16 Climate Change and Carbon Calculator

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16 Climate Change and Carbon Calculator

16.1 Introduction

16.1.1 The Carbon Balance Assessment has been undertaken by Fluid Environmental Consulting.

16.1.2 Increasing atmospheric concentrations of greenhouse gases (GHGs), including carbon dioxide (CO_2) – also referred to as carbon emissions – is resulting in climate change. A major contributor to this increase in GHG emissions is the burning of fossil fuels. With concern growing over climate change, reducing its cause is of utmost importance. The replacement of traditional fossil fuel power generation with renewable energy sources provides high potential for the reduction of GHG emissions. This is reflected in UK and Scottish Governments climate change and renewable energy policy.

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

16.1.4 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 also the indirect changes to hydrology that can result in losses of soil carbon. The footprint of a wind farm's infrastructure will also decrease the area covered by carbon-fixing vegetation. Conversely, restoration activities undertaken post-construction or post-decommissioning could have a beneficial effect on carbon uptake through the restoration of modified bog habitat. Carbon losses and gains during the construction and lifetime of a wind farm and the long term impacts on the peatlands on which they are sited need to be evaluated in order to understand the consequences of permitting such developments.

16.1.5 The aim of this Chapter 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. The Onshore Wind Energy Supplementary Guidance adopted by the Shetland Islands Council (2018) also states that where large scale wind energy development is proposed to be on peat it is expected that a carbon calculation will be used during the preparation of the proposal and it should be demonstrated that the whole life carbon balance of the proposals have been considered. This Chapter explains the policy basis for assessing carbon balance, explains the Scottish Government Carbon Calculator methodology used, details all the inputs into the model and provides an estimate of the expected net carbon savings over the lifetime of the Proposed Development, once carbon losses from materials and ecological disturbance have been taken into account, including a sensitivity analysis for key parameters.

16.2 Legislation, Policy and Guidelines

Legislation

16.2.1 One of the key drivers for the Scottish Government’s renewable targets is the Climate Change (Scotland) Act, 2009. The Act creates the statutory framework for greenhouse gas emissions reductions in Scotland by setting both an interim 42 % reduction target for 2020, and an 80 % reduction target for 2050. It is likely that the Climate Change (Emissions Reduction Targets) (Scotland) Bill, which is in process in the Scottish Parliament, will increase the 2050 target to a 90 % reduction. Decarbonisation of grid electricity through increasing the percentage of electricity generated by renewables is identified as one of the key ways to deliver early carbon reduction but the Climate Change (Scotland) Act also recognises the importance of carbon stores in peat and soils by incorporating a duty to produce a land use strategy.

16.2.2 As part of the UK, Scotland is also subject to the EU Directive 2009/28/EC which commits the EU to generate 20 % of all energy consumed from renewable sources by 2020. This has been translated to individual targets for Member States, depending on their starting points and potential capacity. The UK has a commitment to source 15 % of all energy from renewable resources; this has been translated into a target of 30 % of electricity from renewables by 2020, as renewable sources of other energy uses i.e. heat is potentially harder to tackle.

Policy

16.2.3 The Scottish Energy Strategy (Scottish Government, 2017) has set a new target for the Scottish Energy system to supply the equivalent of 30 % by 2020 and 50 % by 2030 of all the energy for Scotland's heat, transport and electricity consumption from renewable sources. The strategy also reiterates that one of Scotland's energy priorities is renewable and low carbon solutions. The strategy states that Scotland's electricity supply has been largely decarbonised; the target of generating 100 % of electricity demand from renewables in 2020 is ahead of target, and major new capacity is due to connect to the system in the coming years. However, Scottish Government analysis underpinning the 2030 target of 50 % of all energy coming from renewable sources, shows that renewable electricity generation could rise to over 140 % of Scottish electricity consumption, ensuring its contribution to the wider renewable energy target for 2030.

16.2.4 This assumes a considerably higher market penetration of renewable electricity than today – requiring in the region of 17 GW of installed capacity in 2030, compared to 10.5 GW in September 2018 (BEIS, 2018), in order to achieve decarbonisation of heat and transport (Scottish Government, 2017).

16.2.5 At the same time as increasing installed capacity of renewable generation, Scotland has also identified the need to minimise the environmental impacts on landscape, cultural heritage and environmental carbon stores. 'Getting the best from our land – A land-use strategy for Scotland' was produced in March 2011. This highlighted the need to balance maximising renewable generation through onshore wind farms whilst minimising the environmental impacts.

Guidance

16.2.6 One of the key impacts identified for onshore wind farms in Scotland is for sites on areas of peat, where stored carbon can be released through the extraction and drainage of these soils. In 2008 the Scottish Government funded a research report called Calculating carbon savings from wind farms on Scottish peat lands: a new approach (Nayak *et al*, 2008) and associated excel tool (referred to henceforth as the "Carbon Calculator") which utilises a life cycle methodology approach to estimating the wider emissions and savings of carbon associated with wind farms and for calculating how long the development will take to 'pay back' the carbon emitted during its construction. All new applications to the Energy Consents Unit are required to submit a completed Carbon Calculator. This methodology and approach is consistent with the Climate Change Mitigation & EIA Principles of the Institute of Environmental Management and Assessment (IEMA, 2010). The principles state that:

16.2.7 The assessment should aim to consider whole life effects including, but not limited to:

- embodied energy in the manufacture of materials used for the development;
- emissions related to construction - from materials delivery to on-site machinery;
- operational emissions related to the functioning of the development-including appropriate off-site emissions; and
- decommissioning, where relevant.

16.2.8 When evaluating significance, all new greenhouse gas (GHG) emissions contribute to adverse environmental effects; however, some projects will replace existing developments that have higher GHG profiles. The significance of a project's emissions should therefore be based on its net GHG impact, which may be beneficial or adverse.

