCA
	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 within the grid to manage intermittent generation.	
	Carbon emissions from the manufacture and supply of materials for maintenance and repair are included within the boundary of the LCA.	Emissions from use of diesel in generators used to restart turbines following shutdown. This is likely to be a very small emission source.
	Carbon emissions during the lifetime of the Proposed	Carbon removals resulting from the creation or restoration of active

Project phase	Included in assessment	Excluded from assessment
	Development resulting from the loss of active carbon-absorbing peatland habitat.	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.	
Decommissioning	Carbon emissions from the dismantling and disposal of turbine and associated infrastructure are included within the boundary of the LCA but these are not separated from the overall embodied emissions of the turbines in the Carbon Calculator.	-

Temporal Scope

12.6.2 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 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

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

12.6.4 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. 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.

12.7 Significance Criteria

12.7.1 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. Where appropriate, worst-case parameters have been utilised for this assessment, for both the infrastructure dimensions and the restoration areas, to ensure the impacts are accounted for.

Table 12.4 Input parameters used in the Carbon Calculator

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Wind Farm Characteristics					
Dimensions					
No. of turbines	15	15	15	Chapter 3: Development Description states that the Proposed Development comprises of up to 15 wind turbines, each with a maximum tip height of 220 m (with an external transformer kiosk)	None
Life time of wind farm (years)	35	35	35	Chapter 3 states that the Proposed Development has been designed to have an operational lifespan of up to 35 years.	None
Performance					
Turbine capacity (MW)	7.2	7.2	7.2	Chapter 3 states that for assessment purposes, a representative candidate turbine has been used based on specifications available in the marketplace (currently of 7.2 MW nominal capacity), the candidate turbine used in the assessment work is the Vestas 172 unless otherwise stated.	None
Capacity factor – using direct input of capacity factor (percentage efficiency)	27.2	25.6	28.9	Due to the high wind speeds at Dunside, a capacity factor in excess of 40% are anticipated for all suitable turbine options. However, for this assessment a conservative approach has been adopted using the 5-year average wind load factor for Scotland (2017 to 2021) (BEIS, December	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: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				2022, Table 6.1 Renewable electricity capacity and generation). 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.	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.

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				Therefore, this parameter has been reduced by 50% from 5% to 2.5% to represent this onsite balancing.	
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 3 states that for assessment purposes, a representative candidate turbine has been used based on specifications available in the marketplace (currently of 7.2 MW nominal capacity), the candidate turbine used in the assessment work is the Vestas 172 unless otherwise stated. An externally verified lifecycle assessment is not yet available for this candidate turbine but an indicative carbon footprint of 6.4 gCO_2e/kWh produced is provided on the Vestas website (Vestas, 2023) and this is consistent with other published studies.	
Total CO_2 emission from turbine life (tCO_2 MW^{-1}	1,999	1,799	2,199	Units of gCO_2e/kWh have been converted to tCO_2e per MWh and then to tCO_2e/MW installed. 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	

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				tCO_2/MW is incorrectly multiplied by the site capacity factor, the input parameter has been divided by this factor. The embodied carbon of the BESS has been estimated using data from a published LCA of a Lithium-ion BESS (Parlikar, et al. 2021). The value for the net emissions from production and end of life phase per MW have been calculated for the whole site and then added to the embodied turbine emissions.	
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 (°C)	7.7	7.5	7.9	Based on average annual temperature data for East Scotland for the period 2003 – 2022. The data is sourced from the Meteorological Office (2023). Mean: 7.7 Count: 20 Standard Error: 0.10	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

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
					parameter is not included in the sensitivity analysis.
Average depth of peat at the site (m)	0.32	0.31	0.33	This is a spatial average using the peat depth model for peat probes within the red line boundary. Mean: 0.32 Count: 3,088 Standard Error: 0.005	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 drainage features at site (m)	38	30	47	The average extent of drainage has been estimated using Von Post data from 15 cores on-site. Von Post scores were as provided 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 12.8	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)	0.15	0.10	0.19	The minimum annual water table depth is estimated at the mid-depth of the acrotelm/catotelm boundary, assuming	A range of between the surface and the acrotelm/catotelm boundary has

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				that this boundary represents the maximum, although this varied significantly across the site.	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)	0.09	0.07	0.11	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 0.09 g/cm^3 sits within the estimated range for soil with peat layers in the UK which range from between 0.06g cm-3 to 0.4g cm-3 depending on the level of humification, compaction or mineral content (JNCC, 2011). More detail is provided in Section 12.8	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%.

