16 Carbon Calculator

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16 Carbon Calculator

16.1 Executive Summary

16.1.1 This Chapter considers the Carbon Balance Assessment of the Proposed Development and provides an update based on the 2020 Layout.

16.1.2 The results of the Carbon Calculator for the 2020 Layout show that the Proposed Development is estimated to produce annual carbon savings in the region of 180,000 tonnes of CO_2e per year, and lifetime savings of nearly 5.4 Mt of CO_2e through the displacement of grid electricity, based on a counterfactual emission factor of 0.254 $kgCO_2e/kWh$.

16.1.3 The assessment of the carbon losses and gains from the 2020 Layout has estimated an overall loss of around 334,000 tonnes of CO_2e, mainly due to embodied losses from the manufacture of the turbines and provision of backup power to the grid, in comparison to the 311,000 tonnes of CO_2e predicted for the 2019 Layout. It should be noted that the increase in embodied carbon is due to an increase in the installed capacity of the wind farm; there are fewer turbines but each one produces a higher output.

16.1.4 The estimated payback time of the 2020 Layout, using the Scottish Government Carbon Calculator, is estimated at 1.9 years, with a minimum/maximum range of 1.4 to 2.3 years, compared against the estimated 1.7 years payback time for the 2019 Layout. 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 (Emissions Reduction Targets) (Scotland) Act 2019 target by 2045 and therefore the Proposed Development is evaluated to have an overall beneficial effect on climate change mitigation.

16.2 Introduction

16.2.1 This chapter has been undertaken by Fluid Environmental Consulting (Fluid) and considers the Carbon Balance Assessment of the Proposed Development and provides an update to that undertaken as part of the 2019 EIA Report.

16.2.2 This chapter of the 2020 SEI should be read in conjunction with Chapter 16 of the 2019 EIA Report which provides a background to the Carbon Balance Assessment, the legislation behind it and the methodology used. This chapter assesses the effects of the 2020 Layout on the whole life carbon balance of the Proposed Development. With the removal of T1, T2, T3, T4, T7 and T29 and associated infrastructure from the 2019 Layout the input parameters for the assessment have changed and the Carbon Calculator assessment has been updated.

16.2.3 The assessment has been carried out using the Scottish Government’s Carbon Calculator (online version 1.6.0), online reference DLH5-06CU-DC2N.

16.3 Response to Consultation Responses

16.3.1 No responses were received to the 2019 EIA Report in relation to the Carbon Calculator.

16.4 Data Collection

16.4.1 Table 16.1 below details all of the input parameters used, along with the data range, the source and the assumptions, and highlights where these have changed from the 2019 EIA Report.

Table 16.1 Full Input Parameter Table for the Scottish Government Carbon Calculator

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Wind Farm Characteristics								
Dimensions								
No. of turbines	29	29	29	23	23	23	Chapter 3 (Supplementary Environmental Information (SEI)) states that the Proposed Development comprises of 23 turbines.	None
Life time of wind farm (years)	30	30	30	30	30	30	Chapter 3 (EIAR) states that the operational life of the Proposed Development will be 30 years.	None
Performance								
Turbine capacity (MW)	5.0	5.0	6.8	6.9	6.9	6.9	Chapter 3 (SEI) states that the total capacity of the Proposed Development will be up to 160 MW which is an average of 6.9 MW per turbine.	None
Capacity factor – using direct input of capacity factor (percentage efficiency)	51%	48.5%	53.6%	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	A range of +/- 5 % has been used to calculate the likely maximum and minimum.

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
							from the neighbouring Burradale Wind Farm indicate that a higher capacity factor can be used for this location. Estimate of 51 % provided by the Applicant[1].	
Backup								
Extra capacity required for backup (%)	5	5	5	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 2019. This indicates that wind energy made up 56 % of total electricity consumption in Scotland (Energy Statistics for Scotland 2019)	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.

[1] *Burradale Wind Farm on the island of Mainland, Shetland has an average annual capacity factor of 51% 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.*

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10	10	10	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, construction, decommissioning)	Calculate with installed capacity option selected			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 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	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.	