16.2.9 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.

16.3 Methodology

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

16.3.2 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 greenhouse gas, 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 greenhouse gases emitted, or saved, at different project stages.

16.3.3 The temporal scope for savings is set as the same period as the lifespan of the planning consent for the operation of the Proposed Development, i.e. 30 years but, unless it is specified that the Proposed Development site will be restored with respect to hydrology and habitat upon decommissioning, the losses through the indirect effects on peat will continue on until the Carbon Calculator estimates that there is no more oxidisable peat within the vicinity of the infrastructure.

16.3.4 The climate change assessment will cover the following potential sources, and savings, of carbon emissions from the three key project stages:

Table 16.1 – Boundary of the Climate Change Assessment

Project phase	Included in assessment	Excluded from assessment
Construction	Carbon emissions resulting from the extraction, production and manufacture of turbine components. The exact boundary of the lifecycle assessment used is not known as it is the result of a number of different academic studies but it is assumed that it is a cradle to grave assessment including all stages from extraction of materials through to end of life disposal.	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 manufacture of concrete required for foundations	Carbon emissions resulting from the transport of labour to the construction-site.
	Carbon emissions resulting from the direct excavation of peat on-site for building tracks, hardstanding, turbine foundations and other infrastructure.	

Project phase	Included in assessment	Excluded from assessment
Operation	Carbon emissions resulting from manufacture and transport of spare parts and materials for repair required throughout the lifetime of the Proposed Development.	
	Carbon emissions resulting from the transport of labour to the Proposed Development site.	
	Carbon emissions from the indirect impact of drainage on peat surrounding the Proposed Development infrastructure.	
	Carbon savings resulting from the displacement of grid electricity generated by fossil fuels.	
	Carbon emissions resulting from the provision of back up generation	
	Carbon emissions resulting from the loss of active carbon-absorbing habitat.	
	Carbon uptake resulting from the restoration of carbon-absorbing habitat.	
Decommission ing	Carbon emissions resulting from on-site use of plant and equipment.	Carbon emissions resulting from the transport of labour to the Proposed Development site and the transport of waste materials off-site.
	Decommissioning of turbine components	

16.3.5 The assessment has used the following methodologies to estimate the overall impact of the Proposed Development on climate change:

- the Scottish Government's Carbon Calculator , (online version 1.5.1); and
- baseline emissions have been calculated using site-based data and standard conversion factors.

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

16.3.6 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 greenhouse gas emissions arising from large scale wind farm developments on peat land. The calculator looks at the benefit of displacing conventionally generated electricity in the grid compared to the predicted direct and indirect emissions of carbon from construction, operation and decommissioning of a wind farm. It provides an estimate of the carbon payback time for the Proposed Development.

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

16.3.8 The most recent version of the Carbon Calculator is a web-based application and central database, where all the data entered is stored in a structured manner[1]. 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. Individual aspects of the methodology will be discussed further within this chapter of the EIA Report, in the context of actual inputs and outputs of the model.

Methodology for Specific Parameters

16.3.9 Samples were sent to a laboratory for testing dry soil bulk density but the results from the laboratory were higher than expected for peat soil; therefore the method based on core data from across the Proposed Development site that is described below was considered to provide a more reliable estimate of this parameter. This parameter has then been used to estimate average drainage distance, which is a very difficult parameter to measure on-site.

Methodology for Estimating Dry Soil Bulk Density

16.3.10 Within Lindsay's Peatbogs and Carbon; A critical synthesis (2010), a number of studies document the relationship between bulk density and Von Post scale of humification. In particular, 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.

16.3.11 Cores were taken at 174 locations; all the locations registered peat present with both acrotelmic and catotemic layers of peat, indicating a relatively intact peat habitat. Von Post scores for both humification (H score) and saturation (B score) were recorded in the acrotelm and at metre intervals down through the catotelm. The wide coverage of Von Post data across the Proposed Development site meant that it was possible to use this equation to estimate the overall bulk density at the site. The methodology used was:

1) Calculate the average Von Post scores for acrotelm layer (mean = 2.3, count 174);

2) Calculate the average Von Post scores for catotelm layer (multiple measurements per core) (mean = 7.1, count 355);

3) Calculate an average weighted Von Post score, using the average depth of acrotelm and catotelm to weight the score (weighted average score = 6.6)

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

Estimating Average Drainage Distance from Drainage Features

16.3.12 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))

[1] *The latest version of the web-based carbon calculator can be found at https://informatics.sepa.org.uk/CarbonCalculator/index.jsp*

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

16.3.13 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).

16.3.14 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 worst case scenario, as it is highly unlikely that the maximum bulk density of peat (with the greatest amount of stored carbon) would also be have the maximum average drainage distance.

16.4 Data Collection

16.4.1 A variety of data sources contributed to the parameters entered into the input sheets of the Carbon Calculator for the Proposed Development; the main sources of data input are summarised below.

