



APPENDIX 11-2

CARBON CALCULATIONS

Core input data
 ENTER INPUT DATA HERE VALUES SHOULD ONLY BE CHANGED ON THIS SHEET. DO NOT USE EXAMPLE VALUES AS DEFAULTS! ENTER YOUR OWN VALUES THAT ARE SPECIFIC TO YOUR PARTICULAR SITE.
 Note: The input parameters include some variables that can be specified by default values, but others that must be site specific. Variables that can be taken from defaults are marked with purple tags on left hand side.

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Input data	Expected values		Possible range of values		Record source of data
	Enter expected value here	Record source of data	Enter minimum value here	Enter maximum value here	
Windfarm characteristics					
Dimensions					
No. of turbines	14	Fixed	14	14	
Lifetime of windfarm (years)	35		35	35	
Performance					
Power rating of turbines (turbine capacity) (MW)	6.2		6.1	6.3	
Capacity factor	Direct input of capacity fac %		Direct input of capacity fac %	Direct input of capacity fac %	
Enter estimated capacity factor (percentage efficiency)	0.36		0.36	0.36	
Backup					
Extra capacity required for backup (%)	5		5	5	
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10		10	10	
Carbon dioxide emissions from turbine life - (inc. manufacture, construction, decommissioning)	Calculate wet installed cap.		Calculate wet installed cap.	Calculate wet installed cap.	
Characteristics of peatland before windfarm development					
Type of peatland	Acid b		Acid b	Acid b	
Average annual air temperature at site (°C)	9.9		4.9	15.8	
Average depth of peat at site (m)	0.00		0.00	0.00	
C Content of dry peat (% by weight)	53.23		19.57	64.28	
Average extent of drainage around drainage features at site (m)	15.00		10.00	20.00	
Average water table depth at site (m)	0.50		0.10	1.00	
Peat soil bulk density (g cm ⁻³)	0.132		0.072	0.203	
Characteristics of bog plants					
Time required for regeneration of bog plants after restoration (years)	10		5	15	
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha ⁻¹ yr ⁻¹)	0.25		0.2	0.3	
Forestry					
Method used to calculate CO ₂ loss from forest felling	Enter simple data		Enter simple data	Enter simple data	
Area of forestry plantation to be felled (ha)	51.84		51.84	51.84	
Average rate of carbon sequestration in timber (tC ha ⁻¹ yr ⁻¹)	3.50		3.50	3.70	
Counterfactual emission factors					
To update counterfactual emission factors from the web	Yes		Yes	Yes	
Coal-fired plant emission factor (tCO ₂ MWh ⁻¹)	0.945		0.945	0.945	
Grid-mix emission factor (tCO ₂ MWh ⁻¹)	0.207		0.207	0.207	
Fossil fuel-mix emission factor (tCO ₂ MWh ⁻¹)	0.424		0.424	0.424	
Borrow pits					
Number of borrow pits	2		2	2	
Average length of pits (m)	134.8		120	135	
Average width of pits (m)	92.03		91	109	
Average depth of peat removed from pit (m)	0.00		0.00	0.00	
Foundations and hard-standing area associated with each turbine					
Method used to calculate CO ₂ loss from foundations and hard-standing	Rectangular with vertical		Rectangular with vertical	Rectangular with vertical	
Average length of turbine foundations (m)	25		25	25	
Average width of turbine foundations (m)	25		25	25	
Average depth of peat removed from turbine foundations (m)	0.00		0.00	0.00	
Average length of hard-standing (m)	55		55	55	
Average width of hard-standing (m)	35		35	35	
Average depth of peat removed from hard-standing (m)	0.00		0.00	0.00	
Access tracks					
Total length of access track (m)	15500		15500	15500	
Existing track length (m)	2600		2600	2600	
Length of access track that is drained (m)					
Floating road width (m)	0.00		0.00	0.00	
Length of floating road that is drained (m)	0.00		0.00	0.00	
Average depth of drains associated with floating roads (m)	0		0	0	
Length of access track that is excavated road (m)	12900		12900	12900	
Excavated road width (m)	6		6	6	
Average depth of peat excavated for road (m)	0		0	0	
Length of access track that is rock filled road (m)	0		0	0	
Rock filled road width (m)	0		0	0	
Rock filled road depth (m)	0		0	0	
Average depth of drains associated with rock filled roads (m)	0		0	0	
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)					
Average depth of peat cut for cable trenches (m)	0.00		0.00	0.00	
Additional peat excavated already accounted for above					
Volume of additional peat excavated (m ³)					
Area of additional peat excavated (m ²)					
Peat Landslide Hazard					
Peat Landslide Hazard	Neoglacial		Neoglacial	Neoglacial	
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)					
Water table depth in degraded bog before improvement (m)					
Water table depth in degraded bog after improvement (m)					
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)					
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	0		0	0	
Improvement of felled plantation land					
Area of felled plantation to be improved (ha)					
Water table depth in felled area before improvement (m)					
Water table depth in felled area after improvement (m)					
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)					
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	0		0	0	
Restoration of peat removed from borrow pits					
Area of borrow pits to be restored (ha)					
Depth of water table in borrow pit before restoration with respect to the restored surface (m)					
Depth of water table in borrow pit after restoration with respect to the restored surface (m)					
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)					
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	0		0	0	
Early removal of drainage from foundations and hardstanding					
Water table depth around foundations and hardstanding before restoration (m)					
Water table depth around foundations and hardstanding after restoration (m)	0.00		0.00	0.00	
Time to completion of backfilling, removal of any surface drains, and full restoration of the hydrology (years)					
Restoration of site after decommissioning					
Will the hydrology of the site be restored on decommissioning?	No		No	No	
Will you attempt to block any gullies that have formed due to the windfarm?	No		No	No	
Will you attempt to block all artificial ditches and facilitate reconnection?	No		No	No	
Will the habitat of the site be restored on decommissioning?	No		No	No	
Will you control grazing on degraded areas?	No		No	No	
Will you manage areas to favour reintroduction of species	No		No	No	

Note: Capacity factor: The capacity factor of any power plant is the proportion of energy produced during a given period with respect to the energy that would have been produced had the wind farm been running continually at maximum output (DECC 2004). See also www.bmwi.com/energy-factors.html

Capacity Factor = Electricity generated during the period (MWh) / (Installed capacity (MW) x number of hours in the period (h))

Note: We recommend that a site-specific capacity factor should be used (as measured during planning stage), and should represent the average emission factor expected over the lifetime of the windfarm, according to advice on efficiency with age (Ingrubger, 2012). The 2 year average capacity factor for 'Road Bally' for UK, onshore wind between 2010 and 2014, based on average beginning and end of year capacity, was 25.2% (DUKES, 2015).

Note: Extra capacity required for backup: If 20% of national electricity is generated by wind energy, extra capacity required for backup is 20% of the rated capacity of the wind plant (Date et al. 2004). We suggest this should be 3% of the actual output. If it is assumed that only 20% of national electricity is generated by wind energy, a lower percentage should be entered (3%).

Note: The House of Lords Economic Affairs Committee report on the Economics of Renewable Energy (Parliamentary Business, 2008) notes that to cover peak demand a 20% margin of extra capacity has been sufficient to keep the gas power out of the electricity generation at a very low level. The estimate provided by BEPR was a range of 10% to 20% of installed capacity of wind energy. E.ON is reported as proposing that the capacity credit of wind power should be 8%, and the Renewable Energy Foundation proposed the use of the square root of the wind capacity (in GW) as a conventional capacity credit (e.g. 36 GW of wind plant to match 6 GW of conventional plant).

