APPENDIX 14.2: SCOTTISH GOVERNMENT'S CARBON CALCULATOR TOOL

15.1 Methodology

15.1.1 This assessment uses the Scottish Government's Carbon Calculator Tool (version 1.7.0), which is based upon the work of Nayak et al. (2008, 2010) and Smith et al. (2011)[1]. It adopts a lifecycle methodology approach to estimate the GHG emissions and savings associated with onshore windfarms.

Embodied Emissions

15.1.2 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. The Scottish Government's Carbon Calculator Tool includes embodied emissions from Turbines and their foundations, but not for Battery Energy Storage System (BESS). As such, a supplementary life cycle analysis of BESS has been conducted and integrated within the calculator outputs.[2]

Losses due to back-up

15.1.3 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.

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.

The inclusion of a battery energy storage system (BESS) within the Proposed Development removes the need for backup power generation, allowing the input value for this Development to be 0%.

15.2 Input data

15.2.1 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

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[1] 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.

[2] Romare, M., and L. Dahllöf (2017) The Life Cycle Energy Consumption and Greenhouse Gas Emissions from Lithium-Ion Batteries, A Study with Focus on Current Technology and Batteries for light-duty vehicles. IVL Swedish Environmental Research Institute Ltd. C 243

or estimates have been applied. These are detailed below in Table 0.1.1. To reflect design and real-world uncertainty and range of +/- 10% has been applied to many categories.

Table 0.1.1: Input parameter data for the Scottish Government's Carbon Calculator tool

CARBON CALCULATOR TOOL v1.7.0				**Ref: TRP6-0F55-NBIA (v2)**
1. **Input data**	**Expected value**	**Minimum value**	**Maximum value**	**Source of data**
Windfarm Characteristics				
Dimensions				
No. of turbines	10	10	10	Chapter 1: Introduction
Duration of consent (years)	40	40	40	Chapter 1: Introduction
Performance				
Power rating of 1 turbine (MW)	7.0	6.3	7.7	Chapter 1: Introduction
Capacity factor	25.3	22.77	27.83	Chapter 1: Introduction
Backup				
Fraction of output to backup (%)	0	0	0	BESS Present (40 MWh)
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 8: Geology, Hydrogeology, Hydrology and Peat
Average annual air temperature at site (°C)	9.825	6.46	13.19	Met Office – Paisley climate station
Average depth of peat at site (m)	0.6	0	4	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Content of dry peat (% by weight)	48	38	56	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Average extent of drainage around drainage features at site (m)	10	5	25	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Average water table depth at site (m)	0.1	0.05	0.3	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Dry soil bulk density (g cm^{-3})	0.2	0.18	0.22	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	3	2	5	Chapter 8: Geology, Hydrogeology, Hydrology and Peat

CARBON CALCULATOR TOOL v1.7.0				Ref: TRP6-0F55-NBIA (v2)
1. Input data	Expected value	Minimum value	Maximum value	Source of data
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)	0.1	0.09	0.11	Chapter 14: Other issues (Forestry)
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	3.6	2.4	4.4	Chapter 14: Other issues (Forestry)
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	3	3	3	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Average length of pits (m)	83	74.7	91.3	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Average width of pits (m)	93	83.7	102.3	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Average depth of peat removed from pit (m)	0.26	0.18	0.34	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Foundations and hard-standing area associated with each turbine				
Shape (circular/octagonal/hexagnal)	Circular or octagonal			Chapter 2: Proposed Development
Diameter/side at surface (m)	28	28	28	Chapter 2: Proposed Development
Diameter/side at bottom (m)	28	28	28	Chapter 2: Proposed Development
Average depth of peat removed from turbine foundations [m]	0.44	0.1	0.8	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Average length of hard-standing at surface [m]	192	192	192	Chapter 2: Proposed Development
Average length of hard-standing at bottom [m]	192	192	192	Chapter 2: Proposed Development
Average width of hard-standing at surface [m]	58	58	58	Chapter 2: Proposed Development
Average width of hard-standing at bottom [m]	58	58	58	Chapter 2: Proposed Development
Average depth of peat excavated when	0.52	0.5	0.55	Chapter 8: Geology, Hydrogeology, Hydrology and Peat

CARBON CALCULATOR TOOL v1.7.0				Ref: TRP6-0F55-NBIA (v2)
1. Input data	Expected value	Minimum value	Maximum value	Source of data
constructing hard-standing [m]				
Is piling used? (Yes/No)		No		Chapter 2: Proposed Development
Volume of concrete (m^3)	13,044	11,740	14,349	Chapter 9: Traffic & Transport
Access tracks				
Total length of access track (m)	9,200	8,280	10,120	Infrastructure design and aggregate estimates
Existing track length (m)	0	0	0	Infrastructure design and aggregate estimates
Length of access track that is floating road (m)	0	0	0	Infrastructure design and aggregate estimates
Width of access track that is floating road (m)	0	0	0	Infrastructure design and aggregate estimates
Length of access track that is excavated road (m)	9,200	8,280	10,120	Infrastructure design and aggregate estimates
Excavated road width (m)	6	5.5	7	Infrastructure design and aggregate estimates
Average depth of peat excavated for road (m)	0.52	0.52	0.52	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
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 (eg. sand) (m)	0	0	0	Infrastructure design and aggregate estimates
Average depth of peat cut for cable trenches (m)	0	0	0	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Additional peat excavated (not already accounted for above)				
Volume of additional peat excavated (m^3)	3,681	3,600	3,700	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Area of additional peat excavated (m^2)	18,706	18,700	18,800	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Peat Landslide Hazard				
Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments	Negligible	Negligible	Negligible	Fixed
Improvement of C sequestration at site by blocking drains, restoration of habitat etc				

