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.

Input data	Enter your values here	Record comments or assumptions here	Uncertanities Min	Uncertanities Max
Wind farm characteristics				
Dimensions				
No. of turbines	150			
Life time of wind farm (years)	25			
Performance				
Turbine capacity (MW)	3.6		20	30
Capacity factor (percentage efficiency)	45		27	34
Backup				
Extra capacity required for backup (%)	5			
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10			
Carbon dioxide emissions from turbine life - (eg. manufacture, construction, decommissioning)	Calculate wrt installed capacity			
Total CO_2 emission from turbine life (tCO_2 wind farm^{-1}) *(if known use direct input of emissions from turbine life)*				
Characteristics of peatland before wind farm development				
Type of peatland	Acid bog			
Average air temperature at site (°C)	7			
Average depth of peat at site (m)	1.60			
C Content of dry peat (% by weight)	55	From MLURI (1991)		
Average extent of drainage around drainage features at site (m)	100			
Average water table depth at site (m)	1.00			
Dry soil bulk density (g cm^{-3})	0.60			
Average soil pH	4.0			
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	10			
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha^{-1} yr^{-1})	0.25		0.12	0.31
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	0			
Average rate of carbon sequesteration in timber (tC ha^{-1} yr^{-1})	0.00			
Counterfactual emission factors				

Note: Capacity factor. The average capacity factor between 1998 and 2004 for Scotland was 30% (DTI, 2006, Energy Trends, March 2006). We recommend that a site-specific capacity factor site should be used (as measured during planning stage). However, if this is unknown, the best (34%) and worst case capacity factors for Scotland (27%) should be used to determine the likely range of the results .

Note: Extra capacity required for backup. If 20% of national electricity is generated by wind energy, the extra capacity required for backup is 5% of the rated capacity of the wind plant (Dale et al 2004, Energy Policy, 32, 1949-56). We suggest this should be 5% of the actual output. If it is assumed that less than 20% of national electricity is generated by wind energy, a lower percentage should be

Note: Extra emissions due to reduced thermal efficiency of the reserve power generation ≈ 10% (Dale et al 2004, Energy Policy, 32, 1949-56)

Note: Emissions from turbine life. Note, if total emissions for the windfarm are unknown, emissions will be calculated according to turbine capacity. The normal range of CO_2 emissions is 394 to 8147 t CO_2 MW (White & Kulcinski, 2000. Fusion Eng. Des. 48, 473-48; White, 2007, Natural Resources Research. 15, 271 - 281.)

Note: A fen is a type of wetland fed by surface and/or groundwater. A bog is fed primarily by rainwater and often inhabited by sphagnum moss, making it acidic.

Note: Time required for regeneration of previous habitat. It is suggested that loss of fixation should be assumed to be over lifetime of windfarm only.
This time could longer if plants do not regenerate. The requirements for after-use planning include the provision of suitable refugia for peat forming vegetation, the removal of structures, or an assessment of the impact of leaving them in situ. Methods used to reinstatement the site will affect to likely time for regeneration of the previous habitat.
This time could also be shorter if plants regenerate during lifetime of windfarm. If so, enter number of years estimated for regeneration.

Note: Carbon fixation by bog plants. Apparent C accumulation rate in peatland is 0.12 to 0.31 tC ha^{-1} yr^{-1} (Turunen et al., 2001, Global Biogeochemical Cycles, 15, 285-296; Botch et al., 1995, Global Biogeochemical Cycles, 9, 37-46). 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

Coal-fired plant emission factor (t CO_2 MWh^{-1})	0.86
Grid-mix emission factor (t CO_2 MWh^{-1})	0.43
Fossil fuel- mix emission factor (t CO_2 MWh^{-1})	0.607
Borrow pits	
Number of borrow pits	14
Average length of pits (m)	97
Average width of pits (m)	126
Average depth of peat removed from pit (m)	1.60
Wind turbine foundations	
Average length of turbine foundations (m)	25
Average width of turbine foundations(m)	25
Average depth of peat removed from turbine foundations(m)	1.6
Hard-standing area associated with each turbine	
Average length of hard-standing (m)	43.06
Average width of hard-standing (m)	43.06
Average depth of peat removed from hard-standing (m)	1.6
Access tracks	
Total length of access track (m)	117520
Existing track length (m)	0
Length of access track that is floating road (m)	86010
Floating road width (m)	9.25
Floating road depth (m)	0.5
Length of floating road that is drained (m)	86010
Average depth of drains associated with floating roads (m)	1
Length of access track that is excavated road (m)	31510
Excavated road width (m)	9.25
Excavated road depth (m)	1
Length of access track that is rock filled road (m)	0
Rock-filled road width (m)	0
Rock-filled road depth (m)	0
Length of rock-filled road that is drained (m)	0
Average depth of drains associated with rock-filled roads (m)	0
Cable Trenches	
Length of any cable trench that does not follow access tracks and is lined with a permeable medium (eg. sand) (m)	11752
Depth of cable trench (m)	1.0
Peat Landslide Hazard	
Weblink: Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments	0

Note: Area of forestry plantation to be felled. If the forestry was planned to be removed, with no further rotations planted, before the wind farm development, the area to be felled should be entered as zero.

