Scottish Government Windfarm Carbon Assessment Tool - Version 2.14.1

27/01/2023

This spreadsheet calculates payback time for windfarm sited on peatlands using methods given in
Nayak et al, 2008 (http://www.scotland.gov.uk/Publications/2008/06/25114657/0)
and revised equations for GHG emissions (Nayak, D.R., Miller, D., Nolan, A., Smith, P. and Smith, J.U., 2010, Calculating carbon budgets of wind farms on Scottish peatland. Mires and Peat 4: Art. 9. Online: (http://www.mires-and-peat.net/map04/map_04_09.htm)
Version 2.0.0 - Adapted to include detail of forestry management, Smith et al., 2011.
http://www.scotland.gov.uk/WindFarmsAndCarbon
Version 2.14.0 - Corrections to calcualtion of peat removed for hardstanding
plus corrections to emission factors and changes as detailed in previous worksheets
Revised by J.U.Smith to correct forestry and restoration sheets
Version 2.14.1 - Equivalent to version 2.14.0 but with worksheets unprotected for your own use. Do not use this version in planning applications.

INSTRUCTIONS

A There are 6 worksheets giving instructions, data entry and outputs, ...

- Instructions
- Do I need to use this tool? ....Click here to find out [Click here]
- Core input data .... Data needed in all calculations [Click here]
- Forestry input data .... Extra details sometimes needed for forestry calculations
- Construction input data .... Extra details sometimes needed for construction calculations
- Payback time and CO2 emissions [Click here]

...and 8 numbered worksheets showing calculations:

1. Windfarm CO_2 emission saving
2. CO_2 loss due to turbine life
3. CO_2 loss due to backup
4. Loss of CO_2 Fixing Pot.
5. Loss of soil CO_2
   - 5a. Volume of peat removed
   - 5b. CO_2 loss from removed peat
   - 5c. Volume of peat drained
   - 5d. CO_2 loss from drained peat
   - 5e. Emission rates
6. CO_2 loss by DOC & POC loss

7i. Forestry CO_2 loss - simple

7ii. Forestry CO_2 loss - detailed
   - 7a. C sequest. in trees (3PG)
   - 7b. C seq. in soil under trees
   - 7c. Average stand data
   - 7d. Windspeed ratios

8. CO_2 gain - site improvement

In addition, there are spreadsheets containing references and requesting feedback.

- References
- Frequently asked questions

Notes on calculations are given in pale green text boxes.... [Click here to see example of Notes Box]

Protocols for measurements are given in pale yellow comment boxes..... [Click here to see example of Protocol Box]

Assumptions are given in pale blue text boxes.... [Click here to see example of Assumptions Box]

Contributors:

[1]D.Nayak, [1]J.U. Smith , [1]P. Smith, [1]P.Graves

[2]D. Miller, [2]A. Nolan, [2]I. Morrice

Note on official version number

Version X.Y.Z

X refers to the release number
Y refers to released updates on release X
Z refers to unreleased updates on release X.Y

Officially released versions will always have Z=0

If you make changes of your own, please do not refer to your modified spreadsheet using the official version number.

The latest version is published at www.scotland.gov.uk/WindFarmsAndCarbon
Please check you are using the latest official version with Z=0 before submitting a planning application.

Do I need to use this tool?

1. Will the site be drained on construction of the windfarm?	No
2. Is the soil at the site highly organic? i.e. is the soil organo-mineral or organic, (i.e. a peaty gley or peat)?	Yes
3. Does windfarm construction require a significant amount of deforestation? i.e. is removal in excess of keyholing the turbines within the forest boundary?	No

You should use this tool because the soil is highly organic.
Please move to the Core input data sheet and complete the form to obtain an estimate of C payback time

Click here to return to Instructions sheet Click here
Click here to move on to Core input data sheet Click here

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.

