Technical Appendix 4.7: Carbon Balance Assessment

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Executive Summary

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 the Appin Wind Farm (hereafter referred to as the Proposed Development) over its 50-year lifetime, including embodied emissions from the infrastructure and reduction of stored carbon in forestry and peat on site. It should be noted that at the current time (as of 01/10/24), the online Carbon Calculator is not available on the SEPA website and therefore the excel version of the tool has been used to produce these results – the excel version produces almost identical results to the currently unavailable web tool.

The results of the Carbon Calculator show that the Proposed Development is estimated to produce annual carbon savings of around 64,000 tonnes of CO_2e per year, through the displacement of grid electricity, based on the current fossil fuel grid mix. Displacement of existing sources of generating capacity depends on the time of day and how the grid needs to be balanced.

The assessment estimates losses of around 119,000 tonnes of CO_2e, mainly due to off-site activities such as the manufacture of the turbines and provision of grid backup from fossil fuel sources. Overall ecological carbon losses are estimated at around 26,000 tCO_2e, the majority of which come from permanent and temporary felling of existing forestry which reduces future sequestration over the lifetime of the Proposed Development. However, this is an overestimate of losses of ecological carbon because the Carbon Calculator does not account for the carbon that will be gained from replanting temporary felled areas or new compensatory woodland that replaces permanent felling. There is a small gain of around (-) 800 tonnes of CO_2e predicted from the restoration of degraded peatland.

The estimated payback time of the Proposed Development, using the Scottish Government Carbon Calculator, is 1.8 years, with a minimum/maximum range of 1.5 to 2.6 years. 1.8 years is around 3.6% of the anticipated lifespan of the Proposed Development (50 years). 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 less than two years the electricity generated is estimated to be carbon neutral and should displace grid electricity generated from fossil fuel sources. The carbon intensity of the electricity produced by the Proposed Development is estimated at 0.009 $kgCO_2e/kWh$. 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 emissions associated with energy production.

Introduction

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, 28% of electricity was generated from fossil fuels in 2024 (Department for Energy Security and Net Zero, 2025). 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' statutory emission reduction targets.

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.

In addition to the lifecycle emissions from the turbines and associated wind farm infrastructure, where a wind farm displaces other carbon storing or sequestering activity such as woodland, or there are other carbon stores that are disturbed such as peat bogs, there are potential emissions resulting from this displacement. Carbon losses and gains during the construction and lifetime of a wind farm, and the long-term impacts on the locations on which they are sited, need to be evaluated to understand the consequences of permitting such developments.

The aim of this Technical Appendix is to provide clear information about the whole life carbon balance of the Proposed Development. This Technical Appendix 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.

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.

Legislation, Policy and Guidelines

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

Legislation

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 compared to the 1990 baseline.

Policy

The Clean Power 2030 Action Plan which was published at the end of 2024 emphasises that all routes to a Clean Power system by 2030 (defined as using clean sources to generate as much power as Great Britian consumes) will require mass deployment of offshore wind, onshore wind, and solar but also states that 'new energy infrastructure should be built in a way that protects the natural environment by following a "mitigation hierarchy" to do what is possible to avoid damage to nature, and then minimising, restoring and delivering compensation when damage is impossible to avoid.

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.

The Scottish Energy Strategy (Scottish Government, 2017) set a whole-system target to supply the equivalent of 50% of all the energy for Scotland's heat, transport, and electricity consumption from renewable sources by 2030. The 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 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.

National Planning Framework 4 (NPF4) (Scottish Government, 2023) sets the national spatial strategy for Scotland, including spatial principles, regional priorities, national developments, and national planning policy.

Policy 1 states:

> *"When considering all development proposals significant weight will be given to the global climate and nature crises."*

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."

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.