Note: Plantation carbon sequestration. This is dependent on the yield class of the forestry. The SNH technical guidance assumed yield class of 16 m^3 ha^{-1} y^{-1}, compared to the value of 14 m^3 ha^{-1} y^{-1} provided by the Forestry Commission. Carbon sequestered for yield class 16 m^3 ha^{-1} y^{-1} = 3.6 tC ha^{-1} yr^{-1} (Cannell, 1999, Forestry, 72, 238-247)

Note: Coal-Fired Plant and Grid Mix Emission Factors. Coal-fired plant EF = 0.86 t CO_2 MWh^{-1}; Grid-Mix EF = 0.43 t CO_2 MWh^{-1}. Source = DEFRA, 2002. Guidelines for the measurement and reporting of emissions by Direct Participants in UK Emissions Trading Scheme (DEFRA,Oct 2002)

Note: Fossil Fuel Mix Emission Factor. The 5 year average emission factor calculated using estimated CO2 emissions for 2002 and 2003 from the National Atmospheric Emission Inventory (Baggott et al, 2007, http://www.naei.org.uk/reports.php. Report AEAT/ENV/R/2429 13/04/2007) and for 2004 to 2006 (Digest of UK Energy Statistics ,2007, http://www.berr.gov.uk/energy/statistics/source/electricity/page18527.html) is 0.607 tCO_2 MWh^{-1}

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

Note: Peat Landslide Hazard. It is assumed that measures have been taken to may limit damage (Scottish Executive, 2006, Peat Landslide Hazard and Risk Assessments. Best Practice Guide for Proposed Electricity Generation Developments. Scottish Executive, Edinburgh. pp. 34-35) so that C losses due to peat landslide can be assumed to be negligible. Link: http://www.scotland.gov.uk/Publications/2006/12/21162303/1

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)	394			
Water table depth in degraded bog before improvement (m)	1.00			
Water table depth in degraded bog after improvement (m)	1.00			
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	10			
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	0			
Water table depth in felled area before improvement (m)	0.00			
Water table depth in felled area after improvement (m)	0.00			
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	0			
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	15.19			
Water table depth in borrow pit after restoration (m)	1.00			
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	10			
Removal of drainage from foundations and hardstanding				
Water table depth around foundations and hardstanding after restoration (m)	1			
Time to completion of backfilling, removal of any surface drains, and full restoration of the hydrology (years)	25			
Restoration of site after decomissioning				
Will the hydrology of the site be restored on decommissioning?	Yes			
Will the habitat of the site be restored on decommissioning?	Yes			

Note: Restoration of site. If the water table at the site is returned to its original level or higher on decomissioning, and habitat 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%

Choice of methodology for calculating emission factors	Site specific

Note: Choice of methodology for calculating emission factors. The IPPC default methodology is the internationally accepted standard (IPCC, 1997, Revised 1996 IPCC guidelines for national greenhouse gas inventories, Vol 3, table 5-13). However, it is stated in IPCC (1997) that these are rough estimates, and "these rates 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 SEERAD funded ECOSSE project (Smith et al, 2007. ECOSSE: Estimating Carbon in Organic Soils - Sequestration and Emissions. Final Report. SEERAD Report. ISBN 978 0 7559 1498 2. 166pp.)

Note: The carbon payback time of the wind farm is calculated by comparing the loss of C from the site due to windfarm development
with the carbon-savings achieved by the windfarm while displacing electricity generated from coal-fired capacity or Grid-mix.

1. Wind farm CO_2 emission saving

	Carbon dioxide saving ($tCO_2\ yr^{-1}$)
…coal-fired electricity generation	1830665
…grid-mix of electricity generation	915332
…fossil fuel-mix of electricity generation	1292109

Total CO_2 losses due to wind farm

	Carbon dioxide losses ($t\ CO_{2\ eq.}$)			Payback time (months)		
	…coal-fired electricity generation	…grid-mix of electricity generation	…fossil fuel-mix of electricity generation	…coal-fired electricity generation	…grid-mix of electricity generation	…fossil fuel-mix of electricity generation
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	175140	175140	175140	1.1	2.3	1.6
3. Losses due to backup	358919	358919	358919	2.4	4.7	3.3
4. Losses due to reduced carbon fixing potential	496431	496431	496431	3.3	6.5	4.6
5. Losses from soil organic matter	16139191	16139191	16139191	105.8	211.6	149.9
6. Losses due to DOC & POC leaching	2183263	2183263	2183263	14.3	28.6	20.3
7. Losses due to felling forestry	0	0	0	0.0	0.0	0.0
Total losses of carbon dioxide	19352944	19352944	19352944	126.9	253.7	179.7

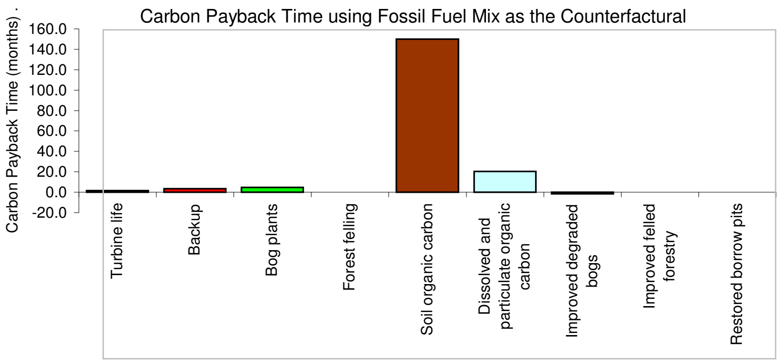
Total CO_2 gains due to improvement of site