Click here to move to Payback Time Click here

Click here to return to Instructions Click here

Input data	Expected values: Enter expected value here	Record source of data	Possible range of values: Enter minimum value here	Record source of data	Enter maximum value here	Record source of data
Windfarm characteristics						
Dimensions						
No. of turbines	9		9		9	Chapter 3- description of Development
Lifetime of windfarm (years)	40		40		40	Chapter 3- description of Development
Performance						
Power rating of turbines (turbine capacity) (MW)	6.667		6.667		6.667	Chapter 3- Description of development, 60MW total
Capacity factor	Direct input of capacity fac		Direct input of capacity fact		Direct input of capacity fact	
Enter estimated capacity factor (percentage efficiency)	26.20		23.58		28.82	Chapter 13 climate change and carbon balance (+/-10% on min& max), using source: BEIS (2024). Digest of UK Energy Statistics (DUKES). Load Factors for Renewable Energy Generation (DUKES 6.3). Available at: https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes [Accessed 20/04/2025]
Backup						
Extra capacity required for backup (%)	5		5		5	The extra electricity generation capacity required to maintain electricity supply during times of low wind generation. The extra capacity needed for backup power generation, backup 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)
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10		10		10	Dale et al 2004
Carbon dioxide emissions from turbine life - (eg. manufacture, construction, decommissioning)	Calculate wrt installed cap.		Calculate wrt installed cap.		Calculate wrt installed cap.	

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 and at maximum output (DECC (2004); see also www.bwea.com/ref/capacityfactors.html).
Capacity Factor = Electricity generated during the period [kWh]/ (Installed capacity [kW] x number of hours in the period [h])
We recommend that a site-specific capacity factor ~~site~~ should be used (as measured during planning stage), and should represent the average emission factor expected over the lifetime of the windfarm, accounting for decline in efficiency with age (Hughes, 2012). The 5 year average capacity factor (or "load factor") for UK onshore wind between 2010 and 2014, based on average beginning and end of year capacity, was 29.2% (DUKES, 2015).

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). 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 entered (0%). 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 risk of a power cut due to insufficient generation at a very low level.' The estimate provided by BERR 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 conventional capacity (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%

Characteristics of peatland before windfarm development						
Type of peatland	Acid b		Acid b		Acid b	
Average annual air temperature at site (°C)	9.2		6.5		11.89	Taken from nearest Met office weather station Dundrennan 1991-2020. 9.2 is the mean of the average min and max temperatures from 1991 to 2020
Average depth of peat at site (m)	0.46		0.460		0.460	Average taken from peat depth survey data from across site.
C Content of dry peat (% by weight)	55.5		49		62	Default value: An estimate of the range of %C in peat of between 49% and 62% is provided by Birnie et al. (1991)
Average extent of drainage around drainage features at site (m)	10.00		5.00		50.00	Generic precautionary values have been entered into the carbon calculator as follows: expected = 10m; minimum = 5m; and maximum = 50m as per Windfarm Carbon Calculator Web Tool User Guidance (SEPA, n.d)
Average water table depth at site (m)	0.30		0.10		0.50	The Carbon Calculator notes that water table depth should be measured on site. However, where site-specific values are not available, for degraded peat, reasonable estimated minimum, expected and maximum values are: 0.1 m, 0.3 m and 0.5 m, respectively

Note: <u>Emissions from turbine life.</u> If total emissions for the windfarm are unknown, emissions should be calculated according to turbine capacity. The normal range of CO_2 emissions is 394 to 8147 t CO_2 MW (White & Kulcinski, 2000; White, 2007).

Note: <u>Type of peatland</u> An ‘acid bog’ is fed primarily by rainwater and often inhabited by sphagnum moss, thus making it acidic (Stoneman & Brooks,1997).
A ‘fen’ is a type of wetland fed by surface and/or groundwater (McBride et al., 2011).