Note: Extra emissions due to reduced thermal efficiency of the reserve power generation = 10%

Note: Emissions from turbine life: If total emissions for the windfarm are unknown, emissions should be calculated according to turbine capacity. The normal range of CO₂ emissions is 946 to 6147 tCO₂ MWh (White & Kucenas, 2000; White, 2007)

Note: Type of peatland: An 'acid bog' is fed primarily by rainwater and often enhanced by sulphur from the burning of peat (Stevens & Brooks 1997)

A 'fen' is a type of wetland fed by surface and/or groundwater (Mabrie et al. 2011)

Note: Time required for regeneration of previous habitat: Loss of heath should be assumed to be over the lifetime of the windfarm. This should be longer if plants are not regenerating. The requirements for after-use planning include the provision of suitable refuge for peat-forming vegetation, the removal of structures, or an assessment of the impact of leaving them in situ. Methods used to regenerate the site will affect the likely time for regeneration of the previous habitat. This time should also be shorter if plants regenerate during the lifetime of the windfarm. If no number of years estimated for regeneration.

Note: Carbon fixation by bog plants

Reported CO₂ accumulation rate in peatland is 0.12 to 0.31 tC ha⁻¹ yr⁻¹ (Turunen et al. 2006; Borch et al. 1995). The SNH guidance uses a value of 0.25 tC ha⁻¹ yr⁻¹.

Note: Area of forestry plantation to be felled: If the forestry was claimed to be removed, with no further rotations planned, before the windfarm development, the area to be felled should be entered as 0.

Note: Peat carbon sequestration: This is dependent on the yield class of the forestry. The SNH technical guidance assumed yield class of 16 m³ ha⁻¹ yr⁻¹, compared to the value of 14 m³ ha⁻¹ yr⁻¹ provided by the Forestry Commission. Carbon sequestration for yield class 16 m³ ha⁻¹ yr⁻¹ is 3.5 tC ha⁻¹ yr⁻¹ (Carter, 1999)

Note: Coal-Fired Plant and Grid-Mix Emission Factors: Coal-fired plant emission factor (EF) from electricity supplied in 2014 = 0.945 tCO₂ MWh⁻¹ Grid-Mix EF for 2014 = 0.394 tCO₂ MWh⁻¹ (Source = DUKES, 2015)

Note: Fossil Fuel-Mix Emission Factor: The emission factor from electricity supplied in 2014 from fossil fuels = 0.642 tCO₂ MWh⁻¹ (Source = DUKES, 2015)

Note: Total length of access track: If areas of access track overlap with hardstanding area, exclude these from the total length of access track to avoid double counting of land area lost.

Note: Floating road depth: Accounts for sinking of floating road. Should be entered as the average depth of the road expected over the lifetime of the windfarm. If no sinking is expected, enter as 0.

Note: Length of floating road that is drained: Refers to any drains running along the length of the road.

Note: Rock filled roads: Rock filled roads are assumed to be roads where no peat has been removed and a rock has been placed on the surface and allowed to settle.

Note: Depth of peat cut for cable trenches: In shallow peats, the cable trenches may be cut below the peat. To avoid overestimating the depth of peat affected by the cable trenches, only enter the depth of the peat that is cut.

Note: Peat Landslide Hazard: It is assumed that measures have been taken to limit damage (British Columbia, 2006). That includes erosion and fire assessments, and these data to informed development. Some erosion channels are 30-50 m so that C losses due to peat landslides can be determined to be negligible. Note: see also the SNH guidance on peat landslides.

Note: Period of time when improvement can be guaranteed: This guarantee should be absolute. Therefore, if you enter a value beyond the lifetime of the windfarm you should provide strong supporting evidence that this improvement can be guaranteed for the full period given. This includes the time requirement for the improvement to become effective. For example if time required for hydrology and habitat to return to its previous state is 10 years and the restoration can be guaranteed over the lifetime of the windfarm (25 years), the period of time when the improvement can be guaranteed should be entered as 20 years, and the improvement will be effective for (25 - 10) = 15 years.

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Note: Period of time when improvement can be guaranteed: This is assumed to be the lifetime of the windfarm as restoration after windfarm decommissioning is already accounted for in restoration of the site.

Note: Restoration of site: If the water table at the site is returned to its original level or higher on decommissioning, and felling at the site is restored, it is assumed that C losses continue only over the lifetime of the windfarm. Otherwise, C losses from drained peat are assumed to be 100%.

Note: Choice of methodologies for calculating emission factors: The IPCC default methodology is the internationally accepted standard (IPCC, 1997). However, it is stated in IPCC (1997) that those are rough estimates, and those used and production periods can be used if countries do not have more appropriate estimates. Therefore, we have developed more site specific estimates for use here based on work from the Scottish Government funded ECOSISE project (see www.ecosise.ac.uk). (Edinburgh Centre for Organic Soils - Separation and Distillation, Final Report, SEDNAG Report: 08/01/10 01/10/10 1.0 10/10/10)

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Windfarm CO₂ emission saving

Note: The total emission savings are given by estimating the total possible electrical output of the windfarm multiplied by the emission factor for the counterfactual case (coal-fire generation and electricity from grid)

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Values taken from input sheet	Total			Forestry Area 1			Forestry Area 2			Forestry Area 3			Forestry Area 4			Forestry Area 5		
	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max
Power Generation Characteristics																		
No. of turbines	14	14	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Power rating of turbines (turbine capacity) (MW)	6.2	6.1	6.3	6.2	6.1	6.3	6.2	6.1	6.3	6.2	6.1	6.3	6.2	6.1	6.3	6.2	6.1	6.3
Power of windfarm (MW)	86.8	85.4	88.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Estimated downtime for maintenance etc. (%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Counterfactual emission factors																		
Coal-fired plant emission factor (t CO ₂ MWh ⁻¹)	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945	0.945
Grid-mix emission factor (t CO ₂ MWh ⁻¹)	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207	0.207
Fossil fuel-mix emission factor (t CO ₂ MWh ⁻¹)	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424	0.424

Calculation of capacity factor	Direct input of capacity factor		
	Exp	Min	Max
Entered capacity factor (%)	0.36	0.36	0.36

Parameters	Slope (a)			Intercept (b)		
	Exp	Min	Max	Exp	Min	Max
Partial power curves for different turbines						
User-defined	0.0	0.0	0.0	0.0	0.0	0.0
Vestas 2.0 MW Optispeed C2	1392.5	1392.5	1392.5	-4291.9	-4291.9	-4291.9

Calculation of capacity factor from forestry management	Total			Forestry Area 1			Forestry Area 2			Forestry Area 3			Forestry Area 4			Forestry Area 5		
	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max
Wind speed ratio calculated in 7d	0	0	0	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####
Average site windspeed (m s ⁻¹)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annual theoretical energy output from turbine (MW turbine ⁻¹ yr ⁻¹)	54312	53436	55188	54312	53436	55188	54312	53436	55188	54312	53436	55188	54312	53436	55188	54312	53436	55188
Power curve				User-defined	User-defined	User-defined	Partial power curves for different turbines	Partial power curves for different turbines	Partial power curves for different turbines	Partial power curves for different turbines	Partial power curves for different turbines	Partial power curves for different turbines	Partial power curves for different turbines	Partial power curves for different turbines	Partial power curves for different turbines	Partial power curves for different turbines	Partial power curves for different turbines	Partial power curves for different turbines
(Power curve code)				1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Slope (a)	0	0	0	0	0	0	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max
Intercept (b)	0	0	0	0	0	0	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max
Annual power output from an individual turbine (MW turbine ⁻¹ yr ⁻¹)				#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####
Calculated capacity factor (%)				#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####