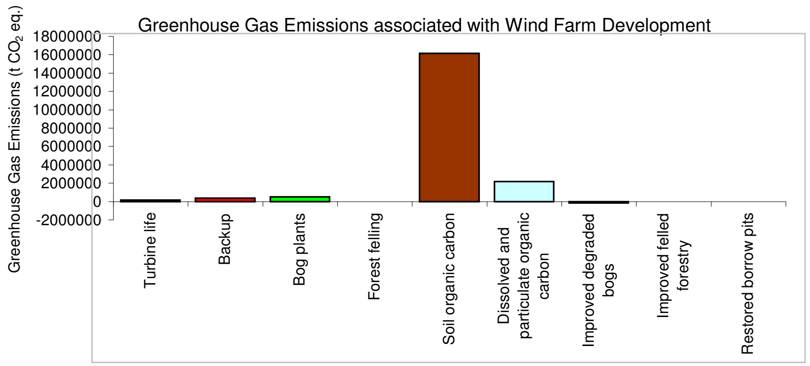
	Carbon dioxide gains ($tCO_{2\ eq.}$)	Reduction in payback time (months)		
		…coal-fired electricity generation	…grid-mix of electricity generation	…fossil fuel-mix of electricity generation
8. Gains due to improvement of degraded bogs	152617	1.0	2.0	1.4
8. Gains due to improvement of felled forestry	0	0.0	0.0	0.0
8. Gains due to restoration of peat from borrow pits	8295	0.1	0.1	0.1
8. Gains due to removal of drainage from foundations & hardstanding	0	0.0	0.0	0.0
Total gains	160912	1.1	2.1	1.5

Net emissions of carbon dioxide ($t\ CO_{2\ eq.}$)	19192032

Payback time

	Total payback time of windfarm (yr)	Total payback time of windfarm (months)
Coal-fired	**10.5**	**126**
Grid-mix	21.0	252
Fossil fuel-mix	**14.9**	**178**





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)

Power Generation Characteristics	
No. of turbines	150
Turbine capacity (MW)	3.6
Power of wind farm (MW)	540
Capacity factor (percentage efficiency)	45
Annual energy output from wind farm (MWh yr^{-1})	2128680

Counterfactual emission factors	
Coal-fired plant emission factor (t CO_2 MWh^{-1})	0.86
Grid-mix emission factor (t CO_2 MWh^{-1})	0.43
Fossil fuel- mix emission factor (t CO2 MWh^{-1})	0.607

Wind farm CO_2 emission saving over…	**Carbon Dioxide Saving (tCO_2 yr^{-1})**
…coal-fired electricity generation	**1830665**
…grid-mix of electricity generation	**915332**
…fossil fuel - mix of electricity generation	**1292109**

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

Method used to estimate CO_2 emissions from turbine life (eg. manufacture, construction, decommissioning)?	Calculate wrt installed capacity

Direct input of emissions due to turbine life (t CO_2 wind farm^{-1})	0

Calculation of emissions due to turbine life from energy output	
CO_2 emissions due to turbine life (tCO_2 turbine^{-1})	1168
No. of turbines	150
Total calculated CO_2 emission of the wind farm due to turbine life (t CO_2 wind farm^{-1})	175140

Selected value for emissions due to turbine life (t CO_2 wind farm^{-1})	175140

Wind farm CO_2 emission saving over…	**Carbon Dioxide Saving (tCO_2 yr^{-1})**
…coal-fired electricity generation	1830665
…grid-mix of electricity generation	915332
…fossil fuel - mix of electricity generation	1292109

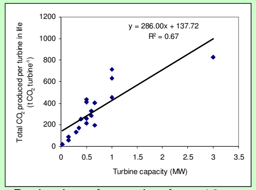
Additional CO_2 payback time of wind farm due to turbine life (eg. manufacture, contruction, decomissioning)	**Additional payback time (yr)**	**Additional payback time (months)**
Coal-fired electricity generation	**0.10**	**1.1**
Grid-mix of electricity generation	0.19	2.3
Fossil fuel - mix of electricity generation	**0.14**	**1.6**

Uncertainty due to estimated CO2 emissions due to turbine life	39%	0.6

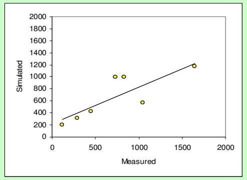
Defensible figures for the specific wind farm should be used wherever possible, but if these are unavailable, carbon dioxide emissions due to the turbine life, L_{life} (t), can be estimated from the turbine capacity, c_{turb} (MW), using the following equation. This equation was derived using data from 18 European sites with a highly significant fit (P>0.95).

$$L_{life} = 138 + (286 \times c_{turb}).$$

Evaluation against independent data indicates that using this equation instead of site specific measurements will introduce an average error in estimated carbon dioxide emissions of 39%. However, the uncertainty in estimated carbon payback time introduced by this error is small and decreases with turbine capacity: uncertainty is less than 6 months for a turbine capacity under 0.5 MW; less than 1.5 months for a turbine capacity between 0.5 and 1 MW, and approximately 1 month for a turbine capacity over 1 MW. Note that inclusion of a life cycle figure for wind farms would ideally require that equivalent life cycle costs for conventional power sources are included in the carbon emission savings figure. However, in the absence of comparative figures for coal and gas generating plants, it should be noted that this is an over-estimate of the life cycle costs of a wind farm. A comprehensive life cycle assessment of a modern UK wind farm would provide more robust figures.