- Data about peat depth and peat characteristics under and around infrastructure components was provided from the data collected during the peat survey campaign. This was carried out in four phases.
  - Phase 1: A first phase of peat depth probing was undertaken in October 2018. The first round of depth of penetration (peat) probing was carried out based on 100 m grid across the Proposed Development site area to identify an initial distribution and depth of peat across the site by Fluid Consulting Limited. A total of 405 peat probes were undertaken.
  - Phase 2: A second phase of probing and coring was undertaken in November 2018 subsequent to the initial design freeze. During this phase further peat probing was undertaken by Fluid Consulting Limited on 10 m grid around the infrastructure layout and every 50 m along access track with 10 m offsets either side to inform micro-siting requirements. An additional 214 peat depth probes and 10 cores were undertaken to verify the probe penetration depths to assess whether they were representative of the peat depth.
  - Phase 3: To assess peat depth across the revised design layout, extensive probing was carried out, where a probe was used to ascertain the depth of penetration to 0.1 m accuracy. In January 2019 subsequent to the final design freeze, further peat probing was undertaken by Fluid Consulting Limited on 10 m grid around the infrastructure layout and every 50 m along access track with 10 m offsets either side.
  - Phase 4: In February 2019 additional peat probing was undertaken in the southern construction compound near the Proposed Development site entrance by ITPE.
- Infrastructure locations and sizes were provided from the GIS shape file for the final design layout.
- Turbine size and description of construction methodologies for foundations, hardstanding and tracks were provided by the Applicant.
- A number of parameters have been sourced from governmental data sources or scientific literature. Where available and appropriate, default values in the Carbon Calculator have been used.

16.4.2 Table 16.2 details all the input parameters used, along with the data range, the source and the assumptions.

Table 16.2 - Full Input Parameter Table for the Scottish Government Carbon Calculator

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Wind Farm Characteristics					
Dimensions					
No. of turbines	29	29	29	Chapter 3 states that the Proposed Development comprises of 29 turbines.	None
Life time of wind farm (years)	30	30	30	Chapter 3 states that the operational life of the Proposed Development will be 30 years.	None
Performance					
Turbine capacity (MW)	5.0	5.0	6.8	Chapter 3 states that the turbines would be up to 200 m to blade tip, up to 130 m hub height and up to 160 m rotor diameter. The maximum turbine capacity for the Proposed Development site is stated as 200 MW, which is 6.8 MW per turbine. An estimate of expected capacity was provided by the Applicant.	The expected and minimum capacity per turbine has been proposed as 5.0 MW but up to a maximum of 6.8 MW.
Capacity factor – using direct input of capacity factor (percentage efficiency)	51%	48.5%	53.6%	The estimate of the capacity factor for new build onshore wind farms in Scotland from Annex A Load factors for each technology (BEIS, 2018) is 35.2 % but independent analysis of the Proposed Development site and data from the neighbouring Burradale Wind Farm indicate that a higher	A range of +/- 5 % has been used to calculate the likely maximum and minimum.

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				capacity factor can be used for this location. Estimate of 51 % provided by the Applicant[2].	
Backup					
Extra capacity required for backup (%)	5	5	5	The Carbon Calculator indicates that if 20 % of national electricity is generated by wind energy, the extra capacity required for backup is 5 % of the rated capacity of the wind plant. SEPA has indicated that, for this parameter, the electricity generation capacity of Scotland, rather than the UK, should be considered. The latest statistics on renewable generation are available for 2016. This indicates that wind energy made up nearly 27 % of total electricity generation in Scotland (Energy in Scotland 2018 and Renewable electricity capacity and generation published by the Department for Business, Energy and Industrial Strategy in September 2018).	This input parameter assumes no improvement in grid management techniques, including demand side management, smart metering or storage over the lifetime of the wind farm.
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10	10	10	Suggested Carbon Calculator literature value 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).
Carbon dioxide emissions from turbine life - (e.g. manufacture,	Calculate with installed capacity option selected			There is no direct Life Cycle Assessment available at this point in time, therefore the inbuilt Carbon Calculator option which allows for emissions to be calculated according to	

[2] *Burradale Wind Farm on the island of Mainland, Shetland has an average annual capacity factor of 52% https://www.burradale.co.uk/. This has been independently validated by a third party consultant using Analysis of the wind resource for the Proposed Development by a third-party consultant independently supports use of this figure.*

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
construction, decommissioning)				turbine capacity has been selected. The equation for turbines with greater than or equal to 1 MW capacity was derived by regression analysis against 7 measurements, and has an associated R^2 value of 85 %.	
Characteristics of peat land before wind farm development					
Type of peat land	Acid Bog	Acid Bog	Acid Bog	Assume that the best habitat description available is ‘acid bog’, which is fed primarily by rainwater and often inhabited by sphagnum moss, thus making it acidic.	
Average air temperature at site (oC)	7.0	6.9	7.1	Based on average annual temperature data for north Scotland for the time period 1910 – 2018. The data is sourced from the Meteorological Office (2019). Mean: 6.97 Count: 109 Standard Error: 0.05	A 95 % confidence level has been calculated as the mean +/- 2 SE to estimate the likely minimum and maximum values of the range. Although, it is probable that average site temperatures are rising due to impacts of global climate change, the overall payback is not sensitive to temperature and therefore this parameter is not included in the sensitivity analysis.
Average depth of peat at the site (m)	1.44	1.43	1.45	Based on peat probe data from within the red line boundary. Mean: 1.44 Count: 12,714	A 95 % confidence level has been calculated as the mean +/- 2 SE to estimate the likely minimum and maximum values of the average.

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				Standard Error: 0.61	
Carbon (C) Content of dry peat (% by weight)	51	48	53	Fifteen samples were taken from the application site for the Proposed Development and measured by an independent laboratory. The carbon content results are within the range of carbon content of peat of between 49 % and 62 % that is provided in the Carbon Calculator as a default range from Birnie *et al* (1991). Mean: 51 % Count: 15 Standard Error: 1.2 %	Carbon (C) content of dry peat was measured by standard analytical procedures. A 95 % Confidence Interval has been calculated as the mean +/- 2 SE to estimate the likely minimum and maximum values.
Average extent of drainage around drainage features at site (m)	27	17	39	The average extent of drainage has been estimated using Von Post data from 174 cores on-site. Von Post scores were recorded at each metre depth down the peat core. 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 the section on Methodology for specific parameters.	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)	0.08	0.00	0.16	The water table was observed on-site at the Proposed Development during peat cores taken to observe Von Post scores. On average the wetness score in both the acrotelm and catotelm was between B3 (moderate moisture content)	The minimum value has been set at zero, and the maximum value 0.16 m