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
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)	0	0	0	No forestry felling is required for this site	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	0.19338	0.19338	0.19338		

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
(tCO_2 MWh^{-1})					
Fossil fuel- mix emission factor (tCO_2 MWh^{-1})	0.432	0.432	0.432		
Borrow Pits					
Number of borrow pits	3	3	3	Appendix 8.3 Peat Management Plan states that the borrow pit search areas are on steep sided lower valley sides and limited probing in these areas shows minimal soil overlying the locations. The potential borrow pits have also not been selected for peat reinstatement. Therefore, although they have been included in this assessment as an infrastructure footprint, they do not impact on the peat excavation volumes.	None
Average length of pits (m)	86	82	90	Chapter 3 provides the expected dimensions of the three borrow pits. These have been converted to an average length and width using the square root of the average area.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Average width of pits (m)	86	82	90		
Average depth of peat removed from pit (m)	0	0	0	Appendix 8.3 lists the excavation volumes of acrotelm and catotelm peat from all three borrow pits as zero.	None
Foundations and hard-standing area associated with each turbine					

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
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)	22.2	21.0	23.3	Chapter 3 states the foundations typically measure up to approximately 25 m diameter. Although the 15 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 minimum and maximum.
Average width of turbine foundations (m)	22.2	21.0	23.3		
Average depth of peat removed from turbine foundations (m)	0.02	0.018	0.021	The average peat depth across all the foundation/hardstanding locations was calculated from the excavated peat volume detailed in Appendix 8.3, divided by the total area of standard permanent and temporary areas for the 15 turbine bases. Due to the patchy peat distribution, the average peat depth is very shallow – in reality this represents areas with no peat and some areas with shallow deposits. However, for the carbon calculator, this is presented as an average across this infrastructure. • Total area (temporary and permanent) = 109,380m^2 • Total volume of peat excavated for turbine foundations and main hardstandings (permanent)	A range of +/- 10 % has been used to calculate the likely minimum and maximum.

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				and secondary crane and blade laydown hardstandings (temporary) = 2,136 m^2 • Average peat depth = 2,136/109,380 = 0.02m	
Average length of hard-standing (m)	82	78	87	The total hardstanding area is made up of both permanent and temporary excavated areas. The area of the turbine foundations was removed from the total. The remaining area was divided by the number of turbines and the square root used to estimate the average length and width, although in reality these shapes are uneven.	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)	82	78	87		
Average depth of peat removed from hard-standing (m)	0.02	0.018	0.021	As above for foundations.	A range of +/- 10 % has been used to calculate the likely minimum and maximum.
Volume of concrete used in entire area	15,000	13,500	16,500	Chapter 3 states each turbine foundation will require approximately 1,000 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)	33,600	31,920	35,280	Chapter 3 states that approximately 17.5 km of existing track will be utilised, and approximately 15 km of new track (including floating tracks) and 1.1 km of light vehicle tracks will be built as part of the Proposed Development.	A range of +/- 5% has been used to calculate the minimum and maximum.

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Existing track length (m)	17,500	16,625	18,375	Chapter 3 states that approximately 17.5 km of existing access tracks will be utilised (including areas of widening/upgrading). It is assumed that minimal peat will be excavated for this upgrading, but all the peat excavated for access tracks has been included in the excavated track section below.	A range of +/- 5% has been used to calculate the likely minimum and maximum
Length of access track that is floating road (m)	586	556	615	Chapter 3 gives the permanent land take area for floating tracks as 4,100m^2. Using an estimated width of 7m, this gives an estimated length of 0.6km.	A range of +/- 5% has been used to calculate the likely minimum and maximum
Floating road width (m)	7.0	6.7	7.4	Appendix 8.3 states that access tracks will comprise a 6m wide running surface. To allow for widening on bends and cable trenches, this has been set at 7m.	A range of +/- 5% has been used to calculate the minimum and maximum.
Floating road depth (m)	0.0	0.0	0.41	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 set as zero for the expected and minimum values. The average peat depth for the floating sections has been estimated from GIS.	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: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Length of floating road that is drained (m)	586	556	615	Cut off ditches may be installed for floating tracks during construction and these locations shall be reviewed based on design requirements post-construction and reinstated where appropriate. Cross drains or other features may be installed as required based on the setting of each access track spur. Therefore, to model the worst-case scenario, it has been assumed that all the floating road 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 +/- 10% has been used to calculate the likely minimum and maximum.
Length of access track that is excavated road (m)	15,514	14,738	16,290	Chapter 3 states that approximately 15 km of proposed wind farm tracks and approximately 1.1 km of proposed light vehicle track would be constructed. The floating track length has been removed from this total.	A range of +/- 5% has been used to calculate the likely minimum and maximum
Excavated road width (m)	7.0	6.7	7.4	Appendix 8.3 states that access tracks will comprise a 6 m wide running surface. To allow for widening on bends and cable trenches, this has been set at 7m.	A range of +/- 5% has been used to calculate the likely minimum and maximum
Average depth of peat excavated for road (m)	0.04	0.036	0.044	The average peat depth has been estimated from excavated peat volume for access tracks provided in	A range of +/- 10% has been used to calculate the likely minimum and maximum

