APPENDIX 8-1

CARBON CALCULATIONS

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Carbon Calculator v1.8.1

Meenbog Wind Farm Substitute Consent Location: 54.733343 -7.924838

Planree Ltd.

Core input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Windfarm characteristics				
Dimensions				
No. of turbines	1	1	1	N/A
Duration of consent (years)	1	1	1	N/A
Performance				
Power rating of 1 turbine (MW)	0.1	0.1	0.1	N/A
Capacity factor	0.1	0.01	0.11	N/A
Backup				
Fraction of output to backup (%)	1.15	1.1	1.2	Default Value Used
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10	10	10	Fixed
Total CO2 emission from turbine life (tCO2 MW^{-1}) (eg. manufacture, construction, decommissioning)	Calculate wrt installed capacity	Calculate wrt installed capacity	Calculate wrt installed capacity	
Characteristics of peatland before windfarm development				
Type of peatland	Acid bog	Acid bog	Acid bog	Default Value Used
Average annual air temperature at site (°C)	10	6	14.8	Ch 11 Climate
Average depth of peat at site (m)	1.7	1.6	1.8	CH 4 Description
C Content of dry peat (% by weight)	55	50	60	Default Value Used
Average extent of drainage around drainage features at site (m)	15	10	20	Default Value Used
Average water table depth at site (m)	0.5	0.1	1	Default Value Used
Dry soil bulk density (g cm^{-3})	0.1	0.09	0.11	Default Value Used
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	2	2	2	Default Value Used
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha^{-1} yr^{-1})	0.25	0.2	0.3	Default Value Used
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	4.4	4.3	4.5	Ch 8 Land Soils and Geology
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	3.6	3.5	3.7	Default Value Used
Counterfactual emission factors				
Coal-fired plant emission factor (t CO2 MWh^{-1})	0.945	0.945	0.945	
Grid-mix emission factor (t CO2 MWh^{-1})	0.207	0.207	0.207	
Fossil fuel-mix emission factor (t CO2 MWh^{-1})	0.424	0.424	0.424	
Borrow pits				
Number of borrow pits	4	4	4	CH 4 Description
Average length of pits (m)	99	98	100	Manually Determined
Average width of pits (m)	100	99	101	Manually Determined
Average depth of peat removed from pit (m)	1.6	1.5	1.7	Peat and Spoil Management Plan

1. CO2 emission saving

Emissions due to turbine life
The carbon payback time of the windfarm due to turbine life (eg. manufacture, construction, decomissioning) is calculated by comparing the emissions due to turbine life with carbon-savings achieved by the windfarm while displacing electricity generated from coal-fired capacity or grid-mix.

Capacity factor calculated from forestry data

Area name	Value type	Capacity factor (%)	Wind speed ratio	Average site windspeed (m/s)	Annual theoretical energy output (MW / turbine yr)

Capacity factor - Direct input

	Exp.	Min.	Max.
Capacity factor (%)	0.1	0.0	0.1

	Exp.	Min.	Max.
Annual energy output from windfarm (MW/yr)			
RESULTS			
Emissions saving over coal-fired electricity generatio...	1	0	1
Emissions saving over grid-mix of electricity generati...	0	0	0
Emissions saving over fossil fuel - mix of electricity g...	0	0	0

2. CO2 loss turbine life

Emissions due to turbine life
The carbon payback time of the windfarm due to turbine life (eg. manufacture, construction, decomissioning) is calculated by comparing the emissions due to turbine life with carbon-savings achieved by the windfarm while displacing electricity generated from coal-fired capacity or grid-mix.

Calculation of emissions with relation to installed capacity

	Exp.	Min.	Max.
Emissions due to turbine frome energy output (t CO2)	52	52	52
Emissions due to cement used in construction (t CO2)	0	0	0

Direct input of emissions due to turbine life

	Exp.	Min.	Max.
Emissions due to turbine life (tCO2/windfarm)			

RESULTS

	Exp.	Min.	Max.
Losses due to turbine life (manufacture, construction, etc.) (t CO2)	52	52	52
Additional CO2 payback time of windfarm due to turbine life			
...coal-fired electricity generation (months)	748	7477	680
...grid-mix of electricity generation (months)	3414	34136	3103
...fossil fuel - mix of electricity generation (months)	1667	16666	1515

3. CO2 loss backup

Emissions due to backup power generation
CO2 loss due to back up is calculated from the extra capacity required for backup of the windfarm given in the input data.