Calculation of annual energy output from wind farm	Total			Forestry Area 1			Forestry Area 2			Forestry Area 3			Forestry Area 4			Forestry Area 5		
	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max
Direct input of capacity factor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capacity factor(%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Annual energy output from windfarm (MW yr ⁻¹)	2737	2693	2781	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

RESULTS	Total			Area 1			Area 2			Area 3			Area 4			Area 5		
	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max
Windfarm CO ₂ emission saving over...																		
...coal-fired electricity generation (tCO ₂ yr ⁻¹)	2587	2545	2628.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
...grid-mix of electricity generation (tCO ₂ yr ⁻¹)	567	557.49	575.77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
...fossil fuel - mix of electricity generation (tCO ₂ yr ⁻¹)	1161	1141.9	1179.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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Windfarm CO₂ emission saving

Note: The total emission savings are given by estimating the total possible electrical output of the windfarm multiplied by the emission factor for the counterfactual case (coal-fire generation and electricity from grid)

Emissions due to turbine life

Note: The carbon payback time of the windfarm due to turbine life (eg. manufacture, construction, decommissioning) 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.

Method used to estimate CO₂ emissions from turbine life (eg. manufacture, construction,	Calculate wrt installed capacity
---	----------------------------------

	Exp	Min	Max
Direct input of emissions due to turbine life (t CO₂ windfarm⁻¹)	0	0	0
Calculation of emissions due to turbine life from energy output			
CO ₂ emissions due to turbine life (tCO ₂ turbine ⁻¹)	5325	5232	5419
No. of turbines	14	14	14
Total calculated CO₂ emission of the wind farm due to turbine life (t CO₂ windfarm⁻¹)	74556	73248	75864

	Total			Construction Area 1			Construction Area 2			Construction Area 3			Construction Area 4			Construction Area 5			
	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	
Calculation of emissions due to cement used in construction																			
Volume of cement used (m ³)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO ₂ emission rate (t CO ₂ m ⁻³ cement)	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316
Total CO₂ emissions due to cement used	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

RESULTS			
Losses due to turbine life (eg. manufacture, construction, decommissioning)	74556	73248	75864
Additional CO₂ payback time of windfarm due to turbine life (eg. manufacture, construction, decommissioning)			
...coal-fired electricity generation (months)	346	345	346
...grid-mix of electricity generation (months)	1579	1577	1581
...fossil fuel - mix of electricity generation (months)	771	770	772

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Emissions due to turbine life

Note: The carbon payback time of the windfarm due to turbine life (eg. manufacture, construction, decommissioning) 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.

http://www.concretecentre.com/PDF/SCF_Table%207%20Embodied%20CO2_April%202013.pdf



Embodied carbon dioxide (CO₂e) of concretes used in buildings

CONCRETE APPLICATION	Concrete designation	CO ₂ e (kgCO ₂ e/m ³) ¹			CO ₂ e (kgCO ₂ e/tonne) ¹		
		CEM I concrete	30% fly ash concrete	50% ggbfs concrete	CEM I concrete	30% fly ash concrete	50% ggbfs concrete
Blinding, mass fill, strip footings, mass foundations, trench foundations ²	GEN1	177	128	101	77	55	44
Reinforced Foundations ²	RC25/30**	318	283	197	133	111	83
Ground floors ²	RC28/35	318	281	198	134	110	79
Structural: in situ floors, superstructure, walls, basements ²	RC32/40	369	313	231	154	131	96
High strength concrete ²	RC40/50	432	351	269	178	146	111
		CO ₂ e (kgCO ₂ e/m ³)			CO ₂ e (kgCO ₂ e/tonne)		
Unreinforced Precast flooring ³							165
Reinforced precast flooring ³							171
Average Generic Concrete Block ⁴							84

* includes 30kg/m² steel reinforcement

** includes 100kg/m² steel reinforcement

Emissions due to backup power generation

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

	Expected	Minimum	Maximum
Reserve capacity required for backup			
No. of turbines	14	14	14
Power rating of turbines (turbine capacity) (MW)	6.2	6.1	6.3
Power of wind farm (MW h ⁻¹)	86.8	85.4	88.2
Rated capacity (MW yr ⁻¹)	760368	748104	772632
Extra capacity required for backup (%)	5	5	5
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10	10	10
Reserve capacity (MWh yr ⁻¹)	3802	3741	3863

Carbon dioxide emissions due to backup power generation			
Coal-fired plant emission factor (t CO ₂ MWh ⁻¹)	0.945	0.945	0.945
Grid-mix emission factor (t CO ₂ MWh ⁻¹)	0.207	0.207	0.207
Fossil fuel- mix emission factor (t CO ₂ MWh ⁻¹)	0.424	0.424	0.424
Lifetime of windfarm (years)	35	35	35
Annual emissions due to backup from...			
...coal-fired electricity generation (tCO ₂ yr ⁻¹)	3593	3535	3651
...grid-mix of electricity generation (tCO ₂ yr ⁻¹)	787	774	800
...fossil fuel - mix of electricity generation (tCO ₂ yr ⁻¹)	1612	1586	1638

RESULTS			
Total emissions due to backup from...			
...coal-fired electricity generation (tCO ₂)	125746	123718	127774
...grid-mix of electricity generation (tCO ₂)	27544	27100	27989
...fossil fuel - mix of electricity generation (tCO ₂)	56419	55509	57329
Additional CO₂ payback time of windfarm due to backup			
...coal-fired electricity generation (months)	583	583	583
...grid-mix of electricity generation (months)	583	583	583
...fossil fuel - mix of electricity generation (months)	583	583	583

Note: 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.

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Emissions due to backup power generation

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

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

	Expected	Minimum	Maximum
Area where carbon accumulation by bog plants is lost			
Total area of land lost due to windfarm construction (m ²)	137911	134940	142530
Total area affected by drainage due to windfarm construction (m ²)	473810	312040	639520
Total area where fixation by plants is lost (m ²)	611721	446980	782050
Total loss of carbon accumulation			
Carbon accumulation in undrained peats (tC ha ⁻¹ yr ⁻¹)	0.25	0.2	0.3
Lifetime of windfarm (years)	35	35	35
Time required for regeneration of bog plants after restoration (years)	10	5	15
Carbon accumulation up to time of restoration (tCO ₂ eq. ha ⁻¹)	41	29	55

Assumptions:
 1. Bog plants are 100% lost from the area where peat is removed for construction.
 2. Bog plants are 100% lost from the area where peat is drained.
 3. The recovery of carbon accumulation by plants on restoration of land is as given in inputs.

RESULTS			
Total loss of carbon accumulation by bog plants			
Total area where fixation by plants is lost (ha)	61	45	78
Carbon accumulation over lifetime of windfarm (tCO ₂ eq. ha ⁻¹)	41	29	55
Total loss of carbon fixation by plants at the site (t CO₂)	2524	1311	4302
Additional CO₂ payback time of windfarm due to loss of CO₂ fixing potential			
...coal-fired electricity generation (months)	12	6	20
...grid-mix of electricity generation (months)	53	28	90
...fossil fuel - mix of electricity generation (months)	26	14	44

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

Emissions due to loss of soil organic carbon

Note: Loss of C stored in peatland is estimated from % site lost by peat removal (sheet 5a), CO₂ loss from removed peat (sheet 5b), % site affected by drainage (sheet 5c), and the CO₂ loss from drained peat (sheet 5d).