Dry soil bulk density (g cm^{-3})	0.132		0.072		0.293	The Windfarm Carbon Calculator Web Tool User Guidance (SEPA, n.d) notes that given the difficulty of collecting sufficient samples to derive a representative site-specific value for this parameter, Scottish generic values for peat may be used instead: expected = 0.132 g/cm3; minimum = 0.072 g/cm3; and maximum = 0.293 g/cm3.
Characteristics of bog plants						
Time required for regeneration of bog plants after restoration (years)	10		5		15	Generic assumptions: "The physical and hydrological restoration of the site post construction, even if no wider site improvements and restoration are undertaken, should allow the vegetation to recover more rapidly than within 15 years. SEPA (n.d) Windfarm Carbon Calculator Web Tool User Guidance
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha^{-1} yr^{-1})	0.25		0.12		0.31	Apparent C accumulation rate in peatland is 0.12 to 0.31 t C ha-1 yr-1 (Turunen et al., 2001; Botch et al., 1995). The SNH guidance uses a value of 0.25 t C ha-1 yr-1.
Forestry Plantation Characteristics						
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)	0		0		0	
Average rate of carbon sequestration in timber (tC ha-1 yr-1)	0.00		0.00		0.00	
Counterfactual emission factors						
To update counterfactual emission factors from the web — Click here (not yet operational)						
Coal-fired plant emission factor (t CO_2 MWh^{-1})	0.093		0.093		0.093	fixed
Grid-mix emission factor (t CO_2 MWh^{-1})	0.394		0.394		0.394	fixed
Fossil fuel-mix emission factor (t CO_2 MWh^{-1})	0.642		0.642		0.642	fixed
Borrow pits						
Number of borrow pits	1		1		1	Chapter 3 - description of development

Note: Time required for regeneration of previous habitat. Loss of fixation should be assumed to be over lifetime of windfarm only. This time could be 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 reinstate the site will affect the 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 t C ha^{-1} yr^{-1} (Turunen et al., 2001; Botch et al., 1995). The SNH guidance uses a value of 0.25 t C ha^{-1} yr^{-1}.

Note: Area of forestry plantation to be felled. If the forestry was planned to be removed, with no further rotations planted, before the windfarm 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} yr^{-1}, compared to the value of 14 m^3 ha^{-1} yr^{-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).

Note: Coal-Fired Plant and Grid Mix Emission Factors. Coal-fired plant emission factor (EF) from electricity supplied in 2014 = 0.093 t CO_2 MWh^{-1}; Grid-Mix EF for 2014 = 0.394 t CO_2 MWh^{-1}. Source = DUKES, 2015b.

Average length of pits (m)	359.64		359.64		359.64	Borrowpit area is 35,964m2. As the borrowpit area is irregular in shape, the length and width values entered will equal 35,964m2 area when length x width is performed. The dimensions entered in this calculator are not reflective of the actual dimensions but the area is correct	Note: Fossil Fuel-Mix Emission Factor. The emission factor from electricity supplied in 2014 from all fossil fuels = 0.642 t CO_2 MWh^{-1}. Source = DUKES, 2015b.
Average width of pits (m)	100		100		100		
Average depth of peat removed from pit (m)	0.27		0.27		0.270	Average taken from on-site peat depth survey data	
Foundations and hard-standing area associated with each turbine							
Method used to calculate CO_2 loss from foundations and hard-standing	Rectangular with vertical w		Rectangular with vertical w		Rectangular with vertical w		
Average length of turbine foundations (m)	531		531		531	Turbine foundation is 531m2. As the turbine foundation is circular in shape not rectangular, the length and width values entered will equal 531m2 area when length x width is performed. The dimensions entered in this calculator are not reflective of the actual dimensions but the area is correct	
Average width of turbine foundations (m)	1		1		1		
Average depth of peat removed from turbine foundations (m)	0.0021		0.0021		0.0021	Calculated from data provided in Technical Appendix 8-2 PMP	
Average length of hard-standing (m)	40		40		40	Figure 3-5	
Average width of hard-standing (m)	38		38		38	Figure 3-5	
Average depth of peat removed from hard-standing (m)	0.11		0.10		0.13	Taken from Peat Survey data	
Access tracks							
Total length of access track (m)	18740		18740		18740	Chapter 3: Description of Development	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.
Existing track length (m)	6100		6100		6100	Chapter 3: Description of Development	
Length of access track that is floating road (m)	490		490		490	Chapter 3: Description of Development	
Floating road width (m)	5.5		5.5		5.5	Figure 3-12	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 zero.
Floating road depth (m)	0.00		0.00		0.00	Chapter 3: Description of Development- "Where the presence of peat has been identified to be greater than 0.5m in depth, floating tracks are proposed to be used"	