At a local level, the Supplementary Guidance to the Local Development Plan 2 for Dumfries and Galloway on wind farm development: Development Management Considerations (Dumfries and Galloway Council, 2020) states that:

> *"…the generation of heat and electricity from renewable energy sources are vital to reducing greenhouse gas emissions. SPP requires that the planning system facilitates the transition to a low carbon economy and supports the Scottish Government targets for meeting electricity and heat demand from renewable sources. The extent to which development proposals help to achieve these targets is a material consideration in the determination of applications."*

However other impacts and considerations include carbon rich soils. The Guidance states that:

> *"Wind farms may be successfully accommodated in areas of peatland where environmental constraints can be addressed, where disturbance to deep peat can be minimised and restoration opportunities maximised. However, siting wind farms on deep peat, even where peat vegetation is not currently dominant, can significantly undermine carbon benefits of renewable energy and prevent the full restoration of important tracts of peatland habitat through drainage impacts of turbine foundations and tracks, causing long- term disruption to hydrology. It is appropriate that constraints are considered at an early stage of development i.e. at site selection, to ensure wind farms are steered towards areas where constraints are likely to be lowest."*

Guidance

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 Technical Appendix.

Assessment Methodology

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

The stored carbon within the Site was estimated from the average peat depth, estimated from the Peat Management Plan (PMP) using the average of the Phase 1 (100 m grid) peat probes only (which provides systematic and uniform sampling) to estimate average depth. It should be noted that this recommended methodology for estimating average peat depth across the site is likely to overestimate the quantity of peat at this site as the peat was unevenly distributed and concentrated in three main areas as noted in Technical Appendix 9.2: Peat Survey Report. The estimated peat volume was multiplied by the estimated percentage of carbon content and dry soil bulk density to get an estimate of stored carbon. 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 4.7.1 shows the parameters used to estimate the baseline of stored carbon.

Table 4.7.1 Parameters used to estimate baseline stored carbon within the Site

Parameter	Expected	Minimum	Maximum
Size of site based on red line boundary (ha)	350	333	368
Average peat depth across site (m)	0.15	0.13	0.17
Carbon content of dry peat (% by weight)	56%	49%	62%
Dry soil bulk density (g/cm^3)	0.13	0.07	0.29

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

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 or forestry. 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 a proposed wind farm on predicted emissions from construction materials and grid backup and losses and gains of stored carbon, including within forestry, but does exclude minor sources such as result of traffic generated during construction or operation.

The most recent version of the Carbon Calculator (v1.8.1) 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. However, as of 01/10/24, the online version is not accessible and there is no published timeframe for when the online version will be available again. Therefore, this Technical Appendix has used the Excel version of the tool (v2.14.1) which produces the same results as the online tool.

Table 4.7.3 at the end of this section outlines the input parameters used in the Carbon Calculator. Individual aspects of the methodology will be discussed further within this Technical Appendix, in the context of actual inputs and outputs of the model.

Scope of Carbon Calculator

Table 4.7.2 shows the following potential emission sources, and savings, of carbon emissions from the three key project stages that are covered by the Carbon Balance Assessment.

Table 0.2 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, batteries and concrete required for foundations. The turbine and battery Lifecycle Carbon Assessment (LCA) values are taken from	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.

Project phase	Included in assessment	Excluded from assessment
	the literature and put into the carbon calculator as direct input of values.	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 savings resulting from the generation of electricity by wind turbines and displacement of grid electricity generated by fossil fuels.	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 emissions resulting from the provision of back up generation within the UK electricity grid for intermittent renewable sources.	
	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 Development resulting from the loss of active carbon-absorbing bog and forestry habitat.	Carbon emissions from the use of plant, equipment and materials from the site restoration – these are not included in the boundary of the LCA or explicitly within the carbon calculator.
	Carbon gains from the restoration of peat bog on site.	Carbon gains from any compensatory planting of forestry and additional planting to achieve biodiversity enhancement.
Decommissioning	Carbon emissions from the dismantling and disposal of turbines and associated infrastructure, including transport, 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

The temporal scope for savings is set as the same period as the anticipated lifespan of the Proposed Development, i.e., 50 years.

