TECHNICAL APPENDIX 14.2: SCOTTISH GOVERNMENT'S CARBON CALCULATOR TOOL

1 Methodology

1.1 This assessment uses the Scottish Government's Carbon Calculator Tool (version 2.14.1), 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.

Embodied Emissions

1.2 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.

Losses due to back-up

1.3 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.

1.4 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.

2 Input Data

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

Table 1 Input parameter data for the Scottish Government's Carbon Calculator tool

CARBON CALCULATOR TOOL v2.14.1				
1. Input data	Expected value	Minimum value	Maximum value	Source of data
Windfarm Characteristics				
Dimensions				
No. of turbines	12	12	12	Chapter 3: Project Description
Duration of consent (years)	40	40	40	Chapter 3: Project Description
Performance				
Power rating of 1 turbine (MW)	6.8	6.8	6.8	Chapter 3: Project Description
Capacity factor	35.0	30.0	40.0	Department of Business, Energy and Industrial Strategy (2020) Renewable electricity in Scotland, Wales, Northern Ireland, and the regions of England in 2020.
Backup				
Fraction of output to backup (%)	5%	5%	5%	Standard value recommended by the carbon calculator (Assumes more than 20% of national electricity is generated by wind energy)
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			
Average annual air temperature at site (°C)	9.58	6.08	13.08	Met Office Climate Station - Dumfries
Average depth of peat at site (m)	0.30	0.20	0.40	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Content of dry peat (% by weight)	55	49	61	Default value.

CARBON CALCULATOR TOOL v2.14.1				
1. **Input data**	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Average extent of drainage around drainage features at site (m)	0.75	0.50	1.00	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Average water table depth at site (m)	0.40	0.20	0.80	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Dry soil bulk density (g cm^{-3})	0.20	0.18	0.22	Default value.
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	3	3	10	Chapter 8: 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.
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	3	3	10	Chapter 14: Other issues
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	3.6	3.24	3.96	Default value.
Counterfactual emission factors				
Coal-fired plant emission factor (t CO_2 MWh^{-1})	0.925	0.925	0.925	Default value (Scottish Government Carbon Calculator)
Grid-mix emission factor (t CO_2 MWh^{-1})	0.0.34885	0.0.34885	0.34885	Default value (Scottish Government Carbon Calculator)
Fossil fuel-mix emission factor (t CO_2 MWh^{-1})	0.477	0.477	0.477	Default value (Scottish Government Carbon Calculator)
Borrow pits				
Number of borrow pits	0	0	0	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Average length of pits (m)	0	0	0	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Average width of pits (m)	0	0	0	Chapter 10: Hydrology, Hydrogeology, Geology and Soils

CARBON CALCULATOR TOOL v2.14.1				
1. Input data	Expected value	Minimum value	Maximum value	Source of data
Average depth of peat removed from pit (m)	0	0	0	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Foundations and hard-standing area associated with each turbine				
Shape (circular/octagonal/hexagnal)	Circular			Infrastructure design and aggregate estimates
Diameter/side at surface (m)	26	26	26	Infrastructure design and aggregate estimates
Diameter/side at bottom (m)	26	26	26	Infrastructure design and aggregate estimates
Average depth of peat removed from turbine foundations [m]	0.2	0.2	0.3	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Average length of hard-standing at surface [m]	94	94	94	Infrastructure design and aggregate estimates
Average length of hard-standing at bottom [m]	94	94	94	Infrastructure design and aggregate estimates
Average width of hard-standing at surface [m]	42	42	42	Infrastructure design and aggregate estimates
Average width of hard-standing at bottom [m]	42	42	42	Infrastructure design and aggregate estimates
Average depth of peat excavated when constructing hard-standing [m]	0.3	0.2	0.3	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Is piling used? (Yes/No)			No	Infrastructure design and aggregate estimates
Volume of concrete (m^3)	9,851	9,851	9,851	Infrastructure design and aggregate estimates
Access tracks				
Total length of access track (m)	31,506	28,355	34,657	Infrastructure design and aggregate estimates
Existing track length (m)	20,985	18,887	23,084	Infrastructure design and aggregate estimates

CARBON CALCULATOR TOOL v2.14.1				
1. Input data	Expected value	Minimum value	Maximum value	Source of data
Length of access track that is floating road (m)	638	574	702	Infrastructure design and aggregate estimates
Width of access track that is floating road (m)	5.5	4.95	6.05	Infrastructure design and aggregate estimates
Floating road depth (m)	0.7	0.6	0.8	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Length of floating road that is drained (m)	320	285	350	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Average depth of drains associated with floating roads (m)	0.3	0.0	0.5	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Length of access track that is excavated road (m)	0	0	0	Infrastructure design and aggregate estimates
Excavated road width (m)	0	0	0	Infrastructure design and aggregate estimates
Average depth of peat excavated for road (m)	0	0	0	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Length of access track that is rock filled road (m)	9,883	8,895	10,871	Infrastructure design and aggregate estimates
Rock filled road width (m)	5.5	4.95	6.05	Infrastructure design and aggregate estimates
Rock filled road depth (m)	0.8	0.6	1.0	Infrastructure design and aggregate estimates
Length of rock filled road that is drained (m)	9,883	8,895	10,871	Infrastructure design and aggregate estimates
Average depth of drains associated with rock filled roads (m)	0.3	0.2	0.5	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 (eg. sand) (m)	0	0	0	Infrastructure design and aggregate estimates