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				and B4 (high moisture content). On average the acrotelm/catotelm boundary was at 0.16 m below the surface although this varied across the site. It can be assumed that this boundary represents the lowest point of the water table and therefore the average water table depth has been set at the midpoint of 0.08 m.	which represents the average depth of the acrotelm/catotelm boundary.
Dry soil bulk density (g/cm^3)	0.12	0.09	0.15	Scottish average bulk density values are unpublished data from the National Soil Inventory of Scotland (2007-2009) for amorphous, well decomposed peat. The range provided by SEPA for use in the Carbon Calculator for blanket peat is 0.132 (0.072 – 0.293 g/cm^3) 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 0.12 g/cm^3 sits within the estimated range provided by SEPA for blanket peat.	A range of +/- 25 % has been used to calculate the likely minimum and maximum.
Characteristics of bog plants					
Time required for regeneration of bog plants after restoration (years)	22.5	15	30	This parameter needs to be estimated and there are relatively few studies available on the average time taken for bog plant communities to regeneration following restoration. Rochefort *et al* (2003) estimate that a significant number of characteristic bog species can be established in 3–5 years, a stable high water-table in about	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

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				a decade, and a functional ecosystem that accumulates peat in perhaps 30 years.	value has been estimated at -25 % of the maximum and the minimum at -50 %.
Carbon accumulation due to C fixation by bog plants in un-drained peats ($t\ C\ ha^{-1}\ yr^{-1}$)	0.215	0.12	0.31	Suggested acceptable literature values from Carbon Calculator. The overall result is not very sensitive to this input, so the default value can be used if measurements are not available.	The range suggested in the methodology from the literature for apparent C accumulation rate in peatland is 0.12 to 0.31 $t\ C\ ha^{-1}\ yr^{-1}$ (Turunen et al., 2001, Global Biogeochemical Cycles, 15, 285-296; Botch et al., 1995, Global Biogeochemical Cycles, 9, 37-46). 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	There is no forestry to be removed on-site.	
Counterfactual emission factors					
Coal-fired plant emission factor ($t\ CO_2\ MWh^{-1}$)	0.918	0.918	0.918	The values in the page of the tool are fixed.	

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Grid-mix emission factor ($t\ CO_2\ MWh^{-1}$)	0.28088	0.28088	0.28088		
Fossil fuel- mix emission factor ($t\ CO_2\ MWh^{-1}$)	0.46	0.46	0.46		
Borrow Pits					
Number of borrow pits	9	9	9	Chapter 3: Proposed Development states there will be nine borrow pits across the Proposed Development site, numbered from A to I	None
Average length of pits (m)	145	138	152	The nine borrow pits are of different sizes and shapes; in order to be able to enter an average value for length and width, the total area of the borrow pits was calculated from the GIS shapefile. This area was divided by the number of borrow pits and then the square root of this value was calculated to get an average length and width.	A range of +5 % has been used to calculate the likely expected and maximum values of both length and width.
Average width of pits (m)	145	138	152		
Average depth of peat removed from pit (m)	1.14	1.09	1.19	The volume of peat in each borrow pit was calculated from the area of each borrow pit multiplied by the average peat depth for that location (averaged from all of the peat probes within a 50 m buffer of the infrastructure). The total volume of peat was divided by the total borrow pit area to provide an average overall peat depth across all nine locations.	A 95 % CI has been calculated as mean +/- 2 SE to estimate the likely minimum and maximum values of peat volume for each borrow pit. The total maximum and minimum volumes were divided by the total area to get an estimate of the range

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
					of the maximum and minimum average depth.
Foundations and hard-standing area associated with each turbine					
Method used to calculate CO_2 loss from foundations and hard-standing	Rectangular with vertical walls			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)	21	20	22	Although the 29 turbine foundations are circular in shape, in order to be able to enter an average value for length and width, the square root of the area of the foundations was calculated to get an average length and width.	A range of + 5% has been used to calculate the likely expected and maximum values of both length and width.
Average width of turbine foundations (m)	21	20	22		
Average depth of peat removed from turbine foundations (m)	1.39	1.31	1.47	The volume of peat at each turbine/hardstanding location was calculated from the turbine area multiplied by the average peat depth for each location (averaged from all of the peat probes within a 50 m buffer of each turbine/hardstanding location). The total volume of peat was divided by the total foundation area to provide an average peat depth across all 29 turbine locations.	A 95 % CI has been calculated as mean +/- 2 SE to estimate the likely minimum and maximum values of peat volume for each turbine foundation. The total maximum and minimum volumes were divided by the total area to get an estimate of the range of the maximum and minimum average depth.
Average length of hard-standing (m)	57	54	60	The 29 hardstandings are of slightly different sizes and shapes; in order to be able to enter an average value for	A range of +5 % has been used to calculate the likely expected and

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average width of hard-standing (m)	57	54	60	length and width, the total area of the hardstanding was calculated from the GIS shapefile. This was divided by the number of hardstanding locations and the square root of this value was calculated to get an average length and width.	maximum values of both length and width.
Average depth of peat removed from hard-standing (m)	1.39	1.31	1.47	The volume of peat at each turbine/hardstanding location was calculated from the hardstanding area multiplied by the average peat depth for each location (averaged from all of the peat probes within a 50 m buffer of each turbine/hardstanding location). The total volume of peat was divided by the total hardstanding area to provide an average peat depth across all 29 turbine locations.	A 95 % CI has been calculated as mean +/- 2 SE to estimate the likely minimum and maximum values of peat volume for each hardstanding. The total maximum and minimum volumes were divided by the total area to get an estimate of the range of the maximum and minimum average depth.
Volume of concrete					
Volume of concrete used (m^3) in the entire area	52,451	49,828	55,073	Chapter 3: Proposed Development states that each foundation would have the average dimensions of 24 m diameter and between 3 to 5 m in depth. The average of these dimensions has been used to calculate an estimated volume of concrete per foundation. The total volume is estimated by multiplying by the number of turbines.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Access tracks					