Study Area

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 forestry 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.

Significance Criteria

In determining whether an application to build and operate a wind farm should be granted consent; the assessment of potential carbon losses and savings is a material consideration for the determining authority. 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 4.7.3 Input parameters used in the Carbon Calculator

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Wind Farm Characteristics					
Dimensions					
No. of turbines	9	9	9	Chapter 4: Description of the Proposed Development states that the Proposed Development will be up to nine variable pitch (three bladed) turbines, each with a maximum blade tip height of up to 200 m.	None
Lifetime of wind farm (years)	50	50	50	Chapter 4 states that the Proposed Development has been designed with an operational life of up to 50 years at the end of which it would be decommissioned, or an application may be submitted to extend the operational period or repower the Site.	None
Performance					
Turbine capacity (MW)	7.2	7.2	7.2	Chapter 4 states that it is anticipated that the turbines would be rated at approximately 7.2 MW, depending upon the dimensions of the selected turbines. A realistic minimum capacity for electricity generation by the Proposed Development would be in the region of 64.8 MW based on current turbine availability.	None

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Capacity factor – using direct input of capacity factor (percentage efficiency)	44.8	42.6	47.0	Based the Contract for Difference (Standard Terms) Regulations that states that the load factor for new build projects (for delivery years 2026-2029) is 44.8% for onshore wind (>5MW) (DESNZ, 2014).	A range of +/- 5% has been used to calculate the likely minimum and maximum.
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 2023, Scotland generated 53% via onshore wind (DESNZ, 2024).	This parameter assumes there is no significant improvement in demand side management or energy storage for intermittent generation over the lifetime of the windfarm.
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. This parameter is not used as the % of back up required is set to zero.	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			The client has stated that the candidate turbine for assessment purposes is the Vestas V162. There is a Lifecycle Assessment available for a Vestas onshore V162-6.2 MW wind plant (Vestas, 2022).	

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Total CO_2 emission from turbine life (tCO_2 MW^{-1})	487	438	535	The LCA assessment is in units of gCO_2e per kWh generated of electricity over the assessment time period of 20-year design life. These have been converted to tCO_2e per MWh and then scaled to electricity generation over 50 years in order to not overestimate the emissions for the longer lifetime of the Proposed Development.	A range of +/- 10% has been used to calculate the likely minimum and maximum.
Characteristics of peat land before wind farm development					
Type of peat land	Acid Bog	Acid Bog	Acid Bog	There are only two options, of which one has to be selected within the Carbon Calculator; acid bog and fen. The hydrology and ecology teams have confirmed that acid bog is the most appropriate classification for this site.	None
Average air temperature at site (°C)	8.5	8.3	8.7	Based on average annual temperature data for West Scotland for the time period 2005 – 2024. The data is sourced from the Meteorological Office (2025). Mean: 8.5 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 parameter is not included in the sensitivity analysis.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average depth of peat at the site (m)	0.15	0.13	0.17	Peat probing was carried out across the Site in accordance with the Scottish Government's Guidance on Developments on Peatland. Phase 1 probing on a 100 m grid was undertaken from September to October 2021 and in November 2022 and only these probes are used in the estimate of average peat depth in order to get a systematic and uniform sampling method. Mean: 0.15 Count: 670 Standard Error: 0.01	A 95% confidence level has been calculated as the mean +/- 2 SE to estimate the likely minimum and maximum values of the range.
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)	10	7.5	12.5	The hydrology and ecology teams have confirmed that 10 m is a reasonable estimate of drainage distance at this site due to the shallow peat deposits.	A range of +/- 25 % has been used to calculate the likely minimum and maximum.
Average water table depth at site (m)	0.15	0.14	0.17	The PMP states that an assumption has been made that the upper 0.3 m of the peat profile is assumed to be acrotelm and any remaining depth is assumed to be catotelm. It is assumed that the water table would sit on average around the middle of the acrotelm and therefore	A range of +/- 10 % has been used to calculate the likely minimum and maximum.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				an estimated water table depth of 0.15 m has been assumed for the site.	
Dry soil bulk density (g/cm^3)	0.132	0.072	0.293	The default values for dry soil bulk density of peat provided in the Carbon Calculator have been used. Expected = 0.132 g/cm^3 Minimum = 0.072 g/cm^3 Maximum = 0.293 g/cm^3	The range suggested in the Carbon Calculator has been used.
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	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