Length of floating road that is drained (m)	0		0		0	Chapter 3: Description of Development- "Where the presence of peat has been identified to be greater than 0.5m in depth, floating tracks are proposed to be used"
Average depth of drains associated with floating roads (m)	0.00		0.00		0.00	Chapter 3: Description of Development- "Where the presence of peat has been identified to be greater than 0.5m in depth, floating tracks are proposed to be used"
Length of access track that is excavated road (m)	12150		12150		12150	Chapter 3: Description of Development Figure 3-12 Calculated from data taken from TA 8-2 PMP
Excavated road width (m)	5.5		5.5		5.5	
Average depth of peat excavated for road (m)	0.13		0.11		0.14	
Length of access track that is rock filled road (m)	0		0		0	
Rock filled road width (m)	5		5		5	
Rock filled road depth (m)	0		0		0	
Length of rock filled road that is drained (m)	0		0		0	
Average depth of drains associated with rock filled roads (m)	0.00		0.00		0.00	
Cable Trenches						
Length of any cable trench on peat that does not follow access tracks and is lined with a permeable medium (eg. sand) (m)	0		0		0	
Average depth of peat cut for cable trenches (m)	0.00		0.00		0.00	
Additional peat excavated (not already accounted for above)						
Volume of additional peat excavated (m^3)	6102		6102		6102	Technical Appendix 8-2 OPMP. Includes infrastructure not previously listed above on peat permanently excavated from the following infrastructure: Auxillary crane tower storage area, Blade storage area, Substation and BESS, earthworks - cut, earthworks - fill
Area of additional peat excavated (m^2)	28488.0		28488.0		28488.0	values given as volume above
Peat Landslide Hazard						
Weblink: Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments	Negligible		negligible		negligible	
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)	88		88		88	Technical Appendix 6-6- habitat management plan

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 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 (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.

Water table depth in degraded bog before improvement (m)	0.30	0.10	0.50	The Carbon Calculator notes that water table depth should be measured on site. However, where site-specific values are not available, for degraded peat, reasonable estimated minimum, expected and maximum values are: 0.1 m, 0.3 m and 0.5 m, respectively.
Water table depth in degraded bog after improvement (m)	0.10	0.05	0.30	The Carbon Calculator notes that water table depth should be measured on site. However, where site-specific values are not available, for intact peat, reasonable estimated minimum, expected and maximum values are: 0.05m, 0.1m, 0.3m respectively.
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	15	5	30	Carbon Calculator requires that a value between 2 and 30 is input. Values of 5, 15 and 30 used for min, max and expected to show worst case scenario
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	30	30	30	This value has been set the maximum that the carbon calculator allows (30 years) as it can be guarenteed through the life of the windfarm.
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	0	0	0	
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)				
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	1.85	1.85	1.85	TA8-2 Peat Management Plan

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 25 years, and the improvement will be effective for (25 -10) = 15 years.

Note: Period of time when improvement can be guaranteed. This gurantee 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 25 years, and the improvement will be effective for (25 -10) = 15 years.

Depth of water table in borrow pit before restoration with respect to the restored surface (m)	0.00		0.00		0.00	This will be dependent upon water table levels and borrow pit design. Due to this, it is assumed on a highly conservative basis for the purpose of the carbon calculator that there will be no change in the water table depth and therefore no "gain". This value is therefore presented as "0"
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.00		0.00		0.00	This will be dependent upon water table levels and borrow pit design. Due to this, it is assumed on a highly conservative basis for the purpose of the carbon calculator that there will be no change in the water table depth and therefore no "gain". This value is therefore presented as "0"
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	30		30		30	Carbon calculator requires a value between 1 and 30 years. 30 years chosen for worst case scenario
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	30		30		30	This value has been set the maximum that the carbon calculator allows (30 years) as it can be guarenteed through the life of the windfarm.
<u>Early removal of drainage from foundations and hardstanding</u>						

Note: <u>Period of time when improvement can be guaranteed</u>. This gurantee 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 25 years, and the improvement will be effective for (25 -10) = 15 years.