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average air temperature at site (°C)	7.0	6.9	7.1	7.5	7.3	7.7	Based on 20 year period (2000 – 2019) average temperature data for region Scotland North (Met Office, 2020). Mean: 7.5 Count: 20 Standard Error: 0.1	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	1.44	1.43	1.45	Based on peat probe data from within the red line boundary. Mean: 1.44 Count: 12,714 Standard Error: 0.61	A 95 % confidence level has been calculated as the mean +/- 2 SE to estimate the likely minimum and

	2019 Layout			2020 Layout				
Parameter	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Data Source	Key Assumptions
								maximum values of the average.
Carbon (C) Content of dry peat (% by weight)	51	48	53	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	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	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.

	2019 Layout			2020 Layout				
Parameter	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Data Source	Key Assumptions
							estimated drainage distance using equations from Nayak et al (2008). More detail is provided in the section on Methodology for specific parameters.	
Average water table depth at site (m)	0.08	0.00	0.16	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) 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.	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.
Dry soil bulk density (g/cm^3)	0.12	0.09	0.15	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	A range of +/- 25 % has been used to calculate the likely minimum and maximum.

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
							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.	
Characteristics of bog plants								
Time required for regeneration of bog plants after restoration (years)	22.5	15	30	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

	2019 Layout			2020 Layout				
Parameter	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Data Source	Key Assumptions
								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	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	0	0	0	There is no forestry to be removed on-site.	

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Counterfactual emission factors								
Coal-fired plant emission factor ($t\ CO_2\ MWh^{-1}$)	0.918	0.918	0.918	0.920	0.920	0.920	Fixed counterfactual emission factors are provided and no entry is required by the applicant. 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 ($t\ CO_2\ MWh^{-1}$)	0.28088	0.28088	0.28088	0.25358	0.25358	0.25358		
Fossil fuel- mix emission factor ($t\ CO_2\ MWh^{-1}$)	0.46	0.46	0.46	0.450	0.450	0.450		
Borrow Pits								
Number of borrow pits	9	9	9	7	7	7	Chapter 3 (SEI) states there will be seven potential temporary borrow pit search areas. All of these have been included in the assessment.	None
Average length of pits (m)	145	138	152	147	140	154	The seven 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.	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	147	140	154		

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
							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.	
Average depth of peat removed from pit (m)	1.14	1.09	1.19	1.22	1.17	1.27	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 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			Rectangular with vertical walls			The simple method of calculation for turbine foundations was used for this application because this is no clear	None

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
							groups of turbines in terms of different peat depths, structures or use of piling.	
Average length of turbine foundations (m)	21	20	22	21	20	22	Although the 23 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	21	20	22		
Average depth of peat removed from turbine foundations (m)	1.39	1.31	1.47	1.47	1.39	1.55	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 23 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.

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average length of hard-standing (m)	57	54	60	57	54	60	The 23 hardstandings are of slightly different sizes and shapes; in order to be able to enter an average value for 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.	A range of +5 % has been used to calculate the likely expected and maximum values of both length and width.
Average width of hard-standing (m)	57	54	60	57	54	60		
Average depth of peat removed from hard-standing (m)	1.39	1.31	1.47	1.47	1.39	1.55	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 23 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.

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Volume of concrete								
Volume of concrete used (m^3) in the entire area	52,451	49,828	55,073	41,599	39,519	43,679	Chapter 3 (EIAR) 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								
Total length of access track (m)	22,066	20,963	23,169	15,290	14,526	16,055	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 6.0 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	A range of +/- 5 % has been used to calculate the likely minimum and maximum.