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
(t C ha-1 yr-1)					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)	62.52	56.27	68.77	Chapter 4 states that a total of 62.52 ha will require to be felled including 22.03 ha of permanent felling and 40.73 ha of temporary felling to enable the construction and operation of the Proposed Development. To assess the worst case scenario, this area includes both the permanent and the temporary felled areas even though the temporary felled area will be replanted on the site and the permanently felled area would have equivalent compensatory planting elsewhere, and therefore the total area felled will effectively be replaced.	A range of +/- 10 % has been used to calculate the likely minimum and maximum.
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	1.92	1.73	2.12	Chapter 4 states that the forest is comprised largely of commercial conifers with small areas of mixed broadleaves and open ground planted in the late 1990s. For the purposes of this assessment, it has been assumed that this area consists of mixed conifers that are on	A range of +/- 10 % has been used to calculate the likely minimum and maximum.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				average 30 years old (Yield class 12, 1.5 spacing, no thin management). The Woodland Carbon Calculation Spreadsheet (April 2024) provides an estimate of total annual carbon sequestered (in tCO_2e/ha/year) for each 5-year age period. The average annual sequestration rate has been looked up for the next 50 years. The CO_2e is converted to C by dividing by 3.67.	
Counterfactual emission factors					
Coal-fired plant emission factor (tCO_2 MWh^{-1})	0.945	0.945	0.945	Fixed counterfactual emission factors are provided in the Carbon Calculator and cannot be altered. 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})	0.207	0.207	0.207		
Fossil fuel- mix emission factor (tCO_2 MWh^{-1})	0.424	0.424	0.424		
Borrow Pits					
Number of borrow pits	3	3	3	Chapter 4 states that the infrastructure will include up to three borrow pits.	None.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average length of pits (m)	75	71	79	Chapter 4 states that the total search area for all three borrow pits will measure approximately 16,888 m^2. The dimensions have been estimated as the square root of this area, divided by 3.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Average width of pits (m)	75	71	79		
Average depth of peat removed from pit (m)	0.0	0.0	0.0	The PMP indicates that there is no peat to be excavated in these areas, therefore this parameter has been set at zero.	No variance required.
Foundations and hard-standing area associated with each turbine					
Method used to calculate CO_2 loss from foundations and hard-standing	Rectangular, with vertical sides			The simple method of calculation for turbine foundations was used for this application.	None.
Average length of turbine foundations (m)	26.6	25.3	27.9	Chapter 4 states that the that the turbines would have gravity foundations laid using reinforced concrete and would have a diameter of approximately 30 m. This equates to a length and width of 26.6 m of the same-sized rectangle.	A range of + 5% has been used to calculate the likely expected and maximum values of both length and width.
Average width of turbine foundations (m)	26.6	25.3	27.9		
Average depth of peat removed from turbine foundations (m)	0.67	0.60	0.72	The volume of peat extracted for the turbine/hardstanding locations is taken from Table 4.1 in the PMP. The total volume is the sum of both permanent and temporary excavated peat for:	A range of +/- 10 % has been used to calculate the likely minimum and maximum.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				1) Hardstandings 2) Ancillary hardstanding 3) Fill earthworks 4) Cut earthworks The average peat depth is calculated as the total volume divided by the sum of the area for turbines/hardstanding.	
Average length of hard-standing (m)	80	76	84	Chapter 4 states that turbines would be erected using mobile cranes brought on to the Site for the construction phase. A crane hardstanding would be built adjacent to each turbine and is likely to have a footprint of approximately 30 m x 80 m.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Average width of hard-standing (m)	30	29	32		
Average depth of peat removed from hard-standing (m)	0.67	0.60	0.72	See above for method of calculating the average peat depth at the turbine/hardstanding.	No variance required.
Volume of concrete used in entire area (m3)	25,434	22,891	27,977	Chapter 4 states the turbines would have gravity foundations laid using reinforced concrete and would have a diameter of approximately 30 m. The depth of the foundation excavation would depend on the need to reach suitable ground. Excavations would be on average approximately 4 m deep. Therefore, it assumed that the concrete volume required for each foundation would be required to fill a cylinder of diameter 30 m and depth 4 m.	A range of +/- 10% has been used to calculate the minimum and maximum.
Access tracks					

