APPENDIX 13-1: THE SCOTTISH GOVERNMENT'S CARBON ASSESSMENT TOOL

13-1 Methodology

This carbon balance calculation uses The Scottish Government's Carbon Assessment Tool (version 2.14.1), which is based upon the work of Nayak *et al*., (2008[1], 2010[2]) and Smith *et al*., (2011)[3]. The latest online version of the Scottish Government Carbon Calculator Tool (version 1.8.1) was unavailable during the course of this assessment while undergoing maintenance and a server upgrade. Version 2.14.1 of the Calculator was provided as an Excel spreadsheet calculator by the Energy Consents Unit as a suitable alternative.

The Carbon Assessment Tool adopts a lifecycle methodology approach to estimate the GHG emissions and savings associated with proposed renewable energy developments. It calculates the anticipated effects of the Proposed Development on peat and forestry habitats, and subsequent implications for greenhouse gas (GHG) emissions. The Carbon Assessment Tool also accounts for the emissions associated with the construction and decommissioning of the Proposed Development, as well as the emissions savings from operation.

<u>Embodied emissions</u>

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.

<u>Losses due to back-up</u>

Due to the inherent variability of wind generated electricity, it is recognised that conventional generation facilities are required to stabilise supply. Nayak *et al.,* (2008) refers to 'backup power generation' and identifies that the balancing capacity (as referred to henceforth) required is estimated as 5% of the rated capacity of the wind farm. It is also stated that balancing capacity is only necessary where wind power contributes more than 20% to the national grid.

It is assumed that the balancing capacity is from fossil fuels and that where such power is required, there will be additional emissions of 10% due to reduced thermal efficiency of the reserve generation. This value is the recommended default through the Carbon Assessment tool, sourced from Dale *et al.,* (2004).

[1] Nayak et al, (2008) Available at: http://www.scotland.gov.uk/Publications/2008/06/25114657/0

[2] Nayak, D.R., Miller, D., Nolan, A., Smith, P. and Smith, J.U., (2010), Calculating carbon budgets of wind farms on Scottish peatland. Mires and Peat 4: Art. 9. Available Online: http://www.mires-and-peat.net/map04/map_04_09.htm

[3] Smith, J.U., Graves, P., Nayak, D.R., Smith, P., Perks, M., Gardiner, B., Miller, D., Nolan, A., Morrice, J., Xenakis, G., Waldron, S., and Drew, S. (2011) Carbon implications of windfarms located on peatlands – Update of the Scottish Government Carbon Calculator tool. Final Report, RERAD Report CR/2010/05.

Input data

A variety of data sources have been utilised to compile the input data needed for The Scottish Government's Carbon Assessment Tool. Wind farm 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 13-1**. To reflect design and real-world uncertainty and range of +/- 10% has been applied to many categories.

Table 10-1: Input parameter data for The Scottish Government's Carbon Assessment Tool

CARBON ASSESSMENT TOOL v2.14.1				
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Wind farm characteristics				
Dimensions				
No. of turbines	8	8	8	Chapter 2: Proposed Development
Duration of consent (years)	35	35	35	Chapter 2: Proposed Development
Power rating of 1 turbine (MW)	6.2	5.7	7.0	Chapter 2: Proposed Development
Capacity factor	39.1	38.2	35.7	Infrastructure design and aggregate estimates
Fraction of output to backup (%)	5	5	5	Default value of carbon calculator - (Nayak *et al*., 2008)
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10	10	10	Default value of carbon calculator - (Dale *et al*., 2004)
Total CO_2 emission from turbine life (tCO_2 MW^{-1}) (e.g. manufacture, construction, decommissioning)	Calculate with reference to installed capacity	Calculate with reference to installed capacity	Calculate with reference to installed capacity	Default value of carbon calculator
Type of peatland	Acid Bog			Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Average annual air temperature at site (°C)	8.73	5.24	12.21	Met office weather station: Fort Augustus
Average depth of peat at site (m)	0.94	0	3.5	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)