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
							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 track - permanent Floating track – temporary, restored after construction Existing track.	
Existing track length (m)	322	306	338	1,040	988	1,092	The length of the existing access track has been estimated from the GIS shape file for existing roads, assuming an average road width of 6.0 m (5.0 m but with additional widening on bends)[2].	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	13,200	12,540	13,860	The length of the floating access track has been estimated from the GIS shape file for floating roads, assuming an average road width of 6.0 m (5.0 m but with additional widening on bends).	A range of +/- 5 % has been used to calculate the likely minimum and maximum

[2] Please note the length of existing track in the 2019 EIAR was incorrect and this has been corrected and there is no increase or change in distance of existing track/road to be upgraded

	2019 Layout			2020 Layout				
Parameter	Expected	Minimum	Maximum	Expected	Minimum	Maximum	Data Source	Key Assumptions
							This includes permanent floating roads and temporary floating roads that will be restored post-construction.	
Floating road width (m)	5.3	5.7	6.3	6.0	5.7	6.3	The average width has been set at 6.0 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 and maximum.
Floating road depth (m)	0	0	3.7	0	0	0.38	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	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.

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
							maximum to represent the worst case scenario.	
Length of floating road that is drained (m)	19,336	18,369	20,303	13,200	12,540	13,860	SEI Appendix 10.1 Revised Peat Management and Restoration Plan states that floated track includes V drains. Therefore, it is assumed that the full length of floating road access track will be drained.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Average depth of drains associated with floating roads (m)	0.43	0.39	0.47	0.43	0.39	0.47	SEI Appendix 10.1 Revised 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	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 6.0 m (5.0 m but with additional widening on bends).	A range of +/- 5 % has been used to calculate the likely minimum and maximum

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Excavated road width (m)	5.3	5.3	5.6	6.0	5.7	6.3	The average width has been set at 6.0 m (5.0 m but with additional widening on bends).	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Average depth of peat excavated for road (m)	1.24	1.19	1.30	1.38	1.31	1.45	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 = 263 Mean = 1.38 m SE = 0.03 m	A 95 % CI has been calculated as mean +/- 2 SE to estimate the likely minimum and maximum values.
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	0	0	0	Chapter 3 (EIAR) 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.

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Additional peat excavated (not accounted for above)								
Volume of additional peat excavated (m^3)	3,640	3,450	3,830	9,070	8,603	9,357	The volume of additional peat excavated has been calculated from the excavated part of substation and the widened section of access track at the entrance. The area of these components 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	65,214	61,953	68,475	The area of additional peat excavated includes the infrastructure components above and also the infrastructure that will be floated. This includes: 3 compounds Laydown areas (23 in total) – restored after construction Floated part of substation The area of each component was estimated from the GIS shape file.	A range of +/- 5 % has been used to calculate the likely minimum and maximum

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Improvement of C sequestration at site by blocking drains, restoration of habitat etc.								
Improvement of degraded bog							SEI Appendix 7.1 Habitat Management Plan states that compensation for onsite blanket bog loss will be made through restoration management in two off-site locations elsewhere on Yell. 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	15.1	13.7	16.7	The seven borrow pit areas 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	1.22	1.17	1.27	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	A range of – 10 % has been used to calculate the likely minimum.

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
							be the expected average depth of peat extracted.	
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.08	0.0	0.16	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	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	30	30	30	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	

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
guaranteed (years)							guaranteed should be entered as 30 years.	
Removal of drainage from foundations and hardstanding							Chapter 3 (EIAR) 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.	
Restoration of Application Site after decommissioning								
Will hydrology of the Proposed Development site be restored on decommissioning?	Yes	Yes	Yes	Yes	Yes	Yes		
Will you attempt to block any gullies that have	Yes	Yes	Yes	Yes	Yes	Yes	SEI Appendix 10.1 Revised Peat Management and Restoration Plan	

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
formed due to the wind farm?							contains details of post-construction restoration, including gully blocking.	
Will you attempt to block all artificial ditches and facilitate rewetting?	Yes	Yes	Yes	Yes	Yes	Yes	SEI Appendix 10.1 Revised 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	Yes	Yes	Yes		
Will you control grazing on degraded areas?	Yes	Yes	Yes	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.	
Will you manage areas to favour reintroduction of species	Yes	Yes	Yes	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	

	2019 Layout			2020 Layout				
Parameter	**Expected**	**Minimum**	**Maximum**	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
							from the existing habitat or commercial seeds of local genetic provenance.	
Choice of methodology for calculating emission factors	Site specific			Site specific			As required for planning applications.	