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Total length of access track (m)	27,700	26,315	29,085	Chapter 4 states that approximately 13 km of new access track with a typical running width of 5 m (wider on bends) and 14.8 km of upgraded existing access track (widened to 5 m).	A range of +/- 5% has been used to calculate the minimum and maximum.
Existing track length (m)	0	0	0	Since the existing track will require some upgrading and has been included in the calculation of permanent land take, it has been included in the excavated road calculations rather than in the existing track length	A range of +/- 5% has been used to calculate the minimum and maximum.
Length of access track that is floating road (m)	0	0	0	All new and existing track is designed on the basis of cut rather than floating.	None.
Length of access track that is excavated road (m)	27,700	26,315	29,085	See above.	A range of +/- 5% has been used to calculate the likely minimum and maximum.
Excavated road width (m)	5.0	4.5	5.5	Chapter 4 states that tracks would be unpaved and constructed of a graded local stone with a typical running width of 5 m. Adjacent to this track will be an assumed 1 m width verge at either side for cabling and drainage, subject to local ground conditions. Track widths may vary in some sections to accommodate bends in the track alignment. To accommodate the combination of new and upgraded track, it has been assumed that the upgraded track requires additional excavation of 3 meters, while the new	A range of +/- 10% has been used to calculate the likely minimum and maximum

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				track requires a width of 6.8 m. This produces an average estimated width of 5m.	
Average depth of peat excavated for road (m)	0.06	0.05	0.07	The volume of peat excavated from tracks has been taken from PMP excavation calculations. The volume of peat was divided by estimated infrastructure area to get an average peat depth removed. It should be noted in reality that this is not a thin layer across the infrastructure but a few smaller pockets of peat. However, the Carbon Calculator only allows an average peat depth across the infrastructure to be entered.	A range of +/- 20% has been used to calculate the likely minimum and maximum
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 underground power cables would run along the side of the access tracks in trenches from each of the turbines to the substation.	Assume all cable trenches follow access track routes.
Additional peat excavated (not accounted for above)					
Volume of additional peat excavated (m^3)	3,726	3,353	4,099	The volume of additional peat extracted is taken from Table 4.1 in the PMP. The total volume is the sum of both permanent and temporary excavated peat for: 1) Clearance areas *2)* Substation	A range of +/- 10% has been used to calculate the likely minimum and maximum.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Area of additional peat excavated (m^2)	4,503	4,278	4,728	The area of additional peat excavated is assumed to be the area of the three compounds listed in Chapter 4. While not all of these are located on peat, they have been included for completeness. 1) On-site substation compound 2) SPEN construction compound *3)* Temporary construction compound	A range of +/- 5% has been used to calculate the likely minimum and maximum.
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)	23.0	20.7	25.3	Area of restoration based on Figure 7.12 Outline Nature Enhancement Management Plan. This is area covered by the 10m benefits around proposed ditch blocking for rewetting.	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 0.1 m.	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	12.5	10	15	Recommended by the Ecology team, although water table can increase rapidly after ditch blocking, noticeable	The minimum range has been set at 10 years and the