Derivation of equation from 18 European sites



Evaluation of equation against independent data

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

Reserve capacity required for backup	
No. of turbines	150
Turbine capacity (MW)	3.6
Power of wind farm ($MW\ h^{-1}$)	540
Rated capacity (MW yr-1)	4730400
Extra capacity required for backup (%)	5
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10
Reserve capacity ($MWh\ yr^{-1}$)	23652

Carbon dioxide emissions due to backup power generation	
Coal-fired plant emission factor ($t\ CO_2\ MWh^{-1}$)	0.86
Grid-mix emission factor ($t\ CO_2\ MWh^{-1}$)	0.43
Fossil fuel- mix emission factor ($t\ CO_2\ MWh^{-1}$)	0.607
Life time of wind farm (years)	25
Annual emissions due to backup from…	
…coal-fired electricity generation	20340.72
…grid-mix of electricity generation	10170.36
…fossil fuel - mix of electricity generation	14356.764
Total emissions due to backup from…	
…coal-fired electricity generation	508518
…grid-mix of electricity generation	254259
…fossil fuel - mix of electricity generation	358919

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.

Wind farm CO_2 emission saving over…	Carbon Dioxide Saving ($tCO_2\ yr^{-1}$)
…coal-fired electricity generation	1830665
…grid-mix of electricity generation	915332
…fossil fuel - mix of electricity generation	1292109

Additional CO_2 payback time of wind farm due to backup	**Additional payback time (yr)**	**Additional payback time (months)**
Coal-fired electricity generation	**0.20**	**2.4**
Grid-mix of electricity generation	0.39	4.7
Fossil fuel-mix of electricity generation	**0.28**	**3.3**

Note: Annual C fixation by the site is calculated by multiplying area of the wind farm by the annual C accumulation due to bog plant fixation

Area where carbon accumulation by bog plants is lost	
Total area of land lost due to wind farm construction (m^2)	1630043
Total area affected by drainage due to wind farm construction (m^{-2})	153087593
Total area where fixation by plants is lost (m^2)	154717635

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

Total loss of carbon accumulation	
Carbon accumulation in undrained peats (tC ha^{-1} yr^{-1})	0.25
Life time of wind farm (years)	25
Time required for regeneration of bog plants after restoration (years)	10
Carbon accumulation up to time of restoration (tCO_2 eq. ha^{-1})	32

Total loss of carbon accumulation by bog plants	
Total area where fixation by plants is lost (ha)	15472
Carbon accumulation over lifetime of wind farm (tCO_2 eq. ha^{-1})	32
Total loss of carbon fixation by plants at the site (t CO_2)	**496431**

Windfarm CO_2 emission saving over…	Carbon Dioxide Saving (tCO_2 yr^{-1})
…coal-fired electricity generation	1830665
…grid-mix of electricity generation	915332
…fossil fuel - mix of electricity generation	1292109

Additional CO_2 payback time of windfarm due to loss of CO_2 fixation	**Additional payback time (years)**	**Additional payback time (months)**
Coal-fired electricity generation	**0.271**	**3.3**
Grid-mix of electricity generation	0.542	6.5
Fossil fuel - mix of electricity generation	**0.384**	**4.6**

Note: Loss of C stored in peatland is estimated from % site lost by peat removal (sheet 5a), CO_2 loss from removed peat (sheet 5b), % site affected by drainage (sheet 5c), and the CO2 loss from drained peat (sheet 5d).

CO_2 loss due to wind farm construction	
CO_2 loss from removed peat (t CO_2 equiv)	1885395
CO_2 loss from drained peat (t CO_2 equiv)	14253796
Total CO_2 loss from peat (removed+ drained) (t CO_2 equiv)	**16139191**

Note: % 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 to the volume of peat removed, area of land lost and % site lost at the bottom of this worksheet.

Peat removed from borrow pits	
Number of borrow pits	14
Average length of pits (m)	97
Average width of pits (m)	126
Average depth of peat removed from pit (m)	1.6
Area of land lost in borrow pits (m^2)	171108
Volume of peat removed from borrow pits (m^3)	273772.8

Peat removed from turbine foundations	
No. of turbines	150
Average length of turbine foundations (m)	25
Average width of turbine foundations(m)	25
Average depth of peat removed from turbine foundations(m)	1.6
Area of land lost in foundations (m^2)	93750
Volume of peat removed from foundation area (m^3)	150000

Peat removed from hard-standing	
No. of turbines	150
Average length of hard-standing (m)	43.06
Average width of hard-standing (m)	43.06
Average depth of peat removed from hard-standing (m)	1.6
Area of land lost in hard-standing (m^2)	278124.54
Volume of peat removed from hardstandingarea (m^3)	444999.264