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Total length of access track (m)	22,066	20,963	23,169	The length of the access track has been estimated from the GIS shape file total area for access track, assuming an average road width of 5.3 m (5.0 m but with additional widening on bends) There might be minor discrepancies between the length and width of tracks used in the Carbon Calculator and stated in the Chapter 3: Proposed Development. This is due to the method of calculation – the Carbon Calculator uses shapefile areas from which the length is then calculated, using a standard average width. These minor discrepancies would have no material impact on the calculation. All the access tracks are included in this category: Excavated track - permanent Floating, new and upgraded – permanent Floating new – restored after construction Existing track, not upgraded.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Existing track length (m)	322	306	338	The length of the existing access track has been estimated from the GIS shape file total area for existing roads, assuming an average road width of 5.3 m (5.0 m but with additional widening on bends).	A range of +/- 5 % has been used to calculate the likely minimum and maximum
Length of access track that is floating road (m)	19,336	18,369	20,303	The length of the floating access track has been estimated from the GIS shape file total area for floating roads, assuming an average road width of 5.3 m (5.0 m but with	A range of +/- 5 % has been used to calculate the likely minimum and maximum

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				additional widening on bends). This includes permanent floating roads (new and existing upgraded) and temporary floating roads that will be restored post-construction.	
Floating road width (m)	5.3	5.3	5.6	The average width has been set at 5.3 m (5.0 m but with additional widening on bends). This includes permanent floating roads (new and existing upgraded) and temporary floating roads that will be restored post-construction.	A range of +5 % has been used to calculate the likely maximum
Floating road depth (m)	0	0	0.37	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 not 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. A cautious estimate of 25 % of the average peat depth has been entered for the maximum to represent the worst case scenario.	Zero value for expected and minimum values. The maximum is estimated at 25 % of the average peat depth for all the floating road locations on-site.
Length of floating road that is drained (m)	19,336	18,369	20,303	The Drainage Strategy states that, for both cut and fill tracks and those on deeper peat, lateral drains will be made on the uphill side of the road with cross drainpipes at appropriate locations.	A range of +/- 5 % has been used to calculate the likely minimum and maximum

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				Therefore it is assumed that the full length of floating road access track will be drained.	
Average depth of drains associated with floating roads (m)	0.43	0.39	0.47	Appendix 10.3 Outline Peat Management and Restoration Plan states that the average depth of the drains for floating roads is estimated as 0.43 metres (assuming a v-shaped cut with sides of length 0.5m).	A range of +/- 10 % has been used to calculate the likely minimum and maximum
Length of access track that is excavated road (m)	2,408	2,288	2,528	The length of the excavated access track has been estimated from the GIS shape file total area for excavated roads, assuming an average road width of 5.3 m (5.0 m but with additional widening on bends).	A range of +/- 5 % has been used to calculate the likely minimum and maximum
Excavated road width (m)	5.3	5.3	5.6	The average width has been set at 5.3 m (5.0 m but with additional widening on bends).	A range of +5 % has been used to calculate the likely maximum
Average depth of peat excavated for road (m)	1.24	1.19	1.30	The average peat depth under excavated track has been calculated using the peat probe data within the track shape and within a 25 m buffer each side. Count = 480 Mean = 1.24 m SE = 0.03 m	A 95 % CI has been calculated as mean +/- 2 SE to estimate the likely minimum and maximum values.

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
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: Proposed Development states cables would be laid in trenches along the edges of tracks 0.5 m deep and 1 m wide, or under the access track.	Assume all cable trenches follow access track routes.
Additional peat excavated (not accounted for above)					
Volume of additional peat excavated (m^3)	3,640	3,450	3,830	The volume of additional peat excavated has been calculated from the excavated part of substation which is the only additional infrastructure component that would require excavation. . The area of this component was estimated from the GIS shape file. The average peat depth at the location (area of component + 50 m buffer) was calculated from GIS, with the standard deviation.	The variation of this component was calculated as a minimum and maximum volume using the 95 % CI calculated as mean +/- 2 SE to estimate the peat depth and +/- 5 % to estimate the area.
Area of additional peat excavated (m^2)	596,368	566,550	626,186	The area of additional peat excavated includes the infrastructure components above and also the infrastructure that will be floated. This includes: Compounds 1 - 4 Laydown areas (29 in total) – restored after construction	A range of +/- 5 % has been used to calculate the likely minimum and maximum

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				Floated part of substation The area of each component was estimated from the GIS shape file.	
Improvement of C sequestration at site by blocking drains, restoration of habitat etc.					
Improvement of degraded bog				Appendix 7.7 Outline Habitat Management Plan contains the objective of restoring and managing active blanket mire habitat in one or more locations on Yell, through local slope-reprofiling, seeding, and control of grazing and peat cutting. However, this has not been included within the Carbon Calculator as it is out with the site boundary.	
Restoration of peat removed from borrow pits					
Area of borrow pits to be restored (ha)	18.9	17.1	20.9	The nine borrow pits are of different sizes and shapes; the total area of the borrow pits was calculated from the GIS shapefile.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	1.14	1.09	1.19	This is a difficult parameter to estimate; however, it is assumed that the water table would be significantly lowered by drainage prior to restoration. It is estimated that the water table would be at the bottom before restoration with respect to the restored surface – therefore the water table depth would be the expected average depth of peat extracted.	A range of – 10 % has been used to calculate the likely minimum.