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
previous state on improvement (years)				restoration resulting in changes to botanical flora composition should be a more precautionary 10 years.	expected/maximum value have been set at +25% and +50%.
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	50	50	50	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 (50 years), the period of time when the improvement can be guaranteed should be entered as 50 years.	None.
Improvement of felled plantation land					
Area of felled plantation to be improved (ha)	0	0	0	There is no planned restoration of forest to bog at this site and therefore this section is not required.	No variance required.
Restoration of peat removed from borrow pits					
Area of borrow pits to be restored (ha)	0	0	0	The PMP states that, while the borrow pits were proposed for reinstatement, they are far from areas of peat and located within steep slopes, so have been excluded for peat reuse.	No variance required.
Early removal of drainage from foundations and hardstanding					
Removal of drainage from foundations and hardstanding	0	0	0	There is no mention of removal of drainage from foundations and hardstanding post-construction so it assumed that this will remain in place to facilitate access for maintenance.	No variance required.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Restoration of Application Site after decommissioning					
Will hydrology of the Proposed Development site be restored on decommissioning?	No	No	No	Chapter 4 states that at the end of its operational life, which would be defined by condition on the grant of any consent, the Proposed Development would be decommissioned unless an application is submitted to extend the operational period or to repower the Site. The decommissioning period would be expected to take up to one year. The ultimate decommissioning protocol would be agreed with DGC and other appropriate regulatory authorities in line with best practice guidance and requirements of the time. This would be done through the preparation and agreement of a Decommissioning, Restoration and Aftercare Strategy in line with current legislation, guidance, policy at that time. Therefore, the response to this question has been marked as 'no' as a worst case scenario. However, it should be noted, changing this response has no impact on the overall carbon payback at this site.	None
Will habitat of the Proposed Development site be restored on decommissioning?	No	No	No		
Choice of methodology for calculating emission factors	Site specific			As required for planning applications.	

Results of Carbon Balance Assessment

Baseline Conditions

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.

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 onsite under existing conditions, as this will enable the percentage loss of this carbon through the Proposed Development to be estimated.

Table 4.7.4 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 4.7.4 Estimated Stored Carbon in Peat at the Site

Parameter	Expected	Minimum	Maximum
Estimated volume of peat (m^3)	525,000	429,000	628,000
Estimated amount of carbon in soils (tC)	38,000	15,000	114,000
Estimated equivalent emissions of CO_2 (tCO_2)	141,000	56,000	419,000

Table 4.7.4 shows that there are approximately 0.5 million tonnes of peat onsite and if this were fully oxidised, this would equate to approximately 141,000 tonnes of CO_2 emissions. It is difficult to assess the future of this stored carbon 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

The results from the Carbon Balance Assessment have been divided into losses from activities resulting in the emission of carbon and savings from the avoidance of carbon emissions by displacing grid electricity from other fuel sources.

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 sources of emissions such as loss of future forest sequestration, it is difficult to be precise about when they will occur in the Proposed Development life cycle.

Table 4.7.5 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 lifecycle and construction materials	32,802	29,522	36,082	27.6%
CO_2 loss from excavated peat	-720	-4,020	14,303	-0.61%

Emission source	Estimated emissions (tCO_2e)			% of overall emissions (expected scenario)
	Expected	Minimum	Maximum	
Subtotal of emissions during construction	**32,081**	**25,502**	**50,385**	**27.0%**