	Expected result	Minimum result	Maximum result
CO ₂ loss due to windfarm construction			
CO ₂ loss from removed peat (t CO ₂ equiv)	-11557	-11801	-6774
CO ₂ loss from drained peat (t CO ₂ equiv)	0	0	0
RESULTS			
Total CO₂ loss from peat (removed + drained) (t CO₂ equiv)	-11557	-11801	-6774
Additional CO₂ payback time of windfarm due to loss of soil CO₂			
...coal-fired electricity generation (months)	-54	-56	-31
...grid-mix of electricity generation (months)	-245	-254	-141
...fossil fuel - mix of electricity generation (months)	-119	-124	-69

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Emissions due to loss of soil organic carbon

Note: Loss of C stored in peatland is estimated from % site lost by peat removal (sheet 5a), CO₂ loss from removed peat (sheet 5b), % site affected by drainage (sheet 5c), and the CO₂ loss from drained peat (sheet 5d).

CO₂ loss from removed peats

Note: 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

	Expected	Minimum	Maximum
CO₂ loss from removed peat			
C Content of dry peat (% by weight)	53.23	19.57	64.28
Dry soil bulk density (g cm ⁻³)	0.13	0.07	0.29
% C contained in removed peat that is lost as CO ₂	100	100	100
Total volume of peat removed (m ³) due to windfarm construction	0	0	0
CO ₂ loss from removed peat (t CO ₂)	0	0	0

Assumption: If peat is not restored, 100% of the carbon contained in the removed peat is lost as CO₂

Check

CO₂ loss from undrained peat left in situ			
Total area of land lost due to windfarm construction (ha)	14	13	14
CO ₂ loss from undrained peat left in situ (t CO ₂ ha ⁻¹)	838	875	475
CO ₂ loss from undrained peat left in situ (t CO ₂)	11557	11801	6774

CO₂ loss attributable to peat removal only			
CO ₂ loss from removed peat (t CO ₂)	0	0	0
CO ₂ loss from undrained peat left in situ (t CO ₂)	11557	11801	6774
RESULTS			
CO₂ loss attributable to peat removal only (t CO₂)	-11557	-11801	-6774

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CO₂ loss from removed peats

Note: 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

Volume of peat drained

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

Extent of drainage around each metre of drainage ditch			
	Exp	Total Min	Max
Average extent of drainage around drainage features at site (m)	15	10	20

Peat affected by drainage around borrow pits			
	Exp	Total Min	Max
Number of borrow pits	2	2	2
Average length of pits (m)	135	120	135
Average width of pits (m)	92	91	109
Average depth of peat removed from pit (m)	0.0	0.0	0.0
Area affected by drainage per borrow pit (m ²)	7705	4620	11360
Total area affected by drainage around borrow pits (m ²)	15410	9240	22720
Total volume affected by drainage around borrow pits (m ³)	0	0	0

Peat affected by drainage around turbine foundation and hardstanding				Construction Area 1			Construction Area 2			Construction Area 3			Construction Area 4			Construction Area 5		
	Exp	Total Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max
No. of turbines	14	14	14	14	14	14	0	0	0	0	0	0	0	0	0	0	0	0
Average length of turbine foundations at base (m)				25	25	25	0	0	0	0	0	0	0	0	0	0	0	0
Average width of turbine foundations at base(m)				25	25	25	0	0	0	0	0	0	0	0	0	0	0	0
Average depth of peat removed from turbine foundations (m)				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average length of hard-standing at base (m)				55	55	55	0	0	0	0	0	0	0	0	0	0	0	0
Average width of hard-standing at base (m)				35	35	35	0	0	0	0	0	0	0	0	0	0	0	0
Average depth of peat removed from hard-standing (m)				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum depth of drains (m)				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total length of foundation and hardstanding (m)				80	80	80	0	0	0	0	0	0	0	0	0	0	0	0
Total width of foundation and hardstanding (m)				80	80	80	0	0	0	0	0	0	0	0	0	0	0	0
Area affected by drainage of foundation and hardstanding area (m ²)	5100	3200	7200	5100	3200	7200	0	0	0	0	0	0	0	0	0	0	0	0
Total area affected by drainage of foundation and hardstanding area (m ²)	71400	44800	100800	71400	44800	100800	0	0	0	0	0	0	0	0	0	0	0	0
Total volume affected by drainage of foundation and hardstanding area (m ³)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Peat affected by drainage of access tracks			
	Exp	Total Min	Max
Floating roads			
Length of floating road that is drained (m)	0	0	0
Floating road width (m)	0.0	0.0	0.0
Average depth of drains associated with floating roads (m)	0.00	0.00	0.00
Area affected by drainage of floating roads (m ²)	0	0	0
Volume affected by drainage of floating roads (m ³)	0	0	0
Excavated Road			
Length of access track that is excavated road (m)	12900	12900	12900
Excavated road width (m)	6	6	6
Average depth of peat excavated for road (m)	0.0	0.0	0.0
Area affected by drainage of excavated roads (m ²)	387000	258000	516000
Volume affected by drainage of excavated roads (m ³)	0	0	0
Rock-filled roads			
Length of rock filled road that is drained (m)	0	0	0
Rock filled road width (m)	0	0	0
Average depth of drains associated with rock filled roads (m)	0.0	0.0	0.0
Area affected by drainage of rock-filled roads (m ²)	0	0	0
Volume affected by drainage of rock-filled roads (m ³)	0	0	0
Total area affected by drainage of access track (m ²)	387000	258000	516000
Total volume affected by drainage of access track (m ³)	0	0	0

Peat affected by drainage of cable trenches			
	Exp	Total Min	Max
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
Average depth of peat cut for cable trenches (m)	0.0	0.0	0.0
Total area affected by drainage of cable trenches (m ²)	0	0	0
Total volume affected by drainage of cable trenches (m ³)	0.00	0.00	0.00

Drainage around additional peat excavated			
	Exp	Total Min	Max
Volume of additional peat excavated (m ³)	0.0	0.0	0.0
Area of additional peat excavated (m ²)	0.0	0.0	0.0
Average depth of excavated peat (m)	0	0	0
Radius of area excavated (m)	0	0	0
Radius of excavated and drained area (m)	0	0	0
Total area affected by drainage (m ²)	0	0	0
Total volume affected by drainage (m ³)	0.00	0.00	0.00

Assumption: Area excavated is assumed to be a circle

RESULTS			
	Exp	Total Min	Max
Total area affected by drainage due to windfarm (m ²)	473810	312040	639520
Total volume affected by drainage due to windfarm (m ³)	0.00036	2.2E-05	0.00504

Click here to move to 5d. CO2 loss from drained peat [Click here](#)
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Volume of peat drained

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

CO₂ loss due to drainage

Note: 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).

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	Expected	Minimum	Maximum
Drained Land			
Total area affected by drainage due to wind farm construction (ha)	47	31	64
Will the hydrology of the site be restored on decommissioning?	No	No	No
Will the habitat of the site be restored on decommissioning?	No	No	No

Calculations of C Loss from Drained Land if Site is NOT Restored after Decommissioning

Check	Total volume affected by drainage due to wind farm (m ³)	0	0	0
	C Content of dry peat (% by weight)	53	20	64
	Dry soil bulk density (g cm ⁻³)	0.13	0.07	0.29
	Total GHG emissions from Drained Land (t CO₂ equiv.)	0	0	0
	Total GHG Emissions from Undrained Land (t CO₂ equiv.)	0	0	0

Assumption: Losses of GHG from drained and undrained land have the same proportion throughout the emission period.