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				Appendix 8.3 divided by the total land permanent land take area for cut and fill tracks, provided in Chapter 3.	
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 3 states that to minimise ground disturbance cables will be routed alongside the access tracks.	Assume all cable trenches follow access track routes.
Additional peat excavated (not accounted for above)					
Volume of additional peat excavated (m^3)	0	0	0	The additional infrastructure components are listed in Chapter 3 as: • Substation Compound/extension (permanent) • Battery Storage (permanent) • Construction Compound 1 and 4 (including parking and staff welfare facilities) - existing levelled areas • Construction Compound 2 and 3 (including concrete batching plant, parking and staff welfare facilities) - proposed areas • On-Site Access Tracks (Existing - area provided is only area of required widening)	None

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				However, none of these require excavation of peat (Appendix 8.3) so they have been assessed but not included in this section.	
Area of additional peat covered by infrastructure (m^2)	0	0	0	As above.	None
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)	77.5	73.6	81.4	Appendix 6.6 Outline Restoration and Enhancement Plan states that two areas close to the centre of the Site are proposed for enhancement of existing marshy grassland/ heath and degraded bog habitat. It is proposed that these areas are encouraged to become wetter by implemented drain blocking to retain and slow the movement of water to aid colonisation by bog-forming and/ or heath species. Supplementary planting may also be appropriate, the requirement of this will be monitored and interventions made as appropriate. The sizes of the two areas have been measured in GIS, however, in order to not overestimate the gains from restoration, it has been assumed that only 50% of the total	A range of +/- 5% has been used to calculate the likely minimum and maximum

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				area will have a water table and vegetation restored to levels optimal for peat creation.	
Water table depth in degraded bog before improvement (m)	0.2	0.15	0.25	The site only has shallow peat deposits and therefore, it is assumed that the water table in the degraded bog area is not too far below the surface but is sub-optimal. An estimated average of 0.2m has been used.	A range of +/- 25% has been used to calculate the likely minimum and maximum.
Water table depth in degraded bog after improvement (m)	0.15	0.1	0.30	Target optimum water table depth for restoring peat is around 0.1m but the mid-point between 0.1 and 0.2 is more realistic.	The minimum has been set at 0.1 m and a range of + 25% & +50% has been used to calculate the likely expected 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 by implemented drain blocking to retain and slow the movement of water to aid colonisation by bog-forming and/ or heath species: 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 degraded bog 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 12.5 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.	None
Restoration of peat removed from borrow pits					

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Area of borrow pits to be restored (ha)	0	0	0	Appendix 8.3 does not require using the borrow pits for reuse of peat. Since no peat was taken out of the borrow pits or will be reinstated back in, this section has been left blank in the Carbon Calculator.	None
Removal of drainage from foundations and hardstanding	0	0	0	Chapter 3 states the hardstanding provides safe access for maintenance and repairs and will therefore remain in place for the operation of the Proposed Development. 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 3 states that after the operational life of the Proposed Development and associated infrastructure, an application could be submitted to retain or replace the turbines, or they could be decommissioned. Although indicative decommissioning actions are listed, Chapter 3 also states that the CEMP will be updated as required to ensure best practice is adopted during decommissioning of the Proposed Development and that activities are carried out in line with the legislation and guidance that is current at time of decommissioning. Due to the lack of detailed information, the response to these	
Will habitat of the Proposed Development site be restored on decommissioning?	No	No	No		

Online calculator reference: 26V5-PSFS-4V3I					
0.4Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				questions 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.	
Choice of methodology for calculating emission factors	Site specific			As required for planning applications.	