CARBON ASSESSMENT TOOL v2.14.1				
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Content of dry peat (% by weight)	55	49	61	Default value of carbon calculator - (Birnie *et al.*, 1991)
Average extent of drainage around drainage features at site (m)	10	2	30	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Average water table depth at site (m)	0.13	0.13	0.13	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Dry soil bulk density (g cm^{-3})	0.2	0.2	0.2	Default value of carbon calculator - (Turunen *et al.*, 2001; Botch *et al.*, 1995)
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	3	3	10	Ecology Specialist (Chapter 6: Ecology)
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha^{-1} yr^{-1})	0.25	0.225	0.275	Default value of carbon calculator - (Lilly *et al.*, 2010)
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	0	0	0	Not applicable
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	0	0	0	Not applicable
Counterfactual emission factors				
Coal-fired plant emission factor (t CO_2 MWh^{-1})	0.945	0.945	0.945	Default value
Grid-mix emission factor (t CO_2 MWh^{-1})	0.207	0.207	0.207	Default value
Fossil fuel-mix emission factor (t CO_2 MWh^{-1})	0.424	0.424	0.424	Default value
Borrow pits				
Number of borrow pits	1	1	2	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Average length of pits (m)	80	80	80	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Average width of pits (m)	61	61	61	Peat Specialist (Chapter 8: Hydrology,

CARBON ASSESSMENT TOOL v2.14.1				
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
				Hydrogeology, Geology and Peat)
Average depth of peat removed from pit (m)	0.0	0	0.0	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Foundations and hard-standing area associated with each turbine				
Shape (circular/octagonal/hexagonal)	Rectangular			Infrastructure design and aggregate estimates
Average length of turbine foundations [m]	27	27	27	Infrastructure design and aggregate estimates
Average width of turbine foundations [m]	27	27	27	Infrastructure design and aggregate estimates
Average depth of peat removed from turbine foundations [m]	0.375	0	1	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Average length of hard-standing [m]	85	78	85	Infrastructure design and aggregate estimates
Average width of hard-standing [m]	35	35	35	Infrastructure design and aggregate estimates
Average depth of peat excavated when constructing hard-standing [m]	0.375	0	1	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Volume of concrete (m^3)	3,465	1,982	4,948	Infrastructure design and aggregate estimates
Access tracks				
Total length of access track (m)	2,295.35	2,295.35	2,295.35	Infrastructure design and aggregate estimates
Existing track length (m)	19,350	19,350	19,350	Infrastructure design and aggregate estimates
Length of access track that is floating road (m)	239	239	239	Infrastructure design and aggregate estimates
Width of access track that is floating road (m)	5.5	5.5	5.5	Chapter 2: Proposed Development
Depth of floating road (m)	0.7	0.6	0.8	Infrastructure design and aggregate estimates

CARBON ASSESSMENT TOOL v2.14.1				
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Length of floating road that is drained (m)	0	0	0	Infrastructure design and aggregate estimates
Average depth of drains associated with floating roads (m)	0	0	0	Infrastructure design and aggregate estimates
Length of access track that is excavated road (m)	2,037	2,037	2,037	Infrastructure design and aggregate estimates
Excavated road width (m)	5.5	5.5	5.5	Infrastructure design and aggregate estimates
Average depth of peat excavated for road (m)	0.8	0	1.2	Peat Specialist (Chapter 12: Land, Soil and Water)
Length of access track that is rock filled road (m)	0	0	0	Infrastructure design and aggregate estimates
Rock filled road width (m)	0	0	0	Infrastructure design and aggregate estimates
Rock filled road depth (m)	0	0	0	Infrastructure design and aggregate estimates
Length of rock filled road that is drained (m)	0	0	0	Infrastructure design and aggregate estimates
Average depth of drains associated with rock filled roads (m)	0	0	0	Infrastructure design and aggregate estimates
Cable trenches				
Length of any cable trench on peat that does not follow access tracks and is lined with a permeable medium (e.g. sand) (m)	0	0	0	Infrastructure design and aggregate estimates
Average depth of peat cut for cable trenches (m)	0	0	0	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Additional peat excavated (not already accounted for above)				
Volume of additional peat excavated (m^3)	0	0	0	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Area of additional peat excavated (m^2)	0	0	0	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Peat Landslide Hazard				