Wind generated electricity is inherently variable, providing unique challenges to the electricity generating industry for provision of a supply to meet consumer demand (Netz, 2004). Backup power is required to accompany wind generation to stabilise the supply to the consumer. This backup power will usually be obtained from a fossil fuel source. At a high level of wind power penetration in the overall generating mix, and with current grid management techniques, the capacity for fossil fuel backup may become strained because it is being used to balance the fluctuating consumer demand with a variable and highly unpredictable output from wind turbines (White, 2007). The Carbon Trust (Carbon Trust/DTI, 2004) concluded that increasing levels of intermittent generation do not present major technical issues at the percentages of renewables expected by 2010 and 2020, but the UK renewables target at the time of that report was only 20%. When national reliance on wind power is low (less than ~20%), the additional fossil fuel generated power requirement can be considered to be insignificant and may be obtained from within the spare generating capacity of other power sectors (Dale et al, 2004). However, as the national supply from wind power increases above 20%, without improvements in grid management techniques, emissions due to backup power generation may become more significant. The extra capacity needed for backup power generation is currently estimated to be 5% of the rated capacity of the wind plant if wind power contributes more than 20% to the national grid (Dale et al 2004). Moving towards the SG target of 50% electricity generation from renewable sources, more short-term capacity may be required in terms of pumped-storage hydro-generated power, or a better mix of offshore and onshore wind generating capacity. Grid management techniques are anticipated to reduce this extra capacity, with improved demand side management, smart meters, grid reinforcement and other developments. However, given current grid management techniques, it is suggested that 5% extra capacity should be assumed for backup power generation if wind power contributes more than 20% to the national grid. At lower contributions, the extra capacity required for backup should be assumed to be zero. These assumptions should be revisited as technology improves.

Assumption: Backup assumed to be by fossil-fuel-mix of electricity generation. Note that hydroelectricity may also be used for backup, so this assumption may make the value for backup generation too high. These assumptions should be revisited as technology develops.

	Exp.	Min.	Max.
Reserve energy (MWh/yr)	10	10	11
Annual emissions due to backup from fossil fuel-mix of electricity generation (tCO2/yr)	0	0	0
RESULTS			
Total emissions due to backup from fossil fuel-mix of electricity generation (tCO2)	0	0	0

4. Loss CO2 fixing pot.

Emissions due to loss of bog plants
Annual C fixation by the site is calculated by multiplying area of the windfarm by the annual C accumulation due to bog plant fixation.

	Exp.	Min.	Max.
Area where carbon accumulation by bog plants is lost (ha)	11.74	9.13	14.48
Total loss of carbon accumulation up to time of restoration (tCO2 eq./ha)	3	2	3
RESULTS			
Total loss of carbon fixation by plants at the site (t CO2)	32	20	48
Additional CO2 payback time of windfarm due to loss of CO2 fixing potential			
...coal-fired electricity generation (months)	468	2912	630
...grid-mix of electricity generation (months)	2137	13293	2874
...fossil fuel - mix of electricity generation (months)	1044	6490	1403

5. Loss of soil CO2 (a, b)

Emissions due to loss of soil organic carbon
Loss of C stored in peatland is estimated from % site lost by peat removal (table 5a), CO2 loss from removed peat (table 5b), % site affected by drainage (table 5c), and the CO2 loss from drained peat (table 5d).

5. Loss of soil C02

	Exp.	Min.	Max.
CO2 loss from removed peat (t CO2 equiv.)	14931.46	10879.38	19987.7
CO2 loss from drained peat (t CO2 equiv.)	34.42	0	208.42
RESULTS			
Total CO2 loss from peat (removed + drained) (t CO2 equiv.)	14965.88	10879.38	20196.13
Additional CO2 payback time of windfarm due to loss of soil C...			
...coal-fired electricity generation (months)	216943....	157706...	266146....
...grid-mix of electricity generation (months)	990396....	719964...	121501...
...fossil fuel - mix of electricity generation (months)	483518....	351492...	593180....