16.5 Results

Carbon Balance Assessment – Emissions

16.5.1 The results from the Carbon Balance Assessment are presented below with comparison against the results from the 2019 Layout. The results are 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.

Table 16.2 - Estimated Carbon Emissions During the Construction Phase

	2019 Layout				**2020 Layout**			
Emission source	**Estimated emissions (tCO_2e)**			**% of overall emissions (expected scenario)**	**Estimated emissions (tCO_2e)**			**% of overall emissions (expected scenario)**
	Expected	**Minimum**	**Maximum**		**Expected**	**Minimum**	**Maximum**	
Losses due to turbine life	138,496	137,667	188,098	43 %	150,673	150,016	151,330	44 %
CO_2 loss from excavated peat	33,691	14,661	48,210	11 %	51,717	29,580	80,621	15%
Subtotal of emissions during construction	**172,187**	**152,328**	**236,308**	**54 %**	**202,390**	**179,596**	**231,951**	**59%**

16.5.2 Table 16.2 shows 59 % of the total emissions 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 16.3 - Estimated Carbon Emissions During the Operational Phase

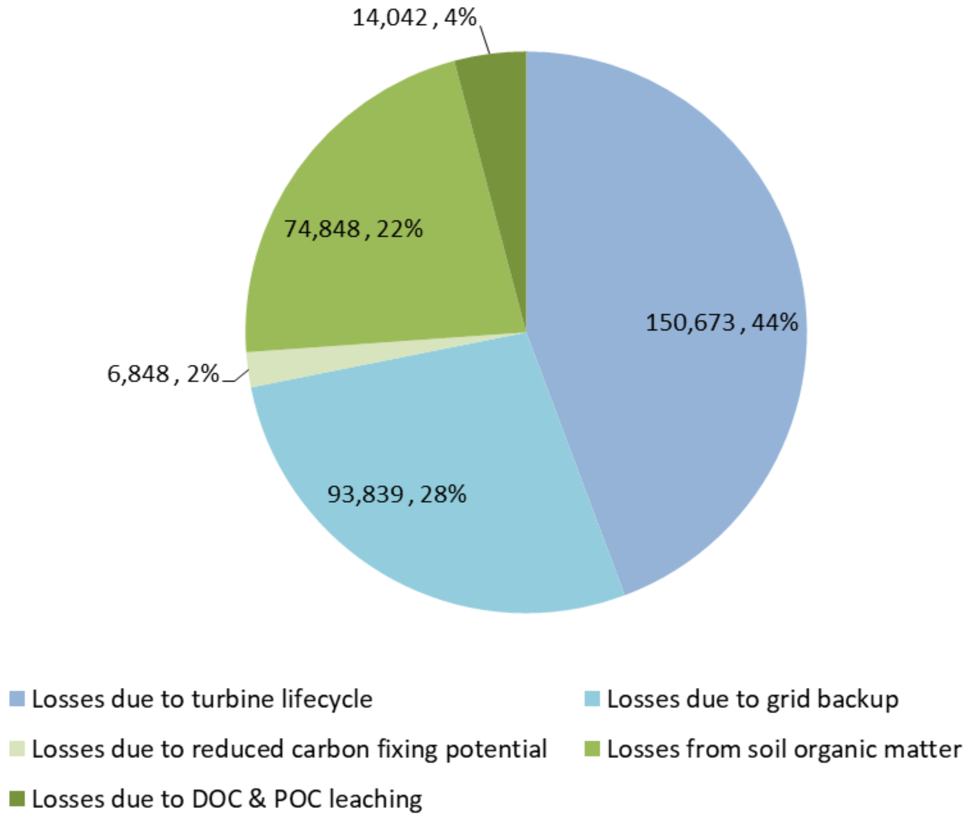
Emission source	2019 Layout: Estimated emissions (tCO_2e)			2019 Layout: % of overall emissions (expected scenario)	2020 Layout: Estimated emissions (tCO_2e)			2020 Layout: % of overall emissions (expected scenario)
	Expected	Minimum	Maximum		Expected	Minimum	Maximum	
Losses due to backup	87,644	87,644	119,196	28%	93,839	93,839	93,839	28%
Losses due to reduced carbon fixing potential	11,823	4,086	26,630	4%	6,848	2,212	16,116	2%
Losses due to DOC & POC leaching	18,580	1,940	60,375	6%	14,042	1,534	44,847	4%
CO_2 loss from drained peat	28,455	-5,184	13,132	9%	23,131	2,896	10,718	7%
Subtotal of emissions during operation	**146,502**	**88,486**	**219,333**	**46%**	**137,860**	**100,481**	**165,520**	**41%**