CARBON ASSESSMENT TOOL v2.14.1				
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments	Low	Low	Low	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology 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)	76.8	25.38	128.17	Ecology Specialist (Chapter 6: Ecology)
Water table depth in degraded bog before improvement (m)	0.6	0.3	1	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Water table depth in degraded bog after improvement (m)	0.1	0	0.3	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	5	5	20	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	35	35	35	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	0	0	0	No improvement assumed.
Water table depth in felled area before improvement (m)	0	0	0	No improvement assumed.
Water table depth in felled area after improvement (m)	0	0	0	No improvement assumed.
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	0	0	0	No improvement assumed.
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	0	0	0	No improvement assumed.
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	0	0	0	Not Applicable
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	0	0	0	Not Applicable

CARBON ASSESSMENT TOOL v2.14.1				
Input data	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0	0	0	Not Applicable
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	0	0	0	Not Applicable
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	0	0	0	Not Applicable
Early removal of drainage from foundations and hardstanding				
Water table depth around foundations and hard standing before restoration (m)	0.13	0.13	0.13	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Water table depth around foundation and hard standing after restoration (m)	0.05	0	0.1	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology and Peat)
Time to completion of backfilling, removal of any surface drains, and full restoration of hydrology (years)	2	1	5	Peat Specialist (Chapter 8: Hydrology, Hydrogeology, Geology 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	Applicant
Will you attempt to block all artificial ditches and facilitate rewetting?	Yes	Yes	Yes	Applicant
Will you control grazing on degraded areas?	No	No	No	Applicant
Will you manage areas to favour reintroduction of species	No	No	No	Applicant
Methodology				
Choice of methodology for calculating emission factors	Site specific (required for planning applications)			

Output data

CARBON ASSESSMENT TOOL v2.14.1			
Output data	**Expected value**	**Minimum value**	**Maximum value**
1. Wind farm CO_2 emission saving over...			
...coal-fired electricity generation (t CO_2 / yr)	160,544	144,200	165,498

CARBON ASSESSMENT TOOL v2.14.1			
Output data	**Expected value**	**Minimum value**	**Maximum value**
...grid-mix of electricity generation (t CO_2 / yr)	35,167	31,587	36,252
...fossil fuel-mix of electricity generation (t CO_2 / yr)	72,032	64,699	74,255
Energy output from windfarm over lifetime (MWh)	5,946,078	5,340,727	6,129,547
2. Total CO_2 losses due to wind farm (tCO_2e)			
2. Losses due to turbine life (e.g. manufacture, construction, decommissioning)	43,698	39,492	50,147
3. Losses due to backup	32,240	29,640	36,400
4. Losses due to reduced carbon fixing potential	214	82	765
5. Losses from soil organic matter	5,017	-64	14,650
6. Losses due to DOC & POC leaching	146	0	1,303
7. Losses due to felling forestry	0	0	0
Total losses of carbon dioxide	**81,315**	**69,150**	**103,265**
8. Total CO_2 changes due to improvement of site (tCO_2e)			
8a. Change in emissions due to improvement of degraded bogs	-39,201	0	-62,504
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	0
8d. Change in emissions due to removal of drainage from foundations & hardstanding	0	0	0
Total change in emissions due to improvements	**-39,201**	**0**	**-62,504**
Results			
Net emissions of carbon dioxide (tCO_2e)	**42,114**	**6,646**	**103,265**
Carbon Payback Time			
...coal-fired electricity generation (years)	0.3	0.0	0.7
...grid-mix of electricity generation (years)	1.2	0.2	3.3
...fossil fuel-mix of electricity generation (years)	0.6	0.1	1.6
Ratio of soil carbon loss to gain by restoration (not used in Scottish applications)	**No Gains**	**No Gains**	**No Gains**