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.08	0.0	0.16	In order to restore the bog habitat in the borrow pits, it is expected that the average annual water table depth needs to be restored to around 0.1 m from the surface. The average annual water table depth is set as the site average as measured from the cores.	The minimum value has been set at zero, and the maximum value 0.16 m which represents the average depth of the acrotelm/catotelm boundary.
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	10	7.5	12.5	It is estimated that due to the relatively small restoration areas and use of acrotelm layers with intact vegetation to restore these areas, the process should be relatively quick to restore hydrology and plant communities.	A range of +/- 25 % has been used to calculate the likely minimum and maximum.
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	30	30	30	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 (30 years), the period of time when the improvement can be guaranteed should be entered as 30 years.	
Removal of drainage from foundations and hardstanding				Chapter 3: Proposed Development states that cut off drains to be placed on the upper slopes above excavated hardstands. Shallow perimeter drainage to be placed around all permanent hardstand hardcore. It is assumed that this drainage will remain in place post-construction, therefore this section of the tool has been left blank. It should be noted that completing it with estimated values does not alter the overall payback time of significantly.	

Online calculator reference: DLH5-06CU-DC2N					
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?	Yes	Yes	Yes		
Will you attempt to block any gullies that have formed due to the wind farm?	Yes	Yes	Yes	Appendix 10.3 Outline Peat Management and Restoration Plan contains details of post-construction restoration, including gully blocking.	
Will you attempt to block all artificial ditches and facilitate rewetting?	Yes	Yes	Yes	Appendix 10.3 Outline Peat Management and Restoration Plan contains details of post-construction restoration, including facilitating rewetting.	
Will habitat of the Proposed Development site be restored on decommissioning?	Yes	Yes	Yes		
Will you control grazing on degraded areas?	Yes	Yes	Yes	Appendix 7.7 Outline Habitat Management Plan states that to encourage restoration of peat in borrow pits on site livestock will be excluded during the establishment phase and controlled thereafter.	

Online calculator reference: DLH5-06CU-DC2N					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Will you manage areas to favour reintroduction of species	Yes	Yes	Yes	Appendix 7.7 states that to encourage restoration of peat in borrow pits on site any areas of bare peat, where vegetation is not re-growing, will be seeded with a seed mixture obtained from the existing habitat or commercial seeds of local genetic provenance.	
Choice of methodology for calculating emission factors	Site specific			As required for planning applications.	

16.5 Results

Baseline Conditions

16.5.1 It is not easy to set a simple baseline for climate change impacts because the impact is due to a global atmospheric pool of greenhouse gas 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.

16.5.2 However, the key climate change impact of constructing a wind farm on peatland 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 project development to be estimated.

16.5.3 Table 16.3 shows how the total stored carbon has been estimated. Estimated volume and emissions have been rounded up to the nearest thousand cubic metres/tonnes.

Table 16.3 – Estimated Stored Carbon in Peat at the Proposed Development Site (Based on Red Line Boundary)

Parameter	Expected	Minimum	Maximum
Size of site based on red line boundary (ha)	1,679	1,596	1,763
Average peat depth across site (m)	1.44	1.43	1.45
Carbon content of dry peat (% by weight)	51%	48%	53%
Dry soil bulk density (g/cm^3)	0.12	0.09	0.15
Estimated volume of peat on-site (m^3)	24,218,000	22,812,000	25,645,000
Estimated amount of carbon in soils on-site (t)	1,474,000	993,000	2,043,000
Estimated equivalent emissions of CO_2 (t)	5,411,000	3,643,000	7,498,000

16.5.4 Table 16.3 shows that there is around 1.5 million tonnes of stored carbon on-site and if this was fully oxidised, this would equate to around 5.4 million tonnes of CO_2 emissions. It is hard to assess the future of this stored carbon on-site in the absence of the Proposed Development but it is probable that future climate change impacts would affect this store – if the site conditions became warmer or drier, it is likely that some of this carbon would be lost.

Carbon Balance Assessment - Emissions

16.5.5 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.

16.5.6 This section looks at the three project stages of construction, operation and decommissioning and allocates emissions to those three 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 16.4 – 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	138,496	137,667	188,098	43 %
CO_2 loss from excavated peat	33,691	14,661	48,210	11 %
Subtotal of emissions during construction	**172,187**	**152,328**	**236,308**	**54 %**

16.5.7 Table 16.4 shows 54 % of the total losses occur during the Proposed Development construction. These are from the manufacture of the turbines and the potential oxidation of excavated peat. A small proportion comes from other materials used in construction (for example concrete for foundations).

Table 16.5 – 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	87,644	87,644	119,196	28%
Losses due to reduced carbon fixing potential	11,823	4,086	26,630	4%
Losses due to DOC & POC leaching	18,580	1,940	60,375	6%
CO_2 loss from drained peat	28,455	-5,184	13,132	9%
Subtotal of emissions during operation	**146,502**	**88,486**	**219,333**	**46%**