Water table depth around foundations and hardstanding before restoration (m)	0.30		0.10		0.50	The Carbon Calculator notes that water table depth should be measured on site. However, where site-specific values are not available, for degraded peat, reasonable estimated minimum, expected and maximum values are: 0.1 m, 0.3 m and 0.5 m, respectively.
Water table depth around foundations and hardstanding after restoration (m)	0.10		0.05		0.30	The Carbon Calculator notes that water table depth should be measured on site. However, where site-specific values are not available, for intact peat, reasonable estimated minimum, expected and maximum values are: 0.05 m, 0.1 m and 0.3 m, respectively.
Time to completion of backfilling, removal of any surface drains, and full restoration of the hydrology (years)	5		5		5	Carbon calculator requires a value between 0.1 and 5 years. 5 years chosen for worst case
Restoration of site after decomissioning						
Will the hydrology of the site be restored on decommissioning?	Yes		Yes		Yes	
Will you attempt to block any gullies that have formed due to the windfarm?	Yes		Yes		Yes	TA 8-2 PMP
Will you attempt to block all artificial ditches and facilitate rewetting?	Yes		Yes		Yes	TA 6-6 HMP
Will the habitat of the site be restored on decommissioning?	Yes		Yes		Yes	
Will you control grazing on degraded areas?	Yes		Yes		Yes	TA 6-6 HMP
Will you manage areas to favour reintroduction of species	Yes		Yes		Yes	TA 6-6 HMP

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 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 (required for planning applications)

Note: Choice of methodology for calculating emission factors. The IPCC default methodology is the internationally accepted standard (IPCC, 1997). 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 Scottish Government 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.).

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.

Click here to move to Payback Time Click here

Click here to return to Instructions Click here

Results

PAYBACK TIME AND CO_2 EMISSIONS

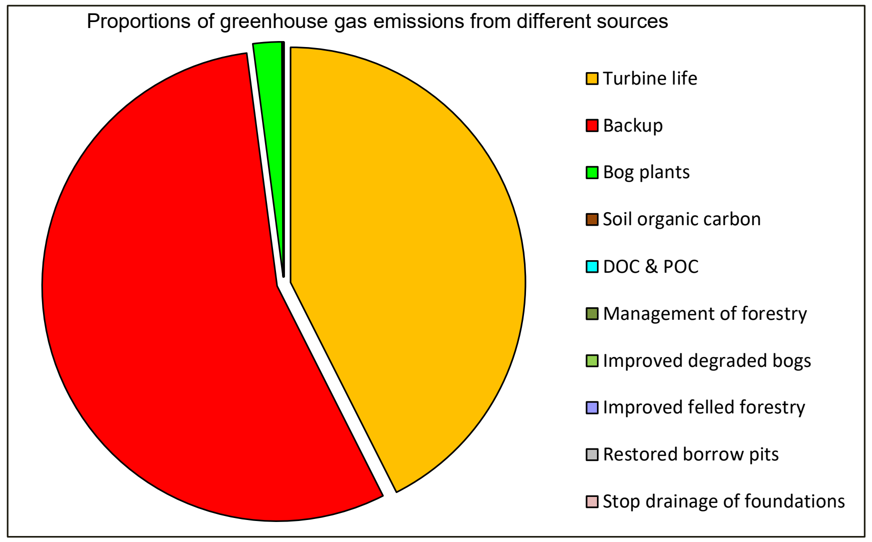
Note: The carbon payback time of the windfarm is calculated by comparing the loss of C from the site due to windfarm development with the carbon-savings achieved by the windfarm while displacing electricity generated from coal-fired capacity or grid-mix.