Peat removed from access tracks	
<u>Floating roads</u>	
Length of access track that is floating road (m)	86010
Floating road width (m)	9.25
Floating road depth (m)	0.5
Area of land lost in floating roads (m^2)	795592.5
Volume of peat removed for floating roads	397796.25
<u>Excavated roads</u>	
Length of access track that is excavated road (m)	31510
Excavated road width (m)	9.25
Excavated road depth (m)	1
Area of land lost in excavated roads (m^2)	291467.5
Volume of peat removed for excavated roads	291467.5
<u>Rock-filled roads</u>	
Length of access track that is rock filled road (m)	0
Rock-filled road width (m)	0
Rock-filled road depth (m)	0
Area of land lost in excavated roads (m^2)	0
Volume of peat removed for rock-filled roads	0
Total area of land lost in access tracks (m^2)	1087060
Total volume of peat removed due to access tracks (m^3)	689263.75

Total volume of peat removed (m^3) due to wind farm construction	**1558035.814**

Total area of land lost due to wind farm construction (m^2)	**1630042.54**

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

CO_2 loss from removed peat	
C Content of dry peat (% by weight)	55
Dry soil bulk density (g cm^{-3})	0.60
% C contained in removed peat that is lost as CO_2	100
Total volume of peat removed (m^3) due to wind farm construction	1558035.814
CO_2 loss from removed peat (t CO_2)	1885395

Assumption: If peat is not restored, 100% of the carbon contained in the removed peat is lost as CO_2

CO_2 loss from undrained peat left in situ	
Total area of land lost due to wind farm construction (ha)	163
CO_2 loss from undrained peat left in situ (t CO_2 ha^{-1})	-86
CO_2 loss from undrained peat left in situ (t CO_2)	-13976

CO_2 loss attributable to peat removal only	
CO_2 loss from removed peat (t CO_2)	1885395
CO_2 loss from undrained peat left in situ (t CO_2)	-13976
CO_2 loss attributable to peat removal only (t CO_2)	**1899371**

Wind farm CO_2 emission saving over…	Carbon Dioxide Saving (tCO_2 yr^{-1})
…coal-fired electricity generation	1830665
…grid-mix of electricity generation	915332
…fossil fuel - mix of electricity generation	1292109

Additional CO_2 payback time of wind farm due to removal of peat during construction	**Additional payback time (years)**	**Additional payback time (months)**
Coal-fired electricity generation	**1.03**	**12.4**
Grid-mix of electricity generation	2.06	24.7
Fossil fuel - mix of electricity generation	**1.46**	**17.5**

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	
Average extent of drainage around drainage features at site (m)	100

Peat affected by drainage around borrow pits	
Number of borrow pits	14
Average length of pits (m)	97
Average width of pits (m)	126
Average depth of peat removed from pit (m)	1.6
Area affected by drainage per borrow pit	84600
Total area affected by drainage around borrowpits (m^2)	1184400
Total volume affected by drainage around borrowpits (m^3)	1895040

Note: Borrow pit area itself not counted in drained area because C losses have already been accounted for in removed peat

Assumption: Depth peat affected due of drainage is equal to the depth of peat removed

Peat affected by drainage around turbine foundation and hardstanding	
No. of turbines	150
Average length of turbine foundations (m)	25
Average width of turbine foundations(m)	25
Average depth of peat removed from turbine foundations(m)	2
Average length of hard-standing (m)	43
Average width of hard-standing (m)	43
Average depth of peat removed from hard-standing (m)	1.6
Total length of foundation and hardstaning area (m)	68
Total width of foundation and hardstanding area (m)	68
Area affected by drainage of foundation and hardstanding area (m^2)	67224
Total area affected by drainage of foundation and hardstanding area (m^2)	10083600
Total volume affected by drainage of foundation and hardstanding area (m^3)	16133760

Note: Hardstanding and turbine foundations. These are counted together to avoid double counting of edges. If hardstanding is sited away from turbine foundations, additional drainage should be included. Hardstanding and turbine foundation area itself not counted in drained area because C losses have already been accounted for in removed peat

Peat affected by drainage of access tracks	
Floating roads	
Length of floating road that is drained (m)	86010
Floating road width (m)	9.3
Average depth of drains associated with floating roads (m)	1.00
Area affected by drainage of floating roads (m^2)	17997593
Volume affected by drainage of floating roads (m^3)	17997593
Excavated Road	
Length of access track that is excavated road (m)	31510
Excavated road width (m)	9
Excavated road depth (m)	1.0
Area affected by drainage of excavated roads (m^2)	6302000
Volume affected by drainage of excavated roads (m^3)	6302000
Rock-filled roads	
Length of rock-filled road that is drained (m)	0
Rock-filled road width (m)	0
Average depth of drains associated with rock-filled roads (m)	0.0
Area affected by drainage of rock-filled roads (m^2)	0
Volume affected by drainage of rock-filled roads (m^2)	0
Total area affected by drainage of access track (m^2)	24299593
Total volume affected by drainage of access track (m^3)	24299593

Assumption: Peat under floating road is also drained when drains are installed

Assumption: Depth peat affected due of drainage is equal to the depth of peat removed

Note: Road area itself not counted in drained because C losses have already been accounted for in removed peat

Assumption: Depth peat affected due of drainage is equal to the depth of peat removed

Assumption: Peat under rock-filled road is compacted and looses water, but remains anaerobic. Therefore, the area of the rock-filled road iteself is not included in the drained area.