16.5.3 Table 16.3 shows that a further 41 % 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 11 %, however, losses of carbon fixing potential from bogs only contributes 2 % of the total losses.

16.5.4 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.

16.5.5 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

16.5.6 Table 16.4 shows the estimated carbon gains over the lifetime of the Proposed Development from improvements through restoration, with a comparison between the 2019 and 2020 Layout.

Table 16.4 - Estimated Carbon Gains During the Construction Phase

	2019 Layout				2020 Layout			
Source of gains	Estimated gains (tCO_2e)			% of overall gains (expected scenario)	Estimated gains (tCO_2e)			% of overall gains (expected scenario)
	Expected	Minimum	Maximum		Expected	Minimum	Maximum	
Change in emissions due to restoration of peat from borrow pits	-7,518	-6,002	-7,598	100%	-6,042	-4,841	-6,111	100%

Comparison with the Baseline

16.5.7 The soil carbon losses from the Proposed Development site are estimated at around 89,000 tonnes of CO_2e. This represents around 1.6 % of the total stored carbon on-site (the estimated stored carbon is set out in Table 16.3 of Chapter 16 of the 2019 EIA Report) and includes anticipated losses from excavated and drained peat and losses due to leaching.

Carbon Balance Assessment – Savings

16.5.8 Table 16.5 shows the estimated annual and lifetime CO_2 savings, based on the three different counterfactual emission factors, with a comparison between the 2019 and 2020 Layout. The layout in 2020 is predicted to generate more units of renewable electricity due to the greater overall output of the wind farm, however, during this time, the grid average emission factor has reduced, so each unit generated is worth less carbon, which is why the grid average savings have actually gone down slightly.

Table 16.5 - Estimated Annual and Lifetime Carbon Savings from the Operation of the Proposed Development from the Displacement of Grid Electricity

	2019 Layout			2020 Layout		
Counterfactual emission factor	Estimated savings (tCO_2e per year)			Estimated savings (tCO_2e per year)		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum
Coal-fired electricity generation	594,682	565,531	849,999	652,287	620,313	685,541
Grid-mix of electricity generation	181,955	173,035	260,074	179,790	170,977	188,956
Fossil fuel - mix of electricity generation	297,989	283,382	425,925	319,054	303,414	335,319
	Estimated savings (tCO_2 over lifetime of the Proposed Development)			Estimated savings (tCO_2 over lifetime of the Proposed Development)		
Coal-fired electricity generation	17,850,000	16,980,000	25,500,000	19,560,000	18,600,000	20,580,000
Grid-mix of electricity generation	5,460,000	5,190,000	7,800,000	5,400,000	5,130,000	5,670,000
Fossil fuel - mix of electricity generation	8,940,000	8,490,000	12,780,000	9,570,000	9,090,000	10,050,000

Payback Time and Carbon Intensity

16.5.9 Table 16.6 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, with a comparison between the 2019 and 2020 Layout.

Table 16.6 - Estimated Payback time in years and carbon intensity of the units of electricity produced.

