APPENDIX A16.6

CARBON PAYBACK CALCULATIONS

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APPENDIX A16.6 CARBON PAYBACK CALCULATIONS

1.1.1 Counter-factual emissions

The capacity factor, or percentage efficiency, of the wind farm has been calculated to be 46.3%, i.e. on average the wind farm will generate 46.3% of its theoretical production capacity.

The annual average energy output of the wind farm, based on 24 hour, 365 days of the year operation is presented in Table A16.1.

Table A16.1 Annual energy output of the wind farm

Characteristic	**Value**
Number of wind turbines	127
Turbine capacity (MW)	3.6
Total power of wind farm (MW)	457.2
Capacity factor (percentage efficiency)	46.3%
Annual average energy output from wind farm (MWh yr^{-1})	1,854,348

A summary of the carbon emissions savings resulting from the wind farm is presented in Table A16.2.

Table A16.2 Carbon offset emissions savings

Characteristic	**Value**
Annual average energy output from wind farm (MWh yr^{-1})	1,854,348
Fossil fuel mix emission factor (tCO_2 MWh^{-1})	0.607
Annual CO_2 emission saving ($MtCO_2$)	1.13
CO_2 emission saving over the 25-year lifetime of the wind farm ($MtCO_2$)	28.14

The proposed wind farm will, therefore, result in a saving of 28.14 Mt (megatonnes) of CO_2 being released to atmosphere.

If, however, the grid mix emissions factor of 0.43 tCO_2 MWh^{-1} is applied then the calculated carbon savings will be reduced by approximately 30%, giving an annual CO_2 emission saving of 0.8 Mt, and 19.93Mt over the lifetime of the wind farm.

1.1.2 Loss of carbon due to turbine lifecycle

The carbon lifecycle of wind turbines included the carbon costs associated with the manufacturing of wind turbines, transportation, on-site construction, ongoing operation and decommissioning. The carbon emissions associated with a typical turbine have been evaluated by a number of companies as discussed in the CCS Report. Based on the results of these studies an equation has been developed to estimate the carbon lifecycle of a turbine based on its generating capacity as follows:

$L_{Life} = (934.35 \times c_{turb}) - 467.55$ where L_{Life} is the carbon lifecycle loss (t CO_2 turbine^{-1});

C_{turb} is the turbine capacity (MW)

It should be noted that the formula is taken from the most recent version of the CCS Spreadsheet (December 2009) and differs from that contained in the original CCS Report. The estimated emissions due to the carbon lifecycle are outlined in Table A16.3.

Table A16.3 Carbon lifecycle loss

Characteristic	Value
Turbine capacity, c_{Turb} (MW)	3.6
Carbon lifecycle loss, L_{Life} (t CO_2 turbine^{-1})	2,896.11
Number of turbines	127
Total carbon lifecycle loss (kte)	**367.8**

The total carbon loss associated with the lifecycle of the turbines is, therefore 367.8 kte.

1.1.3 Loss of carbon due to backup power generation

The emissions associated with the provision of this backup, assuming a fossil-fuelled thermal power generation backup as a worst case, are presented in Table A16.4.

Table 16.4 Backup power generation loss

Characteristic	Value
Rated capacity of wind farm wind farm (MWh yr^{-1})	4,005,071
Backup power generating requirement (MWh yr^{-1}) (5% of rated capacity)	200,253
Addional production requirement due to thermal efficiency reduction (MWh yr^{-1}) (10% of backup power)	20,025
Fossil fuel mix emission factor (tCO_2 MWh^{-1})	0.607
Annual CO_2 emission for backup (MtCO_2)	0.012
CO_2 emission over the 3-year period for which backup will be required (MtCO_2)	0.036

The overall emission associated with the requirement for backup power generation is therefore 0.036Mt CO_2.

1.1.4 Loss of carbon fixing potential of peatlands

The total CO_2 emission associated with the loss of carbon fixing potential is a function of the carbon flux rate and the area of vegetation.

The total surface areas covered by each vegetation type, for each scenario, are presented in Tables 16.5 – 16.7.

Table 16.5 Vegetation Survey Area Classifications, 10m Scenario

Quadrant	Bare Peat	Hagged &Gullied	Improved	Undamaged	None
Delting	0	0.355	0.203	0.060	0
Kergord	0	0.646	0.195	0.009	0
Nesting	0.039	0.601	0.109	0.048	0.014
Total (km^2)	**0.039**	**1.602**	**0.507**	**0.118**	**0.014**
Total (ha)	**3.9**	**160.2**	**50.7**	**11.8**	**1.4**

Table 16.5 Vegetation Survey Area Classifications, 20m Scenario

Quadrant	Bare Peat	Hagged &Gullied	Improved	Undamaged	None
Delting	0	0.505	0.266	0.076	0
Kergord	0	0.885	0.262	0.016	0
Nesting	0.052	0.803	0.153	0.093	0.015
Total (km^2)	**0.052**	**2.193**	**0.681**	**0.185**	**0.015**
Total (ha)	**5.2**	**219.3**	**68.1**	**18.5**	**1.5**