Assumption: Depth peat affected due of drainage is equal to the depth of peat removed

Peat affected by drainage of cable trenches	
Length of any cable trench that does not follow access tracks and is lined with a permeable medium (eg. sand) (m)	11752
Depth of cable trench (m)	1.0
Total area affected by drainage of cable trenches (m^2)	117520000
Total volume affected by drainage of cable trenches (m^3)	117520000.00

Total area affected by drainage due to wind farm (m^2)	**153087593**
Total volume affected by drainage due to wind farm (m^3)	**159848393**

Note: Note, CO_2 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).

Drained Land	
Total area affected by drainage due to wind farm construction (ha)	15309
Will the hydrology of the site be restored on decommissioning?	Yes
Will the habitat of the site be restored on decommissioning?	Yes

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

Total volume affected by drainage due to wind farm (m^3)	159848393
C Content of dry peat (% by weight)	55
Dry soil bulk density (g cm^{-3})	0.60
Total GHG emissions from Drained Land (t CO_2 equiv.)	193434138
Total GHG Emissions from Undrained Land (t CO_2 equiv.)	-19619255

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
Life time of wind farm (years)	25
Time required for regeneration of bog plants after restoration (years)	10
Methane Emissions from Drained Land	
Annual rate of methane emission (t CH_4-C ha^{-1} yr^{-1})	-1.03
Conversion factor: CH_4-C to CO_2 equivalents	30.67
CH_4 emissions from drained land (t CO_2 equiv.)	0
Carbon Dioxide Emissions from Drained Land	
Annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	24.2
CO_2 emissions from drained land (t CO_2)	12941220
Total GHG emissions from Drained Land (t CO_2 equiv.)	12941220

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

Note:Conversion = (23 x 16/12) = 30.67 CO_2 equiv. $(CH_4\text{-}C)^{-1}$

2. Losses if Land is Undrained

Flooded period (days $year^{-1}$)	178
Life time of wind farm (years)	25
Time required for regeneration of bog plants after restoration (years)	10
Methane Emissions from Undrained Land	
Annual rate of methane emission (t CH_4-C ha^{-1} yr^{-1})	-0.96
Conversion factor: CH_4-C to CO_2 equivalents	30.67
CH_4 emissions from undrained land (t CO_2 equiv.)	-7728905
Carbon Dioxide Emissions from Undrained Land	
Annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	23.4
CO_2 emissions from undrained land (t CO_2)	6416328
Total GHG Emissions from Undrained Land (t CO_2 equiv.)	-1312576

Note:Conversion = (23 x 16/12) = 30.67 CO_2 equiv. $(CH_4\text{-}C)^{-1}$

3. CO_2 Losses due to Drainage

Total GHG emissions from Drained Land (t CO_2 equiv.)	12941220
Total GHG Emissions from Undrained Land (t CO_2 equiv.)	-1312576
Total CO_2 losses due to Drainage (t CO_2 equiv.)	**14253796**

Wind farm CO_2 emission saving over…	Carbon Dioxide Saving (tCO_2 yr^{-1})
…coal-fired electricity generation	1830665
…grid-mix of electricity generation	915332
…fossil fuel - mix of electricity generation	1292109

Additional CO_2 payback time of wind farm due to drainage of peat	**Additional payback time (years)**	**Additional payback time (months)**
Coal-fired electricity generation	**7.79**	**93.4**
Grid-mix of electricity generation	15.57	186.9
Fossil fuel - mix of electricity generation	**11.03**	**132.4**

Note: Note, CO_2 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**

Calculations following IPCC default methodology

Type of peatland	Acid Bog

Emission characteristics of acid bogs (IPCC, 1997)

Flooded period (days year^{-1})	178
Annual rate of methane emission (t CH_4-C ha^{-1} yr^{-1})	0.04015
Annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	35.2

Emission characteristics of fens (IPCC, 1997)

Flooded period (days year^{-1})	169
Annual rate of methane emission (t CH_4-C ha^{-1} yr^{-1})	0.219
Annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	35.2

Selected emission characteristics (IPCC, 1997)

Flooded period (days year^{-1})	178
Annual rate of methane emission (t CH_4-C ha^{-1} yr^{-1})	0.04015
Annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	35.2

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 CH_4 emission rate provided for acid bogs is 11 (1-38) mg CH_4-C m^{-2} day^{-1} x 365 days; and for fens is 60 (21-162) mg CH_4-C m^{-2} day^{-1} x 365 days (Aselmann & Crutzen ,1989. J.Atm.Chem. 8, 307-358)

Assumption: CO_2 emissions on drainage of organic soils for upland crops (e.g., grain, vegetables) are 3.667x9.6 (7.9-11.3) t CO_2 ha^{-1} yr^{-1} in temperate climates (Armentano and Menges, 1986. J. Ecol. 74, 755-774).

