15 APPENDIX: SCOTTISH GOVERNMENT'S CARBON CALCULATOR TOOL

15.1 Methodology

This assessment utilises the Scottish Government's Carbon Calculator Tool (version 1.6.1), which is based upon the work of Nayak et al. (2008, 2010) and Smith et al. (2011). It adopts a lifecycle methodology approach to estimate the GHG emissions and savings associated with onshore windfarms.

Carbon and Peatland

The Proposed Development is sited within an area of peatland which hold stocks of carbon. If disturbed, these stocks have the potential to release carbon into the atmosphere, which then forms CO_2. Thus, this assessment considers the implications of all parts of the Proposed Development which could lead to the release of carbon from peat disturbance.

While flooded, any peatland CO_2 emissions are usually exceeded by plant fixation, so the net exchange of carbon within the atmosphere is negative and soil stocks increase. When soils are aerated, such as when they are removed or drained, CO_2 emissions usually exceed plant fixation so the net exchange of carbon within the atmosphere is positive.

To calculate the CO_2 emissions attributable to the removal or drainage of the peat during construction, emissions occurring if the soil had remained in situ and undrained are subtracted from the emissions occurring after removal or drainage.

Emissions due to the indirect, long-term liberation of CO_2 from carbon stored in peat, due to drying and oxidation processes caused by on-site construction, can also be calculated from site-specific data for the Proposed Development. The resultant figure is a reasonable worst-case scenario, as under good practice, peat would be reused onsite to minimise carbon losses for restoration of the renewables project, and for habitat restoration including ditch blocking.

The indirect loss of CO_2 uptake (fixation) by plants originally on the surface of the site but eliminated by construction activity (including the destruction of active bog plants and felling) is calculated using site-specific data collected as part of the EIA process.

Forestry felling

The presence of extensive areas of forestry on and/or in the vicinity of an onshore wind development can significantly reduce the development's energy yield and/or inhibit the emplacement of the turbines during construction. Common practice has thus been to clear forestry from the surrounding area prior to construction, resulting in a loss in the carbon sequestration potential of the land.

The amount of carbon released into the atmosphere as a result of felling is dependent upon the type of trees being felled, the age of the crop, the use of the timber and how quickly the stored carbon is released into the atmosphere. Cannell (1999, in Nayak et al., 2008) provides estimates for the amounts of carbon sequestered by fast-growth (such as poplar), medium-growth (such as Sitka spruce) and slow-growth (such as beech) trees, as outlined in **Table 15-1**.

Table 15-1: Carbon sequestration potential of fast-, medium- and slow-growing tree species (Cannel, 1999)

	Poplar	Sitka	Beech
Yield Class (m^3 ha^{-1} yr^{-1})	12	16	6
Carbon sequestered, G forest (tCO_2 ha^{-1} yr^{-1})	26.8	13.2	8.8
Crop rotation, t forest (years)	26	55	92
CO_2 sequestered per crop rotation (tCO_2 ha^{-1})	694.66	724.68	808.86

The area of forestry to be felled, coupled with average carbon sequestered per year and the lifetime of the onshore wind development, is used to determine the potential loss of CO_2 due to forestry clearance.

Embodied Emissions

GHG emissions from turbine fabrication are based on a full lifecycle analysis of a typical turbine. This includes GHG emissions resulting from material production, transportation, erection, operation, dismantling and removal of turbines, and from foundations and transmission grid connection equipment to the existing electricity grid system.

15.2 Input data

A variety of data sources have been utilised to compile the input data needed for the Scottish Government's Carbon Calculator tool. Windfarm design and site-specific data have been used wherever possible; however, where not available standard (default) data or estimates have been applied. These are detailed below in **Table 15-2**. To reflect design and real-world uncertainty a range of +/- 10% has been applied to many categories if specific minimum and maximum values are not known.

Table 15-2: Input parameter data for the Scottish Government's Carbon Calculator tool

CARBON CALCULATOR TOOL v1.7.0				**Ref: DWB1-CKFP-QSES**
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Windfarm Characteristics				
Dimensions				
No. of turbines	9	9	9	Chapter 1: Introduction
Duration of consent (years)	35	35	35	Chapter 1: Introduction
Performance				