CARBON CALCULATOR TOOL v1.7.0				Ref: TRP6-0F55-NBIA (v2)
1. Input data	Expected value	Minimum value	Maximum value	Source of data
Improvement of degraded bog				
Area of degraded bog to be improved (ha)	89.9	89.94	89.94	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Water table depth in degraded bog before improvement (m)	0.3	0.1	0.5	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Water table depth in degraded bog after improvement (m)	0.1	0.05	0.3	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	5	2	10	Chapter 8: Geology, Hydrogeology, Hydrology and Peat The speed of regeneration depends on species present and their colonising ability and traits, as well as the methods of restoration and maintenance of hydrology. These estimates have been informed by: Whitelee Phase 3 Technical Appendix 9.1 Appendix B Restoring blanket bog from commercial forestry: summary of monitoring and management interventions at two large windfarm sites 2004 – 2011; NaturalEngland (2023) Biodiversity Metric 4 time to target guidance; other online sources, academic literature (e.g. Anderson & Peace, 2017) and observations from other wind farms during surveys.
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	15	10	20	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	0.1	0	0.1	Chapter 14: Other issues (Forestry)
Water table depth in felled area before improvement (m)	0.3	0.1	0.5	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Water table depth in felled area after improvement (m)	0.1	0.05	0.3	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	10	5	15	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	15	10	20	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	2.24	2.2	2.3	Chapter 8: Geology, Hydrogeology, Hydrology and Peat

CARBON CALCULATOR TOOL v1.7.0				Ref: TRP6-0F55-NBIA (v2)
1. Input data	Expected value	Minimum value	Maximum value	Source of data
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	0.3	0.2	0.4	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.2	0.15	0.35	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	10	8	12	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	22	20	23	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Early removal of drainage from foundations and hardstanding				
Water table depth around foundations and hard standing before restoration (m)	0	0	0	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Water table depth around foundation and hard standing after restoration (m)	0	0	0	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Time to completion of backfilling, removal of any surface drains, and full restoration of hydrology (years)	0.1	0.1	0	Chapter 8: Geology, Hydrogeology, Hydrology 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	No	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Will you attempt to block all artificial ditches and facilitate rewetting?	No	No	No	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Will you control grazing on degraded areas?	Yes	Yes	Yes	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Will you manage areas to favour reintroduction of species	No	No	No	Chapter 8: Geology, Hydrogeology, Hydrology and Peat
Methodology				
Choice of methodology for calculating emission factors	Site specific (required for planning applications)			

15.3 Output data

Ref: TRP6-0F55-NBIA (v2)			
Output data	**Expected value**	**Minimum value**	**Maximum value**
1. Windfarm CO_2 emission saving over...			
...coal-fired electricity generation (t CO2 / yr)	155,450	125,914	188,094
...grid-mix of electricity generation (t CO2 / yr)	30,001	24,301	36,301
...fossil fuel-mix of electricity generation (t CO2 / yr)	67,020	54,286	81,095
Energy output from windfarm over lifetime (MWh)	6,205,584	5,026,523	7,508,757
2. Total CO_2 losses due to wind farm (tCO_2e)			
2. Losses due to turbine life (e.g. manufacture, construction, decommissioning)	64,851	57,898	71,804
3. Losses due to backup	0	0	0
4. Losses due to reduced carbon fixing potential	1,890	595	4,944
5. Losses from soil organic matter	29,990	12,883	46,359
6. Losses due to DOC & POC leaching	59	0	306
7. Losses due to felling forestry	53	32	71
8. Losses due to embodied emissions of BESS*	8,000	7,200	8,800
Total losses of carbon dioxide*	104,842	78,608	132,284
3. Total CO_2 changes due to improvement of site (tCO_2e)			
8a. Change in emissions due to improvement of degraded bogs	-7,123	0	-22,894
8b. Change in emissions due to improvement of felled forestry	-4	0	-21
8c. Change in emissions due to restoration of peat from borrow pits	-149	0	-343
8d. Change in emissions due to removal of drainage from foundations & hardstanding	0	0	0
Total change in emissions due to improvements	-7,276	0	-23,258
Results			
Net emissions of carbon dioxide (tCO_2e)*	97,566	55,350	132,284
...coal-fired electricity generation (years)*	0.6	0.3	1.1
...grid-mix of electricity generation (years)*	3.3	1.5	5.4
...fossil fuel-mix of electricity generation (years)*	1.5	0.7	2.4
Ratio of soil carbon loss to gain by restoration (not used in Scottish applications)	4.13	0.55	No gains!
?* Blue shaded cells denote those that have been modified from the carbon calculator output due to the inclusion of embodied emissions from BESS			