CO_2 loss from removed peats
If peat is treated in such a way that it is permanently restored, so that less than 100% of the C is lost to the atmosphere, a lower percentage can be entered in cell C10.

5b. CO2 loss from removed peat

	Exp.	Min.	Max.
CO2 loss from removed peat (t CO2)	15231.36	11192.25	20247.26
CO2 loss from undrained peat left in situ (t CO2)	299.90	312.87	259.56
RESULTS			
CO2 loss atributable to peat removal only (t CO2)	14931.46	10879.38	19987.70

Volume of Peat Removed
% site lost by peat removal is estimated from peat removed in borrow pits, turbine foundations, hard-standing and access tracks. If peat is removed for any other reason, this must be added in as additional peat excavated in the core input data entry.

5a. Volume of peat removed

	Exp.	Min.	Max.
Peat removed from borrow pits			
Area of land lost in borrow pits (m2)	39600	38808	40400
Volume of peat removed from borrow pits (m3)	63360	58212	68680
Peat removed from turbine foundations			
Area of land lost in foundation (m2)	0	0	0
Volume of peat removed from foundation area (m3)	0	0	0
Peat removed from hard-standing			
Area of land lost in hard-standing (m2)	0	0	0
Volume of peat removed from hard-standing area (m3)	0	0	0
Peat removed from access tracks			
Area of land lost in floating roads (m2)	0	0	0
Volume of peat removed from floating roads (m3)	0	0	0
Area of land lost in excavated roads (m2)	9359	8016	10704
Volume of peat removed from excavated roads (m3)	12166.7	9619.2	14985.6
Area of land lost in rock-filled roads (m2)	0	0	0
Volume of peat removed from rock-filled roads (m3)	0	0	0
Total area of land lost in access tracks (m2)	9359	8016	10704
Total volume of peat removed due to access tracks (m3)	12166.7	9619.2	14985.6
RESULTS			
Total area of land lost due to windfarm construction (m2)	48959	46824	51104
Total volume of peat removed due to windfarm construction (m3)	75526.7	67831.2	83665.6

5. Loss of soil CO2 (c,d,e)

Volume of peat drained
Extent of site affected by drainage is calculated assuming an average extent of drainage around each drainage feature as given in the input data.

5c. Volume of peat drained

	Exp.	Min.	Max.
Total area affected by drainage around borrow pits (m2)	27480	17360	38560
Total volume affected by drainage around borrow pits (m3)	21984	13020	32776
Peat affected by drainage around turbine foundation and hardstanding			
Total area affected by drainage of foundation and hardstanding area (m2)	900	400	1600
Total volume affected by drainage of foundation and hardstanding area (m3)	0	0	0
Peat affected by drainage of access tracks			
Total area affected by drainage of access track(m2)	40110	26720	53520
Total volume affected by drainage of access track(m3)	26071.5	16032	37464
Peat affected by drainage of cable trenches			
Total area affected by drainage of cable trenches(m2)	0	0	0
Total volume affected by drainage of cable trneches(m3)	0	0	0
Drainage around additional peat excavated			
Total area affected by drainage (m2)	0	0	0
Total volume affected by drainage (m3)	0	0	0
RESULTS			
Total area affected by drainage due to windfarm (m2)	68490	44480	93680
Total volume affected by drainage due to windfarm (m3)	48055.5	29052	70240

CO_2 loss due to drainage
Note, CO2 losses are calculated using two approaches: IPCC default methodology and more site specific equations derived for this project. The IPCC methodology is included because it is the established approach, although it contains no site detail. The new equations have been derived directly from experimental data for acid bogs and fens (see Nayak et al, 2008 - Final report).