Calculations following ECOSSE based methodology

Drained Land

Total area affected by drainage due to wind farm construction (ha)	15309
Total volume affected by drainage due to wind farm construction (m^3)	159848393

Soil Characteristics that Determine Emission Rates

Average annual air temperature at the site (^{o}C)	7
Average depth of peat at site (m)	1.60
Average soil pH	4
Average water table depth at site (cm)	1
Average water table depth of drained land (m)	1.044162952

Annual Emission Rates following ECOSSE based methodology

Rate of carbon dioxide emission in drained soil (t CO_2 ha^{-1} yr^{-1})	24.15
Rate of carbon dioxide emission in undrained soil (t CO_2 ha^{-1} yr^{-1})	23.37
Rate of methane emission in drained soil ((t CH_4-C) ha^{-1} yr^{-1})	-1.03
Rate of methane emission in undrained soil ((t CH_4-C) ha^{-1} yr^{-1})	-0.96

Note: Equation derived by regression analysis against experimental data from 50 experiments. 41 cases were used and 9 included missing data values. The equation derived was
R_{CO2} = (3.667/1000) x (547 + (71.7 T) + (322 D) + (4810 W))
where R_{CO2} is the annual rate of CO_2 emissions (t CO_2 (ha)$^{-1}$ yr^{-1}), T = average annual air temperature (^{o}C), D is the peat depth (m), and W is the water table depth (m).
The equation has a R^2 value of 53.8%, P < 0.0001. By statistical convention, if P<0.001 this relationship can be considered to be highly significant.

Note: Equation derived by regression analysis against experimental data from 66 experiments. 40 cases were used and 26 included missing data values. The equation derived was
R_{CH4} = (3.667/1000) x (58.4 + (3.11 T) + (16.7 pH) - (410 W))
where R_{CH4} is the annual rate of CH_4 emissions (t CO_2 (ha)$^{-1}$ yr^{-1}), T = average annual air temperature (^{o}C), pH is the soil pH and W is the water table depth (m).
The equation has a R^2 value of 52.7%, P <0.0001. By statistical convention, if P<0.001 this relationship can be considered to be highly significant.

Selected Emission Rates

Rate of carbon dioxide emission in drained soil (t CO_2 ha^{-1} yr^{-1})	24.15
Rate of carbon dioxide emission in undrained soil (t CO_2 ha^{-1} yr^{-1})	23.37
Rate of methane emission in drained soil ((t CH_4-C) ha^{-1} yr^{-1})	-1.03
Rate of methane emission in undrained soil ((t CH_4-C) ha^{-1} yr^{-1})	-0.96

Note: Note, CO_2 losses from DOC are calculated using a simple approach derived from estimates of the total C loss leached as DOC and the percentage of leached DOC lost as CO2

Total C loss	
Gross CO_2 loss from removed peat (t CO_2)	1885395
Gross CO_2 loss from drained land (t CO_2)	6524892
Gross CH_4 loss from drained land (t CO_2 equiv.)	7728905
Gross CO_2 loss from improved land (t CO_2)	70738
Gross CH_4 loss from flooded land (t CO_2 equiv.)	0
Conversion factor: CH_4-C to CO_2 equivalents	30.6667
% total soil C losses, lost as DOC	10
% DOC loss emitted as CO_2 over the long term	100
% total soil C losses, lost as POC	15
% POC loss emitted as CO_2 over the long term	100
Total gaseous loss of C (t C)	2386080
Total C loss as DOC (t C)	238608
Total C loss as POC (t C)	357912

Assumption: The export from temperate and boreal peatlands ranges between 10 and 500 kg DOC ha^{-1} yr^{-1} (Dillon, P.J. and Molot, L.A. (1997) Water Resources Research 33, 2591–2600), which typically represents around 10% of the total C release.

Assumption: In the long term, 100% of leached DOC is assumed to be lost as CO_2

Assumption: The export from temperate and boreal peatlands ranges between 12 and 15% of the total gaseous C loss (Worrall, F., Reed, M., Warburton, J., Burt, T., 2003. Carbon budget for a British upland peat catchment. The Science of the Total Environment, 312, 133–146.) Tables 1 and 2.

Assumption: In the long term, 100% of leached DOC is assumed to be lost as CO_2

Total CO_2 loss due to DOC leaching (t CO_2)	**873305**
Total CO_2 loss due to POC leaching (t CO_2)	**1309958**
Total CO_2 loss due to DOC & POC leaching (t CO_2)	**2183263**

Wind farm CO_2 emission saving over…	Carbon Dioxide Saving (tCO_2 yr^{-1})
…coal-fired electricity generation	1830665
…grid-mix of electricity generation	915332
…fossil fuel - mix of electricity generation	1292109

Additional CO_2 payback time of wind farm due to DOC and POC leaching	**Additional payback time (years)**	**Additional payback time (months)**
Coal-fired electricity generation	**1.19**	**14.3**
Grid-mix of electricity generation	2.39	28.6
Fossil fuel - mix of electricity generation	**1.69**	**20.3**

Note: 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 forectry to be felled should be entered as zero.