Table 4.7.5 shows that in total approximately 27% of the total losses occur during the Proposed Development construction phase. The majority of these are from the turbine lifecycle, with a small proportion due to other materials used in construction (for example concrete for foundations). The excavation of relatively shallow peat for the foundations and hardstanding and access track is predicted as a negative number. The reason that this negative result occurs is that the Carbon Calculator recognises that the infrastructure is planned on areas with minimal peat deposits and therefore excavation of this peat (estimated at approximately 31,000 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 0.6 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	60,171	60,171	60,171	50.6%
Losses due to carbon fixing potential	4,503	1,687	9,118	3.8%
Losses due to Dissolved Organic Carbon (DOC) & Particulate Organic Carbon (POC) leaching	55	13	108	0.05%
CO_2 loss from drained peat	-	-	-	0.0%
Losses due to felling forestry	22,009	17,848	26,732	18.5%
Subtotal of emissions during operation	**86,737**	**79,719**	**96,128**	**73.0%**

Table 4.7.6 shows that 73% of the emissions occur during the operational phase of the Proposed Development. The requirement for back-up power in the grid, which is assumed to come from a fossil fuel source, is the largest source of losses but this is an estimate based on very broad assumptions, including limited energy storage within the grid and no change in demand management. The other significant source is lost future carbon fixing potential both from vegetation covered by the infrastructure footprint and forestry that is permanently or temporarily felled. However, the Carbon Calculator does not account for replanting of woodland and therefore these losses are likely to be overestimated over the lifetime of the Proposed Development as all the temporary felled area will be replanted on site and an area equivalent to the permanently felled area will be subject to compensatory planting offsite. Therefore, the loss in sequestration potential over the lifetime of the Proposed Development is likely to be an overestimate and in fact the forestry replanting could result in an overall gain rather than loss.

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.

Carbon Balance Assessment – Gains

Table 4.7.7 shows the estimated carbon gains over the lifetime of the Proposed Development from restoration of degraded bog. The gains are negative because they are atmospheric removals or avoided emissions. It should be noted that the Carbon Calculator is conservative about estimating the gains from restoration and other biodiversity enhancement measures such as native woodland planting and any compensatory planting required, and therefore only accounts for changes in the balance of methane to carbon dioxide emissions from the restoration of degraded bogs. 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 4.7.7 – 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	-889	-212	-1,795	100.0%

Comparison with the Baseline

The soil carbon losses from the Proposed Development are estimated at around -4,000 tCO_2e. This represents 2.7 % of the estimated total stored carbon onsite (as set out in Table 4.7.4). Therefore, the Carbon Calculator does not assess the Proposed Development to have a significant impact on soil carbon at the site.

Comparison of Soil Carbon Losses with Carbon Gains from Restoration

Table 4.7.8 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 4.7.8 shows that overall, there is a net loss of around 3,000 tCO_2e from soil carbon. The restoration gains are lower than losses but as stated in the Section above on Carbon Balance - Gains, the Carbon Calculator is conservative about estimating restoration gains, and conversely, it assumes that all the excavated peat will be lost, whereas following good restoration practice, a proportion of this peat should be restored across the site.

Table 4.7.8 – 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	-720	Change in emissions due to improvement of degraded bogs	-889
Losses due to reduced carbon fixing potential	4,503	-	-
Losses due to Dissolved Organic Carbon (DOC) & Particulate Organic Carbon (POC) leaching	55	-	-
Total soil carbon losses	**3,837**	**Total restoration gains**	**-889**

Carbon Balance Assessment – Savings

Table 4.7.9 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 from September 2024 when the UK's last coal power station closed, there is no more 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. The fossil fuel mix represents displacement of existing fossil fuel electricity generation plant, the majority of which uses natural gas which is planned to be removed over the lifetime of the Proposed Development. However, to meet Net Zero targets, renewable electricity will be required to displace existing transport (diesel and petrol) and heating (natural gas and burning oil) fuels and therefore, the fossil fuel mix is probably the closest representation of the energy that the Proposed Development's generated electricity would be displacing.