Calculations of C loss from Drained Land if Site IS Restored after Decommissioning**1. Losses if Land is Drained**

	Flooded period (days year ⁻¹)	0	0	0
	Lifetime of windfarm (years)	35	35	35
	Time required for regeneration of bog plants after restoration (years)	10	5	15
	Methane Emissions from Drained Land			
Check	Rate of methane emission in drained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	-0.001	-0.019	0.165
	Conversion factor: CH ₄ -C to CO ₂ equivalents	30.67	30.67	30.67
	CH ₄ emissions from drained land (t CO ₂ equiv.)	-45	-742	16146
	Carbon Dioxide Emissions from Drained Land			
Check	Rate of carbon dioxide emission in drained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	18.64	22.46	4.46
	CO ₂ emissions from drained land (t CO ₂)	39751	28031	14249
	Total GHG emissions from Drained Land (t CO₂ equiv.)	39706	27289	30395

Assumption: The drained soil is not flooded at any time of the year.

Note: Conversion = (23 x 16/12) = 30.67 CO₂ equiv. (CH₄-C)⁻¹

2. Losses if Land is Undrained

	Flooded period (days year ⁻¹)	178	178	178
	Lifetime of windfarm (years)	35	35	35
	Time required for regeneration of bog plants after restoration (years)	10	5	15
	Methane Emissions from Undrained Land			
Check	Rate of methane emission in undrained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.00	-0.02	0.16
	Conversion factor: CH ₄ -C to CO ₂ equivalents	30.67	30.67	30.67
	CH ₄ emissions from undrained land (t CO ₂ equiv.)	-45	-742	16146
	Carbon Dioxide Emissions from Undrained Land			
Check	Rate of carbon dioxide emission in undrained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	18.64	22.46	4.46
	CO ₂ emissions from undrained land (t CO ₂)	39751	28031	14249
	Total GHG Emissions from Undrained Land (t CO₂ equiv.)	39706	27289	30395

Note: Conversion = (23 x 16/12) = 30.67 CO₂ equiv. (CH₄-C)⁻¹

3. CO₂ Losses due to Drainage

	Total GHG emissions from drained land (t CO ₂ equiv.)	0	0	0
	Total GHG emissions from undrained land (t CO ₂ equiv.)	0	0	0
	RESULTS			
	Total GHG emissions due to drainage (t CO₂ equiv.)	0	0	0

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CO₂ loss due to drainage

Note: 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).

Emission rates from soils

Note: 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).

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**Selected Methodology = Site specific (required for planning applications)
 Type of peatland = Acid Bog**

Calculations following IPCC default methodology	Expected	Minimum	Maximum
Emission characteristics of acid bogs (IPCC, 1997)			
Flooded period (days year ⁻¹)	178	178	178
Annual rate of methane emission (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.04015	0.04015	0.04015
Annual rate of carbon dioxide emission (t CO ₂ ha ⁻¹ yr ⁻¹)	35.2	35.2	35.2

Emission characteristics of fens (IPCC, 1997)			
Flooded period (days year ⁻¹)	169	169	169
Annual rate of methane emission (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.219	0.219	0.219
Annual rate of carbon dioxide emission (t CO ₂ ha ⁻¹ yr ⁻¹)	35.2	35.2	35.2

Selected emission characteristics (IPCC, 1997)			
Flooded period (days year ⁻¹)	178	178	178
Annual rate of methane emission (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.04015	0.04015	0.04015
Annual rate of carbon dioxide emission (t CO ₂ ha ⁻¹ yr ⁻¹)	35.2	35.2	35.2

Calculations following ECOSSE based methodology	Expected	Minimum	Maximum
Drained Land			
Total area affected by drainage due to wind farm construction (ha)	47	31	64
Total volume affected by drainage due to wind farm construction (m ³)	0	0	0

Soil Characteristics that Determine Emission Rates	Expected	Minimum	Maximum
Average annual air temperature at the site (°C)	9.9	4.9	15.8
Average water table depth at site (m)	0.50	1.00	0.10
Average water table depth of drained land (m)	0.50	1.00	0.10

Annual Emission Rates following site specific methodology	Expected	Minimum	Maximum
Acid bogs			
Rate of carbon dioxide emission in drained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	18.64	22.46	4.46
Rate of carbon dioxide emission in undrained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	18.64	22.46	4.46
Rate of methane emission in drained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	-0.001	-0.019	0.165
Rate of methane emission in undrained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.00	-0.02	0.16
Fens			
Rate of carbon dioxide emission in drained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	55.52	62.05	11.03
Rate of carbon dioxide emission in undrained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	55.52	62.05	11.03
Rate of methane emission in drained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.001	-0.007	0.214
Rate of methane emission in undrained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.00	-0.01	0.21

Selected emission characteristics following site specific methodology	Expected	Minimum	Maximum
Rate of carbon dioxide emission in drained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	18.64	22.46	4.46
Rate of carbon dioxide emission in undrained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	18.64	22.46	4.46
Rate of methane emission in drained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	-0.001	-0.019	0.165
Rate of methane emission in undrained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.00	-0.02	0.16

RESULTS	Expected	Minimum	Maximum
Selected Emission Rates			
Rate of carbon dioxide emission in drained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	18.64	22.46	4.46
Rate of carbon dioxide emission in undrained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	18.64	22.46	4.46
Rate of methane emission in drained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	-0.001	-0.019	0.165
Rate of methane emission in undrained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.00	-0.02	0.16

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Emission rates from soils

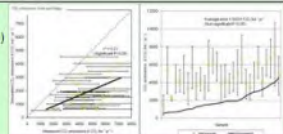
Note: Note, CO₂ losses are calculated using two approaches: IPCC default methodology and more site specific equations derived for this project. The IPCC methodology is included because it is the established approach, although it contains no site detail. The new equations have been thoroughly tested against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

Assumption: The period of flooding is taken to be 178 days yr⁻¹ for acid bogs and 169 days yr⁻¹ based on the monthly mean temperature and the lengths of inundation (IPCC, 1997, Revised 1996 IPCC guidelines for national greenhouse gas inventories, Vol 3, table 5-13)

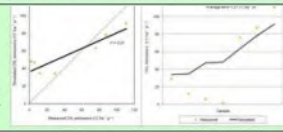
Assumption: The CH₄ emission rate provided for acid bogs is 11 (1-38) mg CH₄-C m⁻² day⁻¹ x 365 days; and for fens is 60 (21-162) mg CH₄-C m⁻² day⁻¹ x 365 days (Aeslmann & Crutzen, 1989, J.Atm.Chem. 8, 307-358)

Assumption: CO₂ emissions on drainage of organic soils for upland crops (e.g., grain, vegetables) are 3.66x9.6 (7.9-11.3) t CO₂ ha⁻¹ yr⁻¹ in temperate climates (Arentano and Menges, 1986, J. Ecol. 74, 755-774).

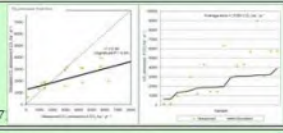
Note: Carbon dioxide emissions from acid bogs. Equation derived by regression analysis against 60 measurements (Nayak et al, 2009). The equation derived was $R_{CO_2} = (3.667/1000) \times (6700 \times \exp(-0.26 \times \exp(-0.0515 \times ((W \times 100) - 50)))) + ((72.54 \times T) - 800)$ where R_{CO_2} is the annual rate of CO₂ emissions (t CO₂ (ha)⁻¹ yr⁻¹), T = average annual peat temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements (r²=0.53, P>0.05). Evaluation against 29 independent experiments shows a significant association (r²=0.21; P>0.05) and an average error of 3023 t CO₂ ha⁻¹ yr⁻¹ which is non-significant (P<0.05) (Smith et al, 1997).