CARBON CALCULATOR TOOL v1.7.0				Ref: DWB1-CKFP-QSES
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Power rating of 1 turbine (MW)	6.6	5.94	7.26	Chapter 1: Introduction (The exact specifications of the wind turbines may vary through the competitive procurement process. Therefore, for the purposes of the calculator, minimum and maximum power ratings +/- 10% have been applied)
Capacity factor	42	37.8	46.2	Lechwe Renewables, based on wind yield assessments.
Backup				
Fraction of output to backup (%)	0	0	0	Design metrics – BESS applicable, and therefore no back-up anticipated
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10	10	10	Fixed
Total CO_2 emission from turbine life (tCO_2 MW^{-1}) (eg. manufacture, construction, decommissioning)	Calculate wrt installed capacity	Calculate wrt installed capacity	Calculate wrt installed capacity	Scottish Government Carbon Calculator
Characteristics of peatland before windfarm development				
Type of peatland	Acid bog	Acid bog	Acid bog	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Average annual air temperature at site (°C)	8.68	5.66	11.7	Met office - Skye: Prabost weather station
Average depth of peat at site (m)	0.98	0	5.4	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Content of dry peat (% by weight)	43.4	28.2	51.1	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Average extent of drainage around drainage features at site (m)	0.75	0.5	1	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Average water table depth at site (m)	0.1	0	0.3	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Dry soil bulk density (g cm^{-3})	0.08	0.07	0.1	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	10	7	25	Default estimate for sites at this latitude and with similar climatic conditions
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha^{-1} yr^{-1})	0.25	0.12	0.31	SNH Guidance (NatureScot) (SNH, 2003) proposes an average value of 0.25 $tCha^{-1}yr^{-1}$. Minimum and maximum values are taken from estimated global averages of Botch et al. (1995) and Turunen et al. (2001) to be 0.12 to 0.31 $tCha^{-1}yr^{-1}$
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	0	0	0	

CARBON CALCULATOR TOOL v1.7.0				Ref: DWB1-CKFP-QSES
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	3.6	2.4	4.4	Default value (Cannell, 1999)
Counterfactual emission factors				
Coal-fired plant emission factor (t CO_2 MWh^{-1})	0.92	0.92	0.92	Default value (Scottish Government Carbon Calculator)
Grid-mix emission factor (t CO_2 MWh^{-1})	0.25358	0.25358	0.25358	Default value (Scottish Government Carbon Calculator)
Fossil fuel-mix emission factor (t CO_2 MWh^{-1})	0.45	0.45	0.45	Default value (Scottish Government Carbon Calculator)
Borrow pits				
Number of borrow pits	2	1	2	Chapter 2: Project Description
Average length of pits (m)	125	70	180	Borrow Pit Assessment: Table 10.3.1
Average width of pits (m)	105	70	140	Borrow Pit Assessment: Table 10.3.1
Average depth of peat removed from pit (m)	0.51	0.2	0.8	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Foundations and hard-standing area associated with each turbine				
Shape (circular/octagonal/hexagnal)	Circular			Figure 2.5 Indicative Wind Turbine Foundations.pdf
Diameter/side at surface	6	6	6	Figure 2.5 Indicative Wind Turbine Foundations.pdf
Diameter/side at bottom	22.8	22.8	22.8	Figure 2.5 Indicative Wind Turbine Foundations.pdf
Average depth of peat removed from turbine foundations [m]	0.75	0.45	1	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Average length of hard-standing at surface [m]	50	50	50	Figure 2.6 Indicative Crane Hardstanding.pdf
Average length of hard-standing at bottom [m]	50	50	50	Figure 2.6 Indicative Crane Hardstanding.pdf
Average width of hard-standing at surface [m]	22.8	22.8	22.8	Figure 2.6 Indicative Crane Hardstanding.pdf
Average width of hard-standing at bottom [m]	36.5	36.5	36.5	Figure 2.6 Indicative Crane Hardstanding.pdf
Average depth of peat excavated when constructing hard-standing [m]	0.75	0.45	1	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Is piling used? (Yes/No)	No			Figure 2.5 Indicative Wind Turbine Foundations.pdf
Volume of concrete (m^3)	7,020	4,054	9,986	Project Metrics
Access tracks				
Total length of access track (m)	14,300	13,590	15,010	Project Metrics
Existing track length (m)	6,800	6,800	6,800	Project Metrics

CARBON CALCULATOR TOOL v1.7.0				Ref: DWB1-CKFP-QSES
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Length of access track that is floating road (m)	1.4	1.3	1.5	Project Metrics (Figure 2.7 Indicative Track Details.pdf)
Width of access track that is floating road (m)	5	5	5.5	Project Metrics (Figure 2.7 Indicative Track Details.pdf)
Length of access track that is excavated road (m)	6,100	5,490	6,710	Project Metrics (Figure 2.7 Indicative Track Details.pdf)
Excavated road width (m)	5	5	5.5	Project Metrics (Figure 2.7 Indicative Track Details.pdf)
Average depth of peat excavated for road (m)	0.6	0	1.2	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Length of access track that is rock filled road (m)	0	0	0	Project Metrics
Rock filled road width (m)	0	0	0	Project Metrics
Rock filled road depth (m)	0	0	0	Project Metrics
Length of rock filled road that is drained (m)	0	0	0	Project Metrics
Average depth of drains associated with rock filled roads (m)	0	0	0	Project Metrics
Cable trenches				
Length of any cable trench on peat that does not follow access tracks and is lined with a permeable medium (eg. sand) (m)	0	0	0	Project Metrics (All cables to be located within track margins)
Average depth of peat cut for cable trenches (m)	0	0	0	N/A
Additional peat excavated (not already accounted for above)				
Volume of additional peat excavated (m^3)	5,643	4,514	6,772	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Area of additional peat excavated (m^2)	8,338	6,670	10,006	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Peat Landslide Hazard				
Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments	Negligible			Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Improvement of C sequestration at site by blocking drains, restoration of habitat etc				
Improvement of degraded bog				
Area of degraded bog to be improved (ha)	60	40	80	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Water table depth in degraded bog before improvement (m)	0.6	0.3	1	Chapter 9: Hydrology, Geology, Hydrogeology and Peat