Table 16.5 Vegetation Survey Area Classifications, 50m Scenario

Quadrant	Bare Peat	Hagged &Gullied	Improved	Undamaged	None
Delting	0	1.057	0.444	0.139	0
Kergord	0	1.769	0.487	0.049	0
Nesting	0.096	1.589	0.295	0.296	0.016
Total (km^2)	**0.096**	**4.415**	**1.226**	**0.483**	**0.016**
Total (ha)	**9.6**	**441.5**	**122.6**	**48.3**	**1.6**

The total carbon flux over the project lifetime is a product of the habitat type and the relevant flux rate. The total flux calculated for each drainage scenario are presented in Tables A16.6 – A16.8.

Table A16.6 Carbon flux over project lifetime, 10m scenario

	Area (ha)	Flux Rate (t CO2 ha^{-1} yr^{-1})	Emission (t CO_2 yr^{-1})	Total over project lifetime (t CO2)
Bare peat	3.9	0	-	-
Hagged and Gullied	160.2	-0.2	-32.04	-801
Improved/shallow peaty soils	50.7	9	-	-
Undamaged	11.8	-4.11	-48.5	-1212.5
None	1.4	**-**	**-**	**-**
Total			**-80.54**	**-2013.5**

Table A16.7 Carbon flux over project lifetime, 20m scenario

	Area (ha)	Flux Rate (t CO2 ha^{-1} yr^{-1})	Emission (t CO_2 yr^{-1})	Total over project lifetime (t CO2)
Bare peat	5.2	0	-	-
Hagged and Gullied	219.3	-0.2	-43.86	-1096.5
Improved/shallow peaty soils	68.1	0	-	-
Undamaged	18.5	-4.11	-76.04	-1901
None	1.5	**-**	**-**	**-**
Total			**-119.9**	**-2997.5**

Table A16.8 Carbon flux over project lifetime, 50m scenario

	Area (ha)	Flux Rate (t CO2 ha^{-1} yr^{-1})	Emission (t CO_2 yr^{-1})	Total over project lifetime (t CO2)
Bare peat	9.6	0	-	-

Hagged and Gullied	441.5	-0.2	-88.3	-2207.5
Improved/shallow peaty soils	122.6	0	-	-
Undamaged	48.3	-4.11	-198.5	-4962.5
None	1.6	-	-	
Total			**-286.8**	**-7170**

The development will, therefore, result in a loss of carbon fixing potential of between 2 – 7kt CO_2 over the lifetime of the project.

1.1.5 Loss of carbon from removed peat

The loss of carbon from removed peat is a function of the total volume of removed peat. The total volume of removed peat from cut roads, turbine bases, temporary and permanent hardstanding has been calculated as part of the Site Materials and Reinstatement Plan. The total volume of peat permanently removed is approximately 300,000 m^3. The carbon loss associated with this loss of peat can be determined by the equation:

$$L_{removed} = (3.667/100) \times pC_{dry\ peat} \times BD_{dry\ soil} \times V_{direct}$$

Where $L_{removed}$ is the carbon loss (tCO_2)

$pC_{dry\ peat}$ is the carbon content of peat (%), assumed to be 50%

$BD_{dry\ soil}$ is the bulk density of dry soil (g/cm^3), assumed to be 0.1 g/cm^3

V_{direct} is the volume of soil lost

Based on the calculated peat loss the total carbon emission will be 55,005 t CO_2.

1.1.6 Loss of carbon from drained peat

Drainage of peat can result in a reduction in the water table level and can result in decomposition causing carbon loss from accumulated peat. The introduction of artificial drains, in the form of structures such as roads and turbine bases or hardstanding may lead to drainage pathways, affecting the surrounding area.

As discussed in Section A16.4.3, the extent of drainage around roads and structures is considered as three scenarios, namely 10m, 20m and 50m.

Using these drainage distances the volume of peat potentially affected by drainage has been calculated using the equations outlined in the CC Report, i.e. calculating the linear area alongside roads and area surrounding turbine bases and hardstanding.

The calculated peat drainage volumes for turbine bases and hardstanding are presented in Table A16.7. The calculations assume a turbine base dimension of 22m by 22m, and a hardstanding dimension of 43m by 43m. The mean peat depth around turbine bases and hardstanding is 1.6m.

Table A16.7 Volume of drained peat around turbine bases and hardstanding

Characteristic	Extent of drainage	Per Turbine		Total	
		Area (ha)	Volume (m^3)	Area (ha)	Volume (m^3)
Volume of drained peat around turbine bases	10m	0.128	2048	16.26	260,096
	20m	0.336	5376	42.67	682,752
	50m	1.440	23,040	182.88	2,926,080
Volume area of drained peat around hardstanding	10m	0.212	3392	26.92	430,784
	20m	0.504	8064	64.01	1,024,128
	50m	1.860	29,760	236.22	3,779,520

The total area of peat drained alongside cut roads is simply a product of the total length of cut roads (25.4 km) and the drainage extent. The average peat depth alongside cut roads is 0.594m. The calculated peat drainage volumes for cut roads are presented in Table A16.8.