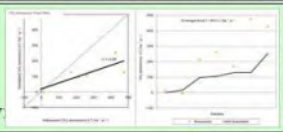
Note: Methane emissions from acid bogs. Equation derived by regression analysis against 60 measurements (Nayak et al, 2009). The equation derived was $R_{CH_4} = (1/1000) \times (500 \times \exp(-0.1234 \times (W \times 100))) + ((3.529 \times T) - 36.67)$ where R_{CH_4} is the annual rate of CH₄ emissions (t CH₄-C (ha)⁻¹ yr⁻¹), T = average annual air temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements (r²=0.54, P>0.05). Evaluation against 7 independent experiments shows a significant association (r²=0.81; P>0.05) and an average error of 271 t CH₄-C ha⁻¹ yr⁻¹ (significance not defined due to lack of replicates - Smith et al, 1997).



Note: Carbon dioxide emissions from fens. Equation derived by regression analysis against 44 measurements (Nayak et al, 2009). The equation derived was $R_{CO_2} = (3.667/1000) \times (16244 \times \exp(-0.175 \times \exp(-0.073 \times ((W \times 100) - 50)))) + (153.23 \times T)$ where R_{CO_2} is the annual rate of CO₂ emissions (t CO₂ (ha)⁻¹ yr⁻¹), T = average annual peat temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements (r²=0.47, P>0.05). Evaluation against 18 independent experiments shows a significant association (r²=0.56; P>0.05) and an average error of 2108 t CO₂ ha⁻¹ yr⁻¹ (significance not defined due to lack of replicates - Smith et al, 1997).



Note: Methane emissions from fens. Equation derived by regression analysis against experimental data from 36 measurements (Nayak et al, 2009). The equation derived was $R_{CH_4} = (1/1000) \times (-10 + 563.62 \times \exp(-0.097 \times (W \times 100))) + (0.862 \times T)$ where R_{CH_4} is the annual rate of CH₄ emissions (t CH₄-C (ha)⁻¹ yr⁻¹), T = average annual air temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements (r²=0.41, P>0.05). Evaluation against 7 independent experiments shows a significant association (r²=0.69; P>0.05) and an average error of 1641 t CH₄-C ha⁻¹ yr⁻¹ (significance not defined due to lack of replicate - Smith et al, 1997).



Emissions due to loss of DOC and POC

Note: 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)

	Expected	Minimum	Maximum
Total C loss			
Gross CO ₂ loss from restored drained land (t CO ₂)	0	0	0
Gross CH ₄ loss from restored drained land (t CO ₂ equiv.)	0	0	0
Gross CO ₂ loss from improved land (t CO ₂)			
Degraded Bog	0	0	0
Felled Forestry	0	0	0
Borrow Pits	0	0	0
Foundations & Hardstanding	0	0	0
Gross CH ₄ loss from improved land (t CO ₂ equiv.)			
Degraded Bog	0	0	0
Felled Forestry	0	0	0
Borrow Pits	0	0	0
Foundations & Hardstanding	0	0	0
Conversion factor: CH ₄ -C to CO ₂ equivalents	30.6667	30.6667	30.6667
% total soil C losses, lost as DOC	26	7	40
% DOC loss emitted as CO ₂ over the long term	100	100	100
% total soil C losses, lost as POC	8	4	10
% POC loss emitted as CO ₂ over the long term	100	100	100
Total gaseous loss of C (t C)	0	0	0
Total C loss as DOC (t C)	0	0	0
Total C loss as POC (t C)	0	0	0

Note: Only restored drained land included because if land is not restored, the C lost has already been counted as carbon dioxide

Assumption: DOC loss ranges between 7 - 40% of the total gaseous loss if calculated from the reported (minimum and maximum) values in Worrall 2009 and is 26% of the total gaseous loss if calculated from the mean of reported maximum and minimum value in Worrall 2009. These DOC values are flux based on soil water concentration (i.e. 12.5 - 85.9 MgC/KM²/yr) and not on flux at catchment outlet (i.e. 10.3 - 21.8 MgC/KM²/yr)
Worrall, F. et al., 2009. The multi-annual carbon budget of a peat-covered catchment. *Science of The*

Assumption: In the long term, 100% of leached DOC is assumed to be lost as CO₂

Assumption: POC loss ranges between 4-10% of the total gaseous loss if calculated from the reported values and is 8% of the total gaseous loss if calculated from the mean of reported maximum and minimum value in Worrall 2009. POC range is (7 - 22.4 MgC/KM²/yr) (Worrall et al, 2009).

Assumption: In the long term, 100% of leached POC is assumed to be lost as CO₂

RESULTS			
Total CO ₂ loss due to DOC leaching (t CO ₂)	0	0	0
Total CO ₂ loss due to POC leaching (t CO ₂)	0	0	0
Total CO₂ loss due to DOC & POC leaching (t CO₂)	0	0	0
Additional CO₂ payback time of windfarm due to DOC & POC			
...coal-fired electricity generation (months)	0	0	0
...grid-mix of electricity generation (months)	0	0	0
(months)	0	0	0

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Emissions due to loss of DOC and POC

Note: 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)

Gains due to site improvement

Note: 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).

Selected Methodology = Site specific (required for planning applications)
Type of peatland = Acid Bog