Counterfactual emission factor	2019 Layout			2020 Layout		
	Estimated time to payback (years)			Estimated time to payback (years)		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum
Coal-fired electricity generation	0.5	0.3	0.8	0.5	0.4	0.6
Grid-mix of electricity generation	1.7	0.9	2.6	1.9	1.4	2.3
Fossil fuel - mix of electricity generation	1.0	0.5	1.6	1.0	0.8	1.3
Carbon intensity (kgCO_2e/kWh)	0.016	0.008	0.024	0.016	0.012	0.019

16.5.10 Table 16.6 shows that the 2020 layout is estimated to have a payback of 1.9 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 0.254 kgCO_2e/kWh is currently used in the Carbon Calculator). The payback has increased very marginally for the average grid factor, mainly because of the increased turbine output, which is modelled in the Scottish Government Carbon Calculator as an increase in the embodied carbon required to create the turbines. In reality, this is unlikely to be the case as the size of the turbines is constant; the improvement is in the technology leading to more efficient energy conversion. There has also been a decrease in the average grid emission factor between 2019 and 2020 and this results in an increased payback even if all other inputs are kept constant.

16.6 Sensitivity Analysis

16.6.1 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 16.7. 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 16.7 - Impact of changing individual parameters on expected payback years

	2019 Layout			2020 Layout		
Sensitivity analysis	**Estimated time to payback (years) (based on expected scenario, grid mix electricity factor)**			**Estimated time to payback (years) (based on expected scenario, grid mix electricity factor)**		
	As assessed: Expected	**Reduce parameter**	**Double parameter**	**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	1.9	1.7	2.2
Average water table depth at site (m) – 0.05 m – impact of halving and doubling	1.7	1.7	1.7	1.9	1.8	1.9
Carbon (C) Content of dry peat (% by weight) – 56 % - impact of decreasing and increasing by 50 %	1.7	1.5	2.0	1.9	1.7	2.1
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	1.9	1.7	2.1

16.6.2 Table 16.7 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 0.3 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.

16.6.3 Increasing either the dry soil bulk density or carbon content parameters by 50 % adds about 0.2 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.

16.6.4 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 1.9 years

16.7 Comparison of Effects

16.7.1 The results of the Carbon Calculator for the 2020 Layout show that the Proposed Development is estimated to produce annual carbon savings in the region of 180,000 tonnes of CO_2e per year, and lifetime savings of nearly 5.4 Mt of CO_2e through the displacement of grid electricity, based on a counterfactual emission factor of 0.254 kgCO_2e/kWh. This is in comparison to the annual carbon savings in the region of 182,000 tonnes of CO_2e per year predicted for the 2019 Layout, 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.

16.7.2 The assessment of the carbon losses and gains from the 2020 Layout has estimated an overall loss of around 334,000 tonnes of CO_2e, mainly due to embodied losses from the manufacture of the turbines and provision of backup power to the grid, in comparison to the 311,000 tonnes of CO_2e predicted for the 2019 Layout. It should be noted that the increase in embodied carbon is due to an increase in the installed capacity of the wind farm; there are fewer turbines but each one produces a higher output. The Scottish Government Carbon Calculator estimates the embodied carbon as a function of installed capacity, assuming that an increase in output will produce a corresponding increase in the embodied carbon required to create the turbines. In reality, this is unlikely to be the case as the size of the turbines is fairly constant; the improvement is in the technology leading to more efficient energy conversion. Ecological carbon losses account for 28 % of the total emissions resulting from the 2020 Layout construction and operation, compared to 29 % predicted for the 2019 Layout.

16.7.3 The estimated payback time of the 2020 Layout, using the Scottish Government Carbon Calculator, is estimated at 1.9 years, with a minimum/maximum range of 1.4 to 2.3 years, compared against the estimated 1.7 years payback time for the 2019 Layout. There are no current guidelines about what payback time constitutes a significant impact but 1.9 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 1.9 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 kgCO2e/kWh. This is within the range of the carbon intensity required by the Scottish Government to meet the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 target by 2045 and therefore the Proposed Development is evaluated to have an overall beneficial effect on climate change mitigation.

16.8 References

As per the 2019 EIA Report, with the addition of the following guidance update:

Scottish Government (2019). Climate Change (Emissions Reduction Targets) (Scotland) Act 2019. Available at: www.legislation.gov.uk

Scottish Government (2019). Energy Statistics for Scotland Q3 2019 Figures. December 2019. Available at: https://www2.gov.scot/Resource/0054/00549213.pdf

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