Table A16.8 Volume of drained peat alongside cut roads

Characteristic	Extent of drainage	Area (ha)	Volume (m^3)
Volume of drained peat aside cut roads	10m	50.8	301,752
	20m	101.6	603,504
	50m	254	1,508,760

For floating roads the area of peat is a function of the road width plus drainage distance and the total length of road. There are two widths of floating roads proposed, single width (6m) of which 60.24km of road is proposed, and double width (10m) of which 17.89km of road is proposed. For floating roads the depth of drainage has been assume to be 0.2m. The calculated peat drainage volumes for cut roads are presented in Table X.

Table A16.9 Volume of drained peat alongside floating roads

Characteristic	Extent of drainage	Area (ha)	Volume (m^3)
Volume of drained peat around single width floating roads	10m	157	313,248
	20m	277	554,208
	50m	639	1,277,088
Volume of drained peat around double width floating roads	10m	54	107,340
	20m	89	178,900

	50m	989	1,977,900

The total potential volumes of drained peat are presented in Table A16.10.

Table A16.10 Total volume of drained peat

	Extent of drainage	**Total Volume (m^3)**
Total volume of drained peat around all features	10m	1,413,220
	20m	3,043,492
	50m	11,469,348

If the site drainage is restored upon following the construction phase and/or decommissioning of the development then it is assumed that local hydrology will return to a stable state. The carbon lost by the peat will, therefore, be that leached over the period during which the drainage is in place.

Emissions of carbon from drained peat are calculated using the method outlined in Section A2.9.2 of the CC Report, based on the calculated annual emission of methane and CO_2 and the number of years that the peat remains in the drained state.

The formulae and calculations are outlined in Appendix 1. The calculated emission rate for methane is a constant emission rate based on local environmental and ground conditions. The methane emission rate is corrected to a CO_2 equivalent emission rate. The CO_2 emission rate is a function of peat depth, therefore different emission rates have been calculated for each feature type. The calculated emission rates are presented in Table A16.11.

Table A16.11 Drained peat, CO_2 equivalent emission rates

Emission	**Feature**	**Emission rate t CO_2 ha^{-1} yr^{-1}**
Methane emission rate (CO_2 equivalent)		5.02
CO_2 emission rate	Cut roads	4.68
	Floating roads	4.21
	Turbines / hardstanding	5.86

The total emission over the period that the peat is drained is a product of the area of drained peat, the relevant emission factors and the time period over which the peat is drained. As a worst case it has been assumed that the peat will remain drained for the 25 year lifetime of the wind farm. The total emission over this period is presented in Table A16.12.

Table A16.12 Total emission from drained peat

	Extent of drainage	Total Emission (t CO_2)
Total CO_2 emission from drained peat	10m	69,283
	20m	138,105
	50m	551,240

1.1.7 Carbon savings due to habitat management plan

The carbon savings associated with the habitat improvement measures are based on the reduction of peat loss over the lifetime of the wind farm. The baseline assessment of peat on the site currently is estimated to be eroding at a rate of 10 – 40mm per annum. If this rate of erosion is applied to an area of one hectare, then the total carbon loss lost per annum is given by:

$$L_{loss} = (3.667/100) \text{ x } pC_{dry\ peat} \text{ x } BD_{dry\ soil} \text{ x } V_{direct}$$

Where L_{loss} is the carbon loss (tCO_2)

$pC_{dry\ peat}$ is the carbon content of peat (%), assumed to be 50%

$BD_{dry\ soil}$ is the bulk density of dry soil (g/cm^3), assumed to be 0.1 g/cm^3

V_{direct} is the volume of soil lost (10-40mm x 1 ha = 100 – 400m^3)

The total carbon loss is, therefore, 18 – 73 t CO_2 ha^{-1} per annum. If this loss is applied across the whole habitat management pilot area of 1,051 ha, then the loss will be 19 – 76 kt per annum.

If it is assumed that the loss of carbon from this pilot area is arrested after 5 years, then it can be assumed that carbon is saved over the remaining 20 year period. The overall carbon saving over this period would, therefore be 378 – 1,513 kt.

A further improvement in carbon fixing potential will be achieved as a result of sustainable grazing practice introduced by the habitat management plan. The estimated annual organic production level was determined to be up to 210 kg ha^{-1}. If this level of re-vegetation is achieved across the HMP pilot area, then the carbon savings will be 220 t per annum or 5 kt over the lifetime of the wind farm. If the savings are applied across the whole development area (15,528 ha) then the savings will be 81 kt over the lifetime of the wind farm.