5d. CO2 loss from drained peat

	Exp.	Min.	Max.
Calculations of C Loss from Drained Land if Site is NOT Restored after Decomissioning			
Total GHG emissions from Drained Land (t CO2 equiv.)	9691.28	4793.62	16998.23
Total GHG emissions from Undrained Land (t CO2 equiv.)	8956.49	4793.62	11820.36
Calculations of C Loss from Drained Land if Site IS Restored after Decomissioning			
Losses if Land is Drained			
CH4 emissions from drained land (t CO2 equiv.)	-0.81	-6.34	13.45
CO2 emissions from drained land (t CO2)	454.77	303.55	670.77
Total GHG emissions from Drained Land (t CO2 equiv.)	453.96	297.21	684.22
Losses if Land is Undrained			
CH4 emissions from undrained land (t CO2 equiv.)	-0.52	-6.34	74.61
CO2 emissions from undrained land (t CO2)	420.06	303.55	401.19
Total GHG emissions from Undrained Land (t CO2 equiv.)	419.54	297.21	475.8
RESULTS			
Total GHG emissions due to drainage (t CO2 equiv.)	34.42	0	208.42

Emission rates from soils
Note, CO2 losses are calculated using two approaches: IPCC default methodology and more site specific equations derived for this project. The IPCC methodology is included because it is the established approach, although it contains no site detail. The new equations have been thoroughly tested against experimental data (see Nayak et al, 2008 - Final report).

5e. Emission rates from soils

	Exp.	Min.	Max.
Calculations following IPCC default methodology			
Flooded period (days/year)	178	178	178
Annual rate of methane emission (t CH4-C/ha year)	0.04	0.04	0.04
Annual rate of carbon dioxide emission (t CO2/ha year)	35.2	35.2	35.2
Calculations following ECOSSE based methodology			
Total area affected by drainage due to wind farm construction (ha)	6.85	4.45	9.37

6. CO2 loss DOC & POC

Emissions due to loss of DOC and POC
Note, CO2 losses from DOC and POC are calculated using a simple approach derived from generic estimates of the percentage of the total CO2 loss that is due to DOC or POC leaching.

No POC losses for bare soil included yet. If extensive areas of bare soil is present at site need modified calculation (Birnie et al, 1991)

	Exp.	Min.	Max.
Gross CO2 loss from restored drained land (t CO2)	34.71	0.00	269.58
Gross CH4 loss from restored drained land (t CO2 equiv.)	0.00	0.00	0.00
Gross CO2 loss from improved land (t CO2)	0.00	0.00	0.00
Gross CH4 loss from improved land (t CO2 equiv.)	0.00	0.00	0.00
Total gaseous loss of C (t C)	9.47	0.00	73.52
Total C loss as DOC (t C)	2.46	0.00	29.41
Total C loss as POC (t C)	0.76	0.00	7.35
RESULTS			
Total CO2 loss due to DOC leaching (t CO2)	9.02	0.00	107.82
Total CO2 loss due to POC leaching (t CO2)	2.78	0.00	26.96
Total CO2 loss due to DOC & POC leaching (t CO2)	11.80	0.00	134.78
Additional CO2 payback time of windfarm due to DOC & POC			
...coal-fired electricity generation (months)	171	0	1776
...grid-mix of electricity generation (months)	781	0	8108
...fossil fuel - mix of electricity generation (months)	381	0	3959

7. Forestry CO2 loss

CO_2 loss from forests - calculation using detailed management information
Forest carbon calculator (Perks et al, 2009)

Total potential carbon squestration loss due to felling of forestry for the wind farm (t CO2)	
Total emissions due to cleared land (t CO2)	
Emissions due to harvesting operations (t CO2)	
Fossil fuel equivalent saving from use of felled forestry as biofuel (t CO2)	
Fossil fuel equivalent saving from use of replanted forestry as biofuel (t CO2)	
RESULTS	
Total carbon loss associated with forest management(t CO2)	

Emissions due to forest felling - calculation using simple management data
Emissions due to forestry felling are calculated from the reduced carbon sequestered per crop rotation. If the forestry was due to be removed before the planned development, this C loss is not attributable to the wind farm and so the area of forestry to be felled should be entered as zero.