CARBON CALCULATOR TOOL v1.7.0				Ref: DWB1-CKFP-QSES
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Water table depth in degraded bog after improvement (m)	0.1	0	0.3	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	30	30	30	It's estimated 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 (Rochefort, Quinty, Campeau, Johnson & Malterer (2003). North American approach to the restoration of Sphagnum dominated peatlands. Wetlands Ecology and Management 11: 3–20)
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	20	15	30	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	0	0	0	No forestry
Water table depth in felled area before improvement (m)	0	0	0	No forestry
Water table depth in felled area after improvement (m)	0	0	0	No forestry
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	2	2	2	No forestry
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	2	2	2	No forestry
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	2.92	2.628	3.212	Lechwe Renewables
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	2	1.8	2.5	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.8	0.5	1	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	20	15	30	Chapter 9: Hydrology, Geology, Hydrogeology and Peat

CARBON CALCULATOR TOOL v1.7.0				Ref: DWB1-CKFP-QSES
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	20	15	30	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Early removal of drainage from foundations and hardstanding				
Water table depth around foundations and hard standing before restoration (m)	0.2	0.1	0.4	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Water table depth around foundation and hard standing after restoration (m)	0.05	0	0.1	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Time to completion of backfilling, removal of any surface drains, and full restoration of hydrology (years)	5	2	5	Chapter 9: Hydrology, Geology, Hydrogeology and Peat
Early removal of drainage from foundations and hardstanding				
Will you attempt to block any gullies that have formed due to the windfarm?	Yes	Yes	Yes	Lechwe Renewables
Will you attempt to block all artificial ditches and facilitate rewetting?	Yes	Yes	Yes	Lechwe Renewables
Will you control grazing on degraded areas?	Yes	Yes	Yes	Lechwe Renewables
Will you manage areas to favour reintroduction of species	Yes	Yes	Yes	Lechwe Renewables
Methodology				
Choice of methodology for calculating emission factors	Site specific (required for planning applications)			

15.3 Output data

Note, these outputs do not include the emissions from the BESS, and therefore may differ to those results presented in the Climate chapter.

Ref: DWB1-CKFP-QSES			
Output data	**Expected value**	**Minimum value**	**Maximum value**
1. Windfarm CO2 emission saving over...			
...coal-fired electricity generation (t CO_2 / yr)	218,982	177,375	264,968
...grid-mix of electricity generation (t CO_2 / yr)	42,262	34,232	51,137
...fossil fuel-mix of electricity generation (t CO_2 / yr)	94,411	76,473	114,238
Energy output from windfarm over lifetime (MWh)	7,649,057	5,664,673	10,048,675

Ref: DWB1-CKFP-QSES			
Output data	**Expected value**	**Minimum value**	**Maximum value**
2. Losses due to turbine life (eg. manufacture, construction, decommissioning)	53,511	47,023	59,998
3. Losses due to backup	0	0	0
4. Losses due to reduced carbon fixing potential	407	115	987
5. Losses from soil organic matter	2,848	-1,449	6,584
6. Losses due to DOC & POC leaching	83	0	533
7. Losses due to felling forestry	0	0	0
Total losses of carbon dioxide	56,849	45,690	68,102
8a. Change in emissions due to improvement of degraded bogs	0	0	0
8b. Change in emissions due to improvement of felled forestry	0	0	0
8c. Change in emissions due to restoration of peat from borrow pits	0	0	-652
8d. Change in emissions due to removal of drainage from foundations & hardstanding	-11	0	-56
Total change in emissions due to improvements	-11	0	-708
Net emissions of carbon dioxide (t CO_2 eq.)	56,838	44,982	68,102
...coal-fired electricity generation (years)	0.3	0.2	0.4
...grid-mix of electricity generation (years)	1.3	0.9	2.0
...fossil fuel-mix of electricity generation (years)	0.6	0.4	0.9
Ratio of soil carbon loss to gain by restoration (not used in Scottish applications)	266.70	-2.05	**No gains**
Ratio of CO_2 eq. emissions to power generation (g/kWh) (for info. only)	7.43	4.48	12.02

15.4 References

Nayak, D.R., Miller, D., Nolan, A., Smith, P., and Smith, J. (2008, revised 2010) Calculating carbon savings from wind farms on Scottish peat lands: a new approach. Available at: https://www.gov.scot/publications/calculating-carbon-savings-wind-farms-scottish-peat-lands-new-approach/

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