12.8 Detailed Methodology Statements

12.8.1 Table 12.2 details the site-based parameters and conversion factors used for the baseline assessment and Table 12.4 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

12.8.2 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.

12.8.3 Cores were taken at 15 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 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 = 3.4, count 14)

Calculate the average Von Post scores for catotelm layer (mean = 4.9, count 7)

Calculate an average weighted Von Post score, using the average depth of acrotelm and catotelm to weight the score (weighted average score = 4.0)

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

12.8.4 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)

12.8.5 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).

12.8.6 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.

12.9 Results of Carbon Balance Assessment

Baseline Conditions

12.9.1 It is not easy to set a simple baseline for the climate change impact of development projects because each individual project has a very small overall impact on a very large global atmospheric pool of

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

12.9.2 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.

12.9.3 Table 12.5 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 12.5 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)	4,154,000	3,831,000	4,489,000
Estimated amount of carbon in soils (tC)	207,000	131,000	306,000
Estimated equivalent emissions of CO_2 (tCO_2)	761,000	482,000	1,124,000

12.9.4 Table 12.5 shows that there are approximately 0.2 million tonnes of stored carbon onsite and if this were fully oxidised, this would equate to approximately 0.8 million tonnes of CO_2 emissions. It is hard to assess the future of this stored carbon onsite 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

12.9.5 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.

12.9.6 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 12.6 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 + batteries and construction materials	58,723	49,739	68,635	61.6%
CO_2 loss from excavated peat	-7,616	-7,079	-9,121	-8.0%
Subtotal of emissions during construction	**51,107**	**42,660**	**59,514**	**53.6%**

12.9.7 Table 12.6 shows that in total approximately 54% of the total losses occur during the Proposed Development construction phase. In fact, approximately 62% of total losses come from the manufacture of the turbines and the batteries, with a small proportion due to other materials used in construction (for example concrete for foundations) but these are reduced by the negative losses of excavated peat. The reason that this negative result occurs is that the Carbon Calculator is not really designed for sites with shallow peat deposits as the results indicate that the excavation of peat (around 6,500 m^3) produces fewer GHG emissions than leaving it in situ (as indicated by the negative emissions). This is because peat bogs release both methane and carbon dioxide, as well as sequestering carbon, while excavated peat is assumed to decompose to just carbon dioxide. Since methane is a much more potent GHG, the emissions of a shallow peat deposit in situ are estimated to be higher.

Table 12.7 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	35,762	35,762	35,762	37.5%
Losses due to reduced carbon fixing potential	8,393	3,112	17,625	8.8%
Losses due to Dissolved Organic Carbon (DOC) & Particulate Organic Carbon (POC) leaching	72	-	187	0.1%
CO_2 loss from drained peat	-	-	-	0.0%
Subtotal of emissions during operation	**44,227**	**38,874**	**53,574**	**46.4%**

12.9.8 Table 12.7 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, however this has been reduced by the inclusion of battery storage on site, which helps reduce the requirement for grid back-up elsewhere. Losses from reduced carbon fixing potential and from DOC/POC leaching make up a further 9%. There are no predicted losses from draining the peat due to the shallow peat deposits, especially around the infrastructure.

12.9.9 Emissions produced during the decommissioning phase are not included separately in the Carbon Calculator assessment, although an 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.

12.9.10 The assessment of the emissions due to construction and operation of the windfarm indicate that site-based carbon losses are minimal; it is the lifecycle of the turbines and batteries and the requirement to provide backup power to the grid for intermittent generation that contribute the bulk of the emissions from the Proposed Development. While lifecycle emissions from the turbines and batteries 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.

Carbon Balance Assessment – Gains

12.9.11 Table 12.8 shows the estimated carbon gains over the lifetime of the Proposed Development from re-wetting two areas close to the centre of the Site which are proposed for enhancement of existing marshy grassland/ heath and degraded bog habitat (EIA Report Appendix 6.6: Outline Restoration and Enhancement Plan refers). The gains from restoration are negative because they are 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 re-wetting of peat.