Table 4.7.9 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	142,690	127,133	153,418
Grid-mix of electricity generation	31,256	27,848	33,606
Fossil fuel - mix of electricity generation	**64,022**	**57,042**	**68,835**
Counterfactual emission factor – lifetime savings (50 years)	**Estimated savings (tCO_2e over lifetime)**		
Coal-fired electricity generation	7,134,500	6,356,650	7,670,900
Grid-mix of electricity generation	1,562,800	1,392,400	1,680,300
Fossil fuel - mix of electricity generation	**3,201,100**	**2,852,100**	**3,441,750**

Payback Time and Carbon Intensity

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.

Table 4.7.10 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 4.7.10 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	0.8	0.7	1.2
Grid-mix of electricity generation	3.8	3.1	5.3
Fossil fuel - mix of electricity generation	**1.8**	**1.5**	**2.6**
Carbon intensity of electricity generated	**Carbon intensity (kgCO_2e/kWh)**		
Carbon intensity of units generated	0.009	0.008	0.012

Table 4.7.10 shows that the Proposed Development is estimated to have a payback of 1.8 years based on the fossil fuel mix and the carbon intensity of units produced would be significantly lower than the current grid mix (the value of 0.207 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

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 in Table 4.7.11 shows the impact of varying three of the key parameters on the payback time under a fossil fuel mix counterfactual emission factor, whilst holding all other parameters constant.

Table 4.7.11 Impact of changing individual parameters on expected payback in years

Sensitivity analysis	Estimated time to payback (years) (based on expected scenario, fossil fuel mix electricity factor)		
	As assessed: Expected	Decrease by 50%	Increase by 50%
Extra capacity required for backup (%)	1.8	1.4	-
Average rate of carbon sequestration in timber (tC ha-1 yr-1) – 1.92 tC ha-1 yr-1	1.8	1.7	2.0
Average extent of drainage around drainage features at Site (m) – 10m	1.8	1.8	1.9

Table 4.7.11 shows that decreasing or increasing the average extent of drainage by 50% has very little impact on the overall payback of the site. This is mainly due to the avoidance of peat by the infrastructure layout. The rate of carbon sequestration in forestry has a slightly larger impact but still only adds or removes around one month

to the payback. Reducing the grid backup requirement percentage has a noticeable impact on payback but the suggested range within the carbon calculator is between 0 and 5% and therefore it unlikely that this would be any higher than 5%, providing an upper limit to this parameter. It is likely that over the lifetime of the windfarm, changes to grid infrastructure, storage and demand balancing would all reduce the requirement for grid backup from its current estimate of 5%, thereby reducing the emissions from the Proposed Development.

Summary

The results of the Carbon Calculator show that the Proposed Development is estimated to produce annual carbon savings of around 64,000 tonnes of CO_2e per year, through the displacement of grid electricity, based on the current fossil fuel grid mix. Displacement of existing sources of generating capacity depends on the time of day and how the grid needs to be balanced.

The assessment of the Proposed Development estimates losses of around 119,000 tonnes of CO_2e, mainly due to off-site activities such as the manufacture of the turbines and provision of grid backup from fossil fuel sources. Overall ecological carbon losses are estimated at around 26,000 tCO_2e, the majority of which come from a temporary and permanent felling of forestry which is calculated to reduce future sequestration over the lifetime of the Proposed Development. However, this does not account for replanting of new woodland areas both on and off site that are equal is size and will start to sequester carbon over the lifetime of the Proposed Development. There is a small gain of around (-) 800 tonnes of CO_2e predicted from the restoration of degraded peatland.

The estimated payback time of the Proposed Development, using the Scottish Government Carbon Calculator, is 1.8 years, with a minimum/maximum range of 1.5 to 2.6 years. There are no current guidelines about what payback time constitutes a significant impact, but 1.8 years is around 3.6% 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 less than two years the electricity generated is estimated to be carbon neutral and should displace grid electricity generated from fossil fuel sources. The carbon intensity of the electricity produced by the Proposed Development is estimated at 0.009 $kgCO_2$e/kWh. This is well below the outcome indicator for maintaining the electricity grid carbon intensity below 0.05 $kgCO_2$e/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 emissions associated with energy production.

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