Reduction in GHG emissions due to improvement of site	Expected result								Minimum result				Maximum result			
	Degraded Bog	Felled Forestry	Borrow Pits	Foundations & Hardstanding	Degraded Bog	Felled Forestry	Borrow Pits	Foundations & Hardstanding	Degraded Bog	Felled Forestry	Borrow Pits	Foundations & Hardstanding	Degraded Bog	Felled Forestry	Borrow Pits	Foundations & Hardstanding
1. Description of site																
Period of time when effectiveness of the improvement can be guaranteed (years)	0	0	0	35	0	0	0	35	0	0	0	35	0	0	0	35
Area to be improved (ha)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average air temperature at site (°C)	9.9	9.9	9.9	9.9	4.9	4.9	4.9	4.9	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8
Depth of peat drained (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth of peat above water table before improvement (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth of peat above water table after improvement (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2. Losses with improvement																
Flooded period (days year ⁻¹)	178	178	178	178	178	178	178	178	178	178	178	178	178	178	178	178
Time required for hydrology and habitat to return to its previous state on restoration (years)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Improved period (years)	0	0	0	35	0	0	0	35	0	0	0	35	0	0	0	35
Methane emissions from improved land																
Site specific methane emission from improved soil on acid bogs (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.498	0.498	0.498	0.498	0.481	0.481	0.481	0.481	0.519	0.519	0.519	0.519	0.519	0.519	0.519	0.519
Site specific methane emission from improved soil on fens (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.560	0.560	0.560	0.560	0.557	0.557	0.557	0.557	0.564	0.564	0.564	0.564	0.564	0.564	0.564	0.564
IPCC annual rate of methane emission on acid bogs (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
IPCC annual rate of methane emission on fens (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.219	0.219	0.219	0.219	0.219	0.219	0.219	0.219	0.219	0.219	0.219	0.219	0.219	0.219	0.219	0.219
Selected annual rate of methane emission (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.498	0.498	0.498	0.498	0.481	0.481	0.481	0.481	0.519	0.519	0.519	0.519	0.519	0.519	0.519	0.519
CH ₄ emissions from improved land (t CO ₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon dioxide emissions from improved land																
Site specific CO ₂ emission from improved soil on acid bogs (t CO ₂ ha ⁻¹ yr ⁻¹)	0.50	0.50	0.50	0.50	-0.83	-0.83	-0.83	-0.83	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07
Site specific CO ₂ emissions from improved soil on fens (t CO ₂ ha ⁻¹ yr ⁻¹)	5.62	5.62	5.62	5.62	2.81	2.81	2.81	2.81	8.94	8.94	8.94	8.94	8.94	8.94	8.94	8.94
IPCC annual rate of carbon dioxide emission on acid bogs (t CO ₂ ha ⁻¹ yr ⁻¹)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IPCC annual rate of carbon dioxide emission on fens (t CO ₂ ha ⁻¹ yr ⁻¹)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Selected annual rate of carbon dioxide emission (t CO ₂ ha ⁻¹ yr ⁻¹)	0.50	0.50	0.50	0.50	-0.83	-0.83	-0.83	-0.83	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07
CO ₂ emissions from improved land (t CO ₂)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total GHG emissions from improved land (t CO₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3. Losses without improvement																
Flooded period (days year ⁻¹)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Time required for hydrology and habitat to return to its previous state on restoration (years)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Improved period (years)	0	0	0	35	0	0	0	35	0	0	0	35	0	0	0	35
Methane emissions from unimproved land																
Site specific methane emission from unimproved soil on acid bogs (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.498	0.498	0.498	0.498	0.481	0.481	0.481	0.481	0.519	0.519	0.519	0.519	0.519	0.519	0.519	0.519
Site specific methane emission from unimproved soil on fens (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.560	0.560	0.560	0.560	0.557	0.557	0.557	0.557	0.564	0.564	0.564	0.564	0.564	0.564	0.564	0.564
IPCC annual rate of methane emission on acid bogs (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IPCC annual rate of methane emission on fens (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Selected annual rate of methane emission (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.498	0.498	0.498	0.498	0.481	0.481	0.481	0.481	0.519	0.519	0.519	0.519	0.519	0.519	0.519	0.519
CH ₄ emissions from unimproved land (t CO ₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon dioxide emissions from unimproved land																
Site specific CO ₂ emission from unimproved soil on acid bogs (t CO ₂ ha ⁻¹ yr ⁻¹)	0.50	0.50	0.50	0.50	-0.83	-0.83	-0.83	-0.83	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07
Site specific CO ₂ emissions from unimproved soil on fens (t CO ₂ ha ⁻¹ yr ⁻¹)	5.62	5.62	5.62	5.62	2.81	2.81	2.81	2.81	8.94	8.94	8.94	8.94	8.94	8.94	8.94	8.94
IPCC annual rate of carbon dioxide emission on acid bogs (t CO ₂ ha ⁻¹ yr ⁻¹)	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20
IPCC annual rate of carbon dioxide emission on fens (t CO ₂ ha ⁻¹ yr ⁻¹)	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20
Selected annual rate of carbon dioxide emission (t CO ₂ ha ⁻¹ yr ⁻¹)	0.50	0.50	0.50	0.50	-0.83	-0.83	-0.83	-0.83	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07
CO ₂ emissions from unimproved land (t CO ₂)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total GHG emissions from unimproved land (t CO₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RESULTS																
4. Reduction in GHG emissions due to improvement of site																
Total GHG emissions from improved land (t CO ₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total GHG emissions from unimproved land (t CO ₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reduction in GHG emissions due to improvement (t CO₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Additional CO₂ payback time of windfarm due to site improvement																
...coal-fired electricity generation (months)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
...grid-mix of electricity generation (months)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
...fossil fuel - mix of electricity generation (months)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: Methane emissions from acid bogs. Equation derived by regression analysis against 57 measurements (Nayak et al. 2009). The equation derived was $R_{CH_4} = (1/1000) \times (500 \times \exp(-0.1234 \times (W \times 100))) + ((3.529 \times T) - 36.67))$ where R_{CH_4} is the annual rate of CH₄ emissions (t CH₄-C (ha⁻¹) yr⁻¹), T = average annual air temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements (r² = 0.54, P > 0.05). Evaluation against 19 independent experiments shows a significant association (r² = 0.81, P < 0.05) and an average error of 27.1 CH₄-C ha⁻¹ yr⁻¹ (significance not defined due to lack of replicates - Smith et al. 1997).

Note: Methane emissions from fens. Equation derived by regression analysis against experimental data from 35 measurements (Nayak et al. 2009). The equation derived was $R_{CH_4} = (1/1000) \times (1.1 \times 10^{0.0252 \times \exp(-0.057 \times (W \times 100))) + (0.622 \times T))$ where R_{CH_4} is the annual rate of CH₄ emissions (t CH₄-C (ha⁻¹) yr⁻¹), T = average annual air temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements (r² = 0.41, P > 0.05). Evaluation against 7 independent experiments shows a significant association (r² = 0.69, P < 0.05) and an average error of 16.4 CH₄-C ha⁻¹ yr⁻¹ (significance not defined due to lack of replicates - Smith et al. 1997).

$R_{CO_2} = (3.667/1000) \times ((6700 \times \exp(-0.26 \times \exp(-0.0515 \times ((W \times 100) - 50)))) + (72.54 \times T) - 8000)$ where R_{CO_2} is the annual rate of CO₂ emissions (t CO₂ (ha⁻¹) yr⁻¹), T = average annual soil temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements (r² = 0.53, P < 0.05). Evaluation against 20 independent experiments shows a significant association (r² = 0.21, P < 0.05) and an average error of 3023 t CO₂ ha⁻¹ yr⁻¹ which is non-significant (P > 0.05) (Smith et al. 1997).

Note: Carbon dioxide emissions from fens. Equation derived by regression analysis against 44 measurements (Nayak et al. 2009). The equation derived was $R_{CO_2} = (3.667/1000) \times (16244 \times \exp(0.175 \times \exp(-0.073 \times ((W \times 100) - 50)))) + (153.23 \times T)$ where R_{CO_2} is the annual rate of CO₂ emissions (t CO₂ (ha⁻¹) yr⁻¹), T = average annual soil temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements (r² = 0.42, P > 0.05). Evaluation against 18 independent experiments shows a significant association (r² = 0.86, P < 0.05) and an average error of 2108 t CO₂ ha⁻¹ yr⁻¹ (significance not defined due to lack of replicates - Smith et al. 1997).

Note: Methane emissions from acid bogs. As above

Note: Methane emissions from fens. As above

Note: CO₂ emissions from acid bogs. As above

Note: CO₂ emissions from fens. As above

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Gains due to site improvement

Note: 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).