Table 12.8 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	-5,713	-	-11,168	100.0%
Total estimated gains	**-5,713**	**-**	**-11,168**	**100%**

Comparison with the Baseline

12.9.1 The soil carbon losses from the Proposed Development are estimated at around 849 tonnes of CO_2e. This represents 0.1 % of the estimated total stored carbon onsite (as set out in Table 12.5) and includes losses due to leaching and losses from reduced carbon fixing potential. The avoidance of peat deposits when designing the infrastructure layout has meant that the soil carbon losses for the Proposed Development are predicted to be minimal.

Comparison of Soil Carbon Losses with Carbon Gains from Restoration

12.9.2 Table 12.9 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 12.9 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	-7,616	Change in emissions due to improvement of degraded bogs -	-5,713
CO_2 loss from drained peat	-		
Losses due to reduced carbon fixing potential	8,393		
Losses due to Dissolved Organic Carbon (DOC) & Particulate Organic Carbon (POC) leaching	72		
Total soil carbon losses	**849**	**Total restoration gains**	**-5,713**

12.9.3 Table 12.9 shows that the ratio between soil carbon loss and restoration gains is positive; there are far more gains predicted than losses from soil carbon.

Carbon Balance Assessment – Savings

12.9.4 Table 12.10 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 12.10 looks at the impact of grid decarbonisation on the payback period of the Proposed Development.

Table 12.10 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	257,848	242,681	273,964
Grid-mix of electricity generation	49,763	46,836	52,873
Fossil fuel - mix of electricity generation	111,168	104,629	118,116
Counterfactual emission factor – lifetime savings	**Estimated savings (tCO_2e over lifetime)**		
Coal-fired electricity generation	9,024,680	8,493,835	9,588,740
Grid-mix of electricity generation	1,741,705	1,639,260	1,850,555
Fossil fuel - mix of electricity generation	3,890,880	3,662,015	4,134,060

Payback Time and Carbon Intensity

12.9.5 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.

12.9.6 Table 12.11 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 the carbon intensity of the units produced.

Table 12.11 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	0.3	0.2	0.5
Grid-mix of electricity generation	1.8	1.3	2.5
Fossil fuel - mix of electricity generation	0.8	0.6	1.1
Carbon intensity of electricity generated	**Carbon intensity ($kgCO_2e/kWh$)**		

Counterfactual emission factor	Estimated time to payback (years)		
	Expected	Minimum	Maximum
Carbon intensity based on grid-mix	0.010	0.007	0.014

12.9.7 Table 12.11 shows that the Proposed Development is estimated to have a payback of 1.8 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.

Sensitivity analysis

12.9.8 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 three of the key site parameters on the payback time under a grid mix counterfactual emission factor, whilst holding all other parameters constant, as shown in Table 12.12.

Table 12.12 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) – 38m, impact of decreasing and increasing by 50%	1.8	1.7	1.9
Average water table depth at site (m) – 0.13m, impact of decreasing and increasing by 50%	1.8	1.8	1.7
Dry soil bulk density (g cm^{-3}) – 0.11m, impact of decreasing and increasing by 50%	1.8	1.8	1.8

12.9.9 Table 12.12 shows that varying the three site-based parameters by 50% has minimal impact on the overall expected payback predicted by the Carbon Calculator.

12.10 Impact of Electricity Grid Decarbonisation

12.10.1 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-mix 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.

12.10.2 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 2062) 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 1.8 years to 12.5 years. However, this would not affect the carbon intensity of the project, estimated at 0.01 $kgCO_2e/kWh$, 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.

12.11 Summary

12.11.1 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 50,000 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.

12.11.2 The assessment of the Proposed Development estimates losses of around 90,000 tonnes of CO_2e, nearly all of which come from the lifecycle emissions of the turbines and the batteries. Ecological carbon losses account for only 1% of the total losses resulting from the Proposed Development construction and operation activities, and the baseline assessment demonstrated that only 0.1% of the soil carbon within the Site would be lost. Re-wetting of degraded peat bogs on the Site are estimated to produce gains over the lifetime of the wind farm of around 5,700 tonnes of CO_2e.

12.11.3 The estimated payback time of the Proposed Development, using the Scottish Government Carbon Calculator, is 1.8 years, with a minimum/maximum range of 1.3 to 2.5 years. There are no current guidelines about what payback time constitutes a significant impact, but 1.8 years is around 5% 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 low carbon footprint, and after 1.8 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 0.01 $kgCO_2e/kWh$. This is well below the outcome indicator for maintaining the electricity grid carbon intensity below 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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