Emissions due to forestry felling	
Area of forestry plantation to be felled (ha)	0
Carbon sequestered (tC ha^{-1} yr^{-1})	0
Life time of wind farm (years)	25
Carbon sequestered over the lifetime of the wind farm (t C ha^{-1})	0
Total carbon loss due to felling of forestry (t CO_2)	0

Wind farm CO_2 emission saving over…	Carbon dioxide saving (tCO_2 yr^{-1})
…coal-fired electricity generation	1830665
…grid-mix of electricity generation	915332
…fossil fuel - mix of electricity generation	1292109

Additional CO_2 payback time of wind farm due to felling of forestry	**Additional payback time (yr)**	**Additional payback time (months)**
Coal-fired electricity generation	**0.00**	**0.0**
Grid-mix of electricity generation	**0.00**	**0.0**
Fossil fuel - mix of electricity generation	**0.00**	**0.0**

Note: Note, CO_2 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).

Choice of methodology for calculating emission factors	**Site specific**

Reduction in GHG emissions due to improvement of site

Improvement of…	**Degraded Bog**	**Felled Forestry**	**Borrow Pits**	**Foundations & Hardstanding**
1. Description of site				
Life time of wind farm (years)	25	25	25	25
Area to be improved (ha)	394	0	15.19	1008
Average air temperature at site (^oC)	7	7	7	7
Average soil pH	4	4	4	4
Average depth of peat at site (m)	1.60	1.60	1.60	1.60
Water table depth before improvement (m)	1.00	0.00	1.60	1.60
Water table depth after improvement (m)	1.00	0.00	1.00	1.00
2. Losses with improvement				
Flooded period (days $year^{-1}$)	178	178	178	178
Time required for hydrology and habitat to return to its previous state on restoration (years)	10	0	10	25
Improved period (years)	15	25	15	0
Methane emissions from improved land				
Site specific annual rate of methane emission (t CO_2 ha^{-1} yr^{-1})	-29.58	16.53	-29.58	-29.58
IPCC annual rate of methane emission (t CO_2 ha^{-1} yr^{-1})	1.23	1.23	1.23	1.23
Selected annual rate of methane emission (t CO_2 ha^{-1} yr^{-1})	-29.58	16.53	-29.58	-29.58
CH_4 emissions from improved land (t CO_2 equiv.)	-85251	0	-3287	0
Carbon dioxide emissions from improved land				
Site specific annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	23.4	5.7	23.4	23.4
IPCC annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	35.2	35.2	35.2	35.2
Selected annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	23.4	5.7	23.4	23.4
CO_2 emissions from improved land (t CO_2)	70773	0	2729	0
Total GHG emissions from improved land (t CO_2 equiv.)	**-14478**	**0**	**-558**	**0**
3. Losses without improvement				
Flooded period (days $year^{-1}$)	0	0	0	0
Time required for hydrology and habitat to return to its previous state on restoration (years)	10	0	10	25
Improved period (years)	15	25	15	0
Methane emissions from unimproved land				
Site specific annual rate of methane emission (t CO_2 ha^{-1} yr^{-1})	-29.58	16.53	-57.24	-57.24
IPCC annual rate of methane emission (t CO_2 ha^{-1} yr^{-1})	1.23	1.23	1.23	1.23
Selected annual rate of methane emission (t CO_2 ha^{-1} yr^{-1})	-29.58	16.53	-57.24	-57.24
CH_4 emissions from unimproved land (t CO_2 equiv.)	0	0	0	0
Carbon dioxide emissions from unimproved land				
Site specific annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	23.4	5.7	34.0	34.0
IPCC annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	35.2	35.2	35.2	35.2
Selected annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	23.4	5.7	34.0	34.0
CO_2 emissions from unimproved land (t CO_2)	138139	0	7737	0
Total GHG emissions from unimproved land (t CO_2 equiv.)	**138139**	**0**	**7737**	**0**
4. Reduction in GHG emissions due to improvement of site				
Total GHG emissions from improved land (t CO_2 equiv.)	-14478	0	-558	0
Total GHG emissions from unimproved land (t CO_2 equiv.)	138139	0	7737	0
Reduction in GHG emissions due to improvement (t CO_2 equiv.)	**152617**	**0**	**8295**	**0**

Reduction in CO_2 payback time of wind farm due improvement of site

Wind farm CO_2 emission saving over…	Carbon Dioxide Saving (tCO_2 yr^{-1})
…coal-fired electricity generation	1830665
…grid-mix of electricity generation	915332
…fossil fuel - mix of electricity generation	1292109

Reduction in CO_2 payback time of wind farm due improvement of	**Degraded Bog**	**Felled Forestry**	**Borrow Pits**	**Foundations & Hardstanding**	**Total**
		Reduction in payback time (years)			
Coal-fired electricity generation	**0.08**	**0.00**	**0.00**	**0.00**	**0.09**
Grid-mix of electricity generation	0.17	0.00	0.01	0.00	0.18
Fossil fuel - mix of electricity generation	**0.12**	**0.00**	**0.01**	**0.00**	**0.12**
		Reduction in payback time (months)			
Coal-fired electricity generation	**1.00**	**0.00**	**0.05**	**0.00**	**1.05**
Grid-mix of electricity generation	2.00	0.00	0.11	0.00	2.11
Fossil fuel - mix of electricity generation	**1.42**	**0.00**	**0.08**	**0.00**	**1.49**