	Exp.	Min.	Max.
Area of forestry plantation to be felled (ha)	4.4	4.3	4.5
Carbon sequestered (t C ha-1 yr-1)	3.6	3.5	3.7
Lifetime of windfarm (years)	1	1	1
Carbon sequestered over the lifetime of the windfarm (t C ha-1)	3.6	3.5	3.7
RESULTS			
Total carbon loss due to felling of forestry (t CO2)	58.08	55.18	61.05
Additional CO2 payback time of windfarm due to management of forestry			
...coal-fired electricity generation (months)	841.93	7999.4	804.53
...grid-mix of electricity generation (months)	3843.59	36518.98	3672.85
...fossil fuel - mix of electricity generation (months)	1876.47	17828.84	1793.12

8. CO2 gain - site improvement

Gains due to site improvement
Note, CO2 losses are calculated using two approaches: IPCC default methodology and more site specific equations derived for this project. The IPCC methodology is included because it is the established approach, although it contains no site detail. The new equations have been thoroughly tested against experimental data (see Nayak et al, 2008 - Final report).

Degraded Bog

	Exp.	Min.	Max.
1. Description of site			
Area to be improved (ha)	0	0	0
Depth of peat above water table before improvement (m)	0	0	0
Depth of peat above water table after improvement (m)	0	0	0
2. Losses with improvement			
Improved period (years)	0	0	0
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.499	0.485	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.535	-0.529	1.812
CO2 emissions from improved land (t CO2 equiv.)	0	0	0
Total GHG emissions from improved land (t CO2 eqiv.)	0	0	0
3. Losses without improvement			
Improved period (years)	0	0	0
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.499	0.485	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.535	-0.529	1.812
CO2 emissions from unimproved land (t CO2 equiv.)	0	0	0
Total GHG emissions from unimproved land (t CO2 eqiv.)	0	0	0

Borrow Pits

	Exp.	Min.	Max.
1. Description of site			
Area to be improved (ha)	0	0	0
Depth of peat above water table before improvement (m)	0	0	0
Depth of peat above water table after improvement (m)	0	0	0
2. Losses with improvement			
Improved period (years)	0	0	0
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.499	0.485	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.535	-0.529	1.812
CO2 emissions from improved land (t CO2 equiv.)	0	0	0
Total GHG emissions from improved land (t CO2 eqiv.)	0	0	0
3. Losses without improvement			
Improved period (years)	0	0	0
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.499	0.485	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.535	-0.529	1.812
CO2 emissions from unimproved land (t CO2 equiv.)	0	0	0
Total GHG emissions from unimproved land (t CO2 eqiv.)	0	0	0

Felled Forestry

	Exp.	Min.	Max.
1. Description of site			
Area to be improved (ha)	0	0	0
Depth of peat above water table before improvement (m)	0	0	0
Depth of peat above water table after improvement (m)	0	0	0
2. Losses with improvement			
Improved period (years)	0	0	0
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.499	0.485	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.535	-0.529	1.812
CO2 emissions from improved land (t CO2 equiv.)	0	0	0
Total GHG emissions from improved land (t CO2 eqiv.)	0	0	0
3. Losses without improvement			
Improved period (years)	0	0	0
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.499	0.485	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.535	-0.529	1.812
CO2 emissions from unimproved land (t CO2 equiv.)	0	0	0
Total GHG emissions from unimproved land (t CO2 eqiv.)	0	0	0

Foundations & Hardstanding

	Exp.	Min.	Max.
1. Description of site			
Area to be improved (ha)	0	0	0
Depth of peat above water table before improvement (m)	0	0	0
Depth of peat above water table after improvement (m)	0	0	0
2. Losses with improvement			
Improved period (years)	1	1	1
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.499	0.485	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.535	-0.529	1.812
CO2 emissions from improved land (t CO2 equiv.)	0	0	0
Total GHG emissions from improved land (t CO2 eqiv.)	0	0	0
3. Losses without improvement			
Improved period (years)	1	1	1
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.499	0.485	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.535	-0.529	1.812
CO2 emissions from unimproved land (t CO2 equiv.)	0	0	0
Total GHG emissions from unimproved land (t CO2 eqiv.)	0	0	0