Ch 15: Material Assets, Table 15-8					Distance Assumptions	TII Embodied Carbon Tool Inputs						TII Transport Inputs		
Material	Total no. Truck Loads	Truck Type	TII Embodied Carbon	TII Traffic	Distance (km)	Category	Sub-Category	Material	Quantity	Unit	Embodied CO2e	Transport Type	Distance (km)	Transport CO2e
Concrete	1498	Trucks	✓	✓	20	Series number 1700 - Structural Concrete	In Situ Concrete - General	In-Situ Concrete, General	29,960,000.00	kg	2778.328	HGV - Rigid - Average	29,960.00	30.786
Delivery of plant	54	Large artic		✓	131							HGV - All - Average	7,074.00	7.672
Fencing & gates	4	Large artic		✓	20							HGV - All - Average	80.00	0.087
Compound setup	56	Large artic		✓	131							HGV - All - Average	7,336.00	7.956
Steel	38	Large artic	✓	✓	20	Other	Structural Steelwork	Anchorage and holding down bolt assemblies	760.00	tonnes	1362.756	HGV - All - Average	760.00	0.824
Rock and stone (Wind Farm & Grid Connection)	2951	Truck	✓	✓	20	Series 2400 - Brickwork, Blockwork and Stonework	Brickwork and Blockwork	General Stone	59,020.00	tonnes	440.879	HGV - Rigid - Average	59,020.00	60.647
Ducting and cabling (internal)	410	Large artic		✓	20							HGV - All - Average	8,200.00	8.893
Grid connection cable laying	5444			✓	20							HGV - All - Average	108,880.00	122.467
Tree Felling	104				20									
Crane (to lift steel)	2	Large artic		✓	131							HGV - All - Average	262.00	0.284
Road construction	2,000	Truck		✓	20							HGV - Rigid - Average	40,000.00	41.102
Substation	114	Large artic		✓	20							HGV - All - Average	2,280.00	2.476
BESS	500	Large artic			20									
Cranes for turbines	24	Large artic		✓	131							HGV - All - Average	3,144.00	3.41
Refuelling for plant	290	Large artic		✓	20							HGV - All - Average	5,800.00	6.29
Site maintenance	210	Large artic		✓	20							HGV - All - Average	4,200.00	4.555
Miscellaneous	140	Large artic		✓	20							HGV - All - Average	2,800.00	3.037
Total											4,581.96			300.49

List of Assumptions

Embodied Carbon Assumptions			Traffic Assumptions		
Item	Description	Assumption	Item	Description	Assumption
Volume of Average Artic Truck	Calculation completed based on the average artic truck having a carrying capacity of 20 tonnes	20	Import (P) Distance	For modelling purposes, the average distance from Shannon Foynes Port, Limerick City and Ringaskiddy, Co. Cork for transport of all other materials for the site	131
Ducting and cabling (internal)	Embodied carbon of electrical equipment not included as an option in TII Carbon Tool	-	Quarry (Q) Distance	Distances from key townships for the Deliveries of Stone and Ready-Mix Concrete from Quarries to the Proposed Project Site	20
Grid connection cable laying	Embodied carbon of electrical equipment not included as an option in TII Carbon Tool	-	Truck Emissions Factor	Calculated from an HGV - Rigid - Average emission factor as provided in the TII Carbon Tool	0.26784
Turbine Lifecycle	Embodied carbon of the overall turbine lifecycle is included in the Macaulay Institute Carbon Calculator for Wind Farms on Peatland	-	Large Artic Emission Factor	Calculated from an HGV - All - Average emission factor as provided in the TII Carbon Tool	1.0845

Embodied Carbon Assumptions			Traffic Assumptions			Carbon Fixing Vegetation Assumptions		
Item	Description	Assumption	Item	Description	Assumption	Item	Description	Assumption
Volume of Concrete Mixer	Calculation completed based on the average concrete mixer holding 8m³ of concrete	8	Import (P) Distance	For modelling purposes, the average distance from Shannon Foynes Port, Limerick City and Port of Galway, Co. Galway for transport of all other materials for the site	131	Calculation of Carbon Storage Potential in Enhancement Measures	The carbon storage capacity of restored habitats will vary over time as vegetation matures and land use and the baseline environment change. Therefore, while it can be assumed that native woodland replanting and enhancement of wet heath habitat on the Site will result in an increased capacity of carbon storage due to the carbon storage potential that exists within these habitats, to ensure the assessment below is identified under a theoretical precautionary scenario the quantification of these potential carbon savings (via an increase in carbon storage potential) associated with these measures has not been included in the carbon savings assessment. Please note, the carbon sequestration potential associated with the replanting of native woodland will be able to be determined in the future via the Teagasc Forest Carbon Tool ; currently this is not able to be completed due to Teagasc carrying out further analysis and validation on current data and the sequestration potential not being available in the public domain.	Not considered in assessment or quantified
Volume of Average Artic Truck	Calculation completed based on the average artic truck having a carrying capacity of 20 tonnes	20	Quarry (Q) Distance	Distances from key townships for the Deliveries of Stone and Ready-Mix Concrete from Quarries to the Site	20	Calculation of Carbon Loss from removal of carbon fixing vegetation	Carbon losses associated with the removal of other carbon fixing vegetation will result in additional carbon losses. These have not been quantified as the lack of consistent national level field data and methodologies limits the ability to make accurate projections on carbon sequestration potential for other carbon fixing habitat types, i.e., hedgerow, grassland, etc., and therefore carbon loss associated with removal. While it can be assumed that loss of carbon fixing vegetation will occur as part of the Proposed Development due to the removal of these habitat types, the exact carbon loss is not quantifiable.	Not considered in assessment or quantified
Ducting and cabling (internal)	Embodied carbon of electrical equipment not included as an option in TII Carbon Tool	-	Concrete Mixer Emission factor	Calculated from an HGV - Rigid - All emission factor as provided in the TII Carbon Tool. Source: 2024 DEZNZ emission factors - 'Delivery vehicles' tab, All Rigid HGVs and used Average laden weight. 2024 DEZNZ emission factors - 'WTT - delivery vehs & freight' tab, all Rigid HGVs and used Average laden weight.	1.02736			
Grid connection cable laying	Embodied carbon of electrical equipment not included as an option in TII Carbon Tool	-	Large Artic Emission Factor	Calculated from an HGV - All - Average emission factor as provided in the TII Carbon Tool. Source: 2024 DEZNZ emission factors - 'Delivery vehicles' tab, All artic HGVs and used Average laden weight. 2024 DEZNZ emission factors - 'WTT - delivery vehs & freight' tab, all artic HGVs and used Average laden weight.	1.0845			
Tree Felling	Embodied carbon of tree felling is included in the Macaulay Institute Carbon Calculator for Wind Farms on Peatland	-	Truck Emissions Factor	Calculated from an HGV - Articulated - Average emission factor as provided in the TII Carbon Tool. Source: 2024 DEZNZ emission factors - 'Delivery vehicles' tab, All artic HGVs and used Average laden weight. 2024 DEZNZ emission factors - 'WTT - delivery vehs & freight' tab, all artic HGVs and used Average laden weight.	1.12479			
Turbine Lifecycle	Embodied carbon of the overall turbine lifecycle is included in the Macaulay Institute Carbon Calculator for Wind Farms on Peatland	-						
Volume of Concrete Material	The density of concrete to be used at the Proposed Wind Farm is assumed to have average density of approximately 2,243m³/kg. Based on an assumed 11,984m³ of concrete being required (based on 1,498 truckloads of concrete with a 8m³ carrying capacity) this would result in approximately 5,760,024kg being used for the Proposed Project	26880112						
Volume of Steel	An assumed 760 tonnes of steel is required (based on 38 truckloads of steel with a 20 tonne carrying capacity) for the Proposed Project	760.00						
Volume of Stone	An assumed total of 30,020 tonnes of stone is required (based on 2,951 truckloads of stone with a 20 tonne carrying capacity) for the Proposed Wind Farm, Proposed Grid Connection, proposed onsite 11kV Substation, and proposed met mast	30020						