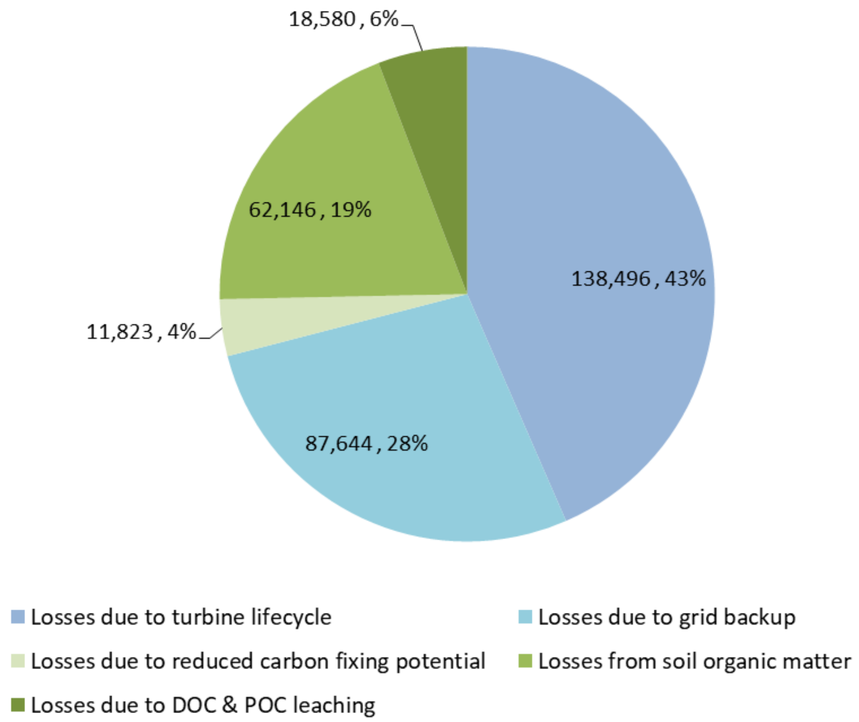
16.5.8 Table 16.5 shows that a further 46 % of the emissions occur during operation of the Proposed Development. The most significant of these is the requirement for back-up power in the grid, which is assumed to come from a fossil fuel source. Carbon losses due to leaching of carbon and also from oxidation of drained peat account for a further 15 %, however, losses of carbon fixing potential from bogs only contributes 4 % of the total losses.

16.5.9 Emissions produced during the decommissioning phase are not included separately in the Carbon Calculator assessment, as included in the overall 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.

16.5.10 Graph 16.1 shows how the emissions are split between sources; the majority of emissions result from activities largely outside of the control of the Applicant (shown in blue); lifecycle emissions from the turbines can be potentially reduced through consideration at the procurement phase but availability and delivery timescales of appropriate turbines are usually more important factors in selection. The second largest emission source is from back-up power and this depends on both the grid mix and future grid management policies and is not under the control of the Applicant.

16.5.11 Emissions under the control of the Applicant are shown in green. These include the losses of carbon due to the extraction and drainage of peat and loss of carbon fixing potential. Therefore, mitigation measures for climate change include siting infrastructure away from deep peat areas where possible and floating infrastructure where this avoidance is not possible.

Graph 16.1 – Breakdown of Emission Sources for the Proposed Development



Carbon Balance Assessment – Gains

16.5.12 Table 16.6 shows the estimated carbon gains over the lifetime of the Proposed Development from improvements through restoration. 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 restored area and not accounting for any additional carbon sequestration that might occur from restored areas.

Table 16.6 – Estimated Carbon Gains during the Construction Phase

Source of gains	Estimated gains (tCO_2e)			% of overall gains (expected scenario)
	Expected	Minimum	Maximum	
Change in emissions due to restoration of peat from borrow pits	-7,518	-6,002	-7,598	100%

Comparison with the Baseline

16.5.13 The soil carbon losses from the Proposed Development site are estimated at around 81,000 tonnes of CO_2e. This represents around 1.5 % of the total stored carbon on-site (the estimated stored carbon is set out in Table 16.3) and includes anticipated losses from excavated and drained peat and losses due to leaching. In reality this percentage is likely to be lower because the method used by the Carbon Calculator tool is likely to overestimate the volume of drained peat around infrastructure and also assumes that all excavated peat will be oxidised, whereas good management and re-use at site is likely to prevent at least a proportion of this oxidation.

Carbon Balance Assessment – Savings

16.5.14 Table 16.7 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, while this could be the case in the short term, it is not the most probable scenario in the longer-term. The grid-mix of electricity generation represents the overall carbon emissions from the grid per unit of electricity and includes nuclear and renewables as well as fossil fuels.

Table 16.7 – Estimated Annual and Lifetime Carbon Savings from the Operation of the Proposed Development from the Displacement of Grid Electricity

Counterfactual emission factor	**Estimated savings (tCO_2e per year)**		
	Expected	**Minimum**	**Maximum**
Coal-fired electricity generation	594,682	565,531	849,999
Grid-mix of electricity generation	181,955	173,035	260,074
Fossil fuel - mix of electricity generation	297,989	283,382	425,925
	Estimated savings (tCO_2 over lifetime of the Proposed Development)		
Coal-fired electricity generation	17,850,000	16,980,000	25,500,000
Grid-mix of electricity generation	5,460,000	5,190,000	7,800,000
Fossil fuel - mix of electricity generation	8,940,000	8,490,000	12,780,000

Payback Time and Carbon Intensity

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

16.5.16 Table 16.8 shows the estimated payback time, if the electricity generated by the Proposed Development is assumed to displace electricity generated by the grid at the current average grid factor and also the carbon intensity of the units produced.

Table 16.8 – Estimated payback time in years and carbon intensity of the units of electricity produced

Counterfactual emission factor	Estimated time to payback (years)		
	Expected	Minimum	Maximum
Coal-fired electricity generation	0.5	0.3	0.8
Grid-mix of electricity generation	1.7	0.9	2.6
Fossil fuel - mix of electricity generation	1.0	0.5	1.6
Carbon intensity (kgCO_2e/kWh)	0.016	0.008	0.024

16.5.17 Table 16.8 shows that the Proposed Development is estimated to have a payback of 1.7 years based on the current grid mix and the carbon intensity of units produced would be significantly lower than the current grid mix (the value of 0.281 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.