CARBON CALCULATOR TOOL v2.14.1				
1. Input data	Expected value	Minimum value	Maximum value	Source of data
Average depth of peat cut for cable trenches (m)	0	0	0	Infrastructure design and aggregate estimates
Additional peat excavated (not already accounted for above)				
Volume of additional peat excavated (m^3)	23,251	23,251	23,251	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Area of additional peat excavated (m^2)	81,839	81,839	81,839	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Peat Landslide Hazard				
Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments	None			Chapter 10: Hydrology, Hydrogeology, Geology and Soils
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)	17.7	17.7	17.7	Outline Habitat Management Plan
Water table depth in degraded bog before improvement (m)	0.60	0.30	1.00	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Water table depth in degraded bog after improvement (m)	0.10	0.00	0.30	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	35	20	50	As per Natural Englands England Peat Action Plan, good hydrological and ecological functionality possible in a minimum of 20 years and maximum of 50 years, expected value is in the middle of these.
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	5	0	20	As per Natural Englands England Peat Action Plan, good hydrological and ecological functionality possible in a minimum of 20 years and maximum of 50 years,

CARBON CALCULATOR TOOL v2.14.1				
1. Input data	Expected value	Minimum value	Maximum value	Source of data
				expected value is in the middle of these.
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	5.14	5.14	5.14	Chapter 14: Other issues
Water table depth in felled area before improvement (m)	0.24	0.03	0.45	Allott et al. (2009)
Water table depth in felled area after improvement (m)	0.25	0.03	0.48	Allott et al. (2009)
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	20	15	30	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	20	10	25	Chapter 10: Hydrology, Hydrogeology, Geology and Soils
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	0	0	0	N/A
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	0	0	0	N/A
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0	0	0	N/A
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	0	0	0	N/A
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	0	0	0	N/A
Early removal of drainage from foundations and hardstanding				
Water table depth around foundations and hard standing before restoration (m)	0	0	0	N/A
Water table depth around foundation and hard standing after restoration (m)	0	0	0	N/A
Time to completion of backfilling, removal of any surface drains, and full restoration of hydrology (years)	0	0	0	N/A
Early removal of drainage from foundations and hardstanding				

CARBON CALCULATOR TOOL v2.14.1				
1. Input data	Expected value	Minimum value	Maximum value	Source of data
Will you attempt to block any gullies that have formed due to the windfarm?	No	No	Yes	Scottish Power
Will you attempt to block all artificial ditches and facilitate rewetting?	No	No	Yes	Scottish Power
Will you control grazing on degraded areas?	Not applicable	Not applicable	Not applicable	Scottish Power
Will you manage areas to favour reintroduction of species	No	No	Yes	Scottish Power
Methodology				
Choice of methodology for calculating emission factors	Site specific (required for planning applications)			

3 Output data

Output data	Expected value	Minimum value	Maximum value
1. Windfarm CO_2 emission saving over...			
...coal-fired electricity generation (t CO_2 / yr)	231,422	198,361	264,482
...grid-mix of electricity generation (t CO_2 / yr)	87,277	74,809	99,745
...fossil fuel-mix of electricity generation (t CO_2 / yr)	119,339	102,290	136,387
Energy output from windfarm over lifetime (MWh)	10,007,424	8,577,792	1,1437,056
2. Total CO_2 losses due to wind farm (tCO_2e)			
2. Losses due to turbine life (e.g. manufacture, construction, decommissioning)	73,745	73,745	73,745
3. Losses due to backup	68,193	68,193	68,193
4. Losses due to reduced carbon fixing potential	1119	850	1604
5. Losses from soil organic matter	18309	-332	43532
6. Losses due to DOC & POC leaching	0	0	57
7. Losses due to felling forestry	105182	94664	115700
Total losses of carbon dioxide*	266549	237120	302832
3. Total CO_2 changes due to improvement of site (tCO_2e)			
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	- 512
8c. Change in emissions due to restoration of peat from borrow pits	0	0	0

Output data	Expected value	Minimum value	Maximum value
8d. Change in emissions due to removal of drainage from foundations & hardstanding	0	0	0
Total change in emissions due to improvements	0	0	-512
Results			
Net emissions of carbon dioxide (tCO_2e)*	266,549	236,608	302,832
...coal-fired electricity generation (years)*	1.2	0.9	1.5
...grid-mix of electricity generation (years)*	3.1	2.4	4.0
...fossil fuel-mix of electricity generation (years)*	2.2	1.7	3.0
Ratio of soil carbon loss to gain by restoration (not used in Scottish applications)	No gains	No gains	No gains