16.6 Cumulative Impact

16.6.1 The most significant cumulative impact of the Proposed Development is on the long-term grid electricity carbon factor. As the renewable generation capacity increases, the overall carbon intensity of the National Grid will decrease; this grid decarbonisation is a key component of the Scottish Government's strategy to reduce overall emissions and meet the Climate Change (Scotland) Act 2009 targets. The cumulative impact of multiple renewable projects therefore would be to reduce the projected emissions savings of each individual project, as each unit of grid electricity generated would be worth less carbon. The impact of this strategy is greater the further into the future it occurs but at the same time the exact generation composition of the grid, and therefore the carbon emissions per unit of electricity, is less predictable.

16.6.2 Although there is a great deal of uncertainty surrounding the future grid factor, the Intergovernmental Analysts Group at the Department for Business, Energy and Industrial Strategy have produced projections which are based on the UK achieving renewable energy targets and successfully implementing the UK Energy Policy. The projections predict an average grid factor over the expected lifetime of the Proposed Development (2025 to 2054) of approximately 0.073 kgCO_2e/kWh (IAG, 2017). 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 time from 1.7 years to 6.6 years. However, this would not affect the carbon intensity of the Proposed Development, which is estimated at 0.016 kgCO_2e/kWh, would be well below the projected average for the lifetime of the Proposed Development and would therefore contribute towards this grid decarbonisation.

16.7 Sensitivity Analysis

16.7.1 The sensitivity analysis shows the impact of varying four of the key parameters on the payback time under a grid mix counterfactual emission factor, whilst holding all other parameters constant, as shown in Table 16.9. Within the model there are a number of parameters known to have a potentially large impact on overall estimated payback time; for some of these parameters there is also a degree of uncertainty over the inputs due to data collection restraints.

Table 16.9 – 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	Double parameter
Average extent of drainage around drainage features at site (m) – 28 m – impact of halving and doubling	1.7	1.6	2.1
Average water table depth at site (m) – 0.05 m – impact of halving and doubling	1.7	1.7	1.7
Carbon (C) Content of dry peat (% by weight) – 56 % - impact of decreasing and increasing by 50 %	1.7	1.5	2.0
Dry soil bulk density (g/cm^3) – 0.12 g/cm^3– impact of decreasing and increasing by 50 %	1.7	1.5	2.0

16.7.2 Table 16.9 shows that, while the average drainage distance around drainage features on-site is a potentially important parameter in terms of the area of peat that would be drained by the Proposed Development infrastructure, doubling this parameter from 27 m to 54 m only increases the payback time by 0.4 years. Halving or doubling the water table depth has even less impact on overall payback time, removing or adding less than one tenth of a year to the overall payback time.

16.7.3 Increasing either the dry soil bulk density or carbon content parameters by 50 % adds about 0.3 years to the overall payback. In reality these parameters are usually interrelated, with increases in bulk density usually associated with increased mineral content and lower carbon content.

16.7.4 Overall there is relatively little sensitivity to the overall outcome from changing the individual parameters below, which increases the confidence in the estimated payback time of around 1.7 years.

16.8 Mitigation

16.8.1 Although the results from the climate change assessment show that the impact of the Proposed Development on climate change mitigation is beneficial after an estimated 1.7 years of operation, there are ways to reduce this payback time further.

Design Phase

16.8.2 The Proposed Development has been designed to avoid areas of deeper peat – the evolution of the design is discussed further in Chapter 2: Site Selection and Design Iterations.

Construction phase

16.8.3 The following activities will contribute to lower carbon emissions during the construction phase of the Proposed Development.

- Implement a Site Waste Management Plan to reduce materials wastage.
- Implement a vehicle idling policy to ensure that, where practicable plant and equipment are turned off when not in use, as part of the Construction and Decommissioning Environmental Management Plan.
- Implement a Peat Restoration Plan as part of the Construction Environmental Management Plan, including ditch blocking in order to allow peat habitats to be restored and groundwater levels to be raised to near surface. Appendix 10.3 presents the areas where the peat that will be excavated from the infrastructure footprint will be reused to create new peatland habitat and restore surfacing. These plans will enable the excavated peat to retain its integrity, retain carbon and allow areas of previous degraded and afforested peatland to regenerate and start to produce peat again.

16.9 Summary

16.9.1 The results of the Carbon Calculator for the Proposed Development show that the Proposed Development is estimated to produce annual carbon savings in the region of 182,000 tonnes of CO_2e per year, and lifetime savings of nearly 5.5 Mt of CO_2e through the displacement of grid electricity, based on a counterfactual emission factor of 0.281 $kgCO_2e/kWh$. This represents displacing grid electricity at the current average annual grid mix. Displacement of existing sources of generating capacity depends on the time of day and how the grid needs to be balanced.

16.9.2 The assessment of the carbon losses and gains has estimated an overall loss of around 311,000 tonnes of CO_2e, mainly due to embodied losses from the manufacture of the turbines and provision of backup power to the grid. Ecological carbon losses account for 29 % of the total emissions resulting from the Proposed Development and operation.

16.9.3 The estimated payback time of the Proposed dDevelopment, using the Scottish Government Carbon Calculator, is estimated at 1.7 years, with a minimum/maximum range of 0.9 to 2.6 years. There are no current guidelines about what payback time constitutes a significant impact but 1.7 years is only around 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 significant emissions during operation due to combustion of fossil fuels, the Proposed Development has a very low carbon footprint and after 1.7 years, the electricity generated is estimated to be carbon neutral and will displace grid electricity generated from fossil fuel sources. The carbon intensity of the electricity produced by the Proposed Development is estimated at 0.016 $kgCO_2e/kWh$. This is within the range of the carbon intensity required by the Scottish Government to meet the Climate Change Act 2009 target by 2050 and therefore the Proposed Development is evaluated to have an overall beneficial effect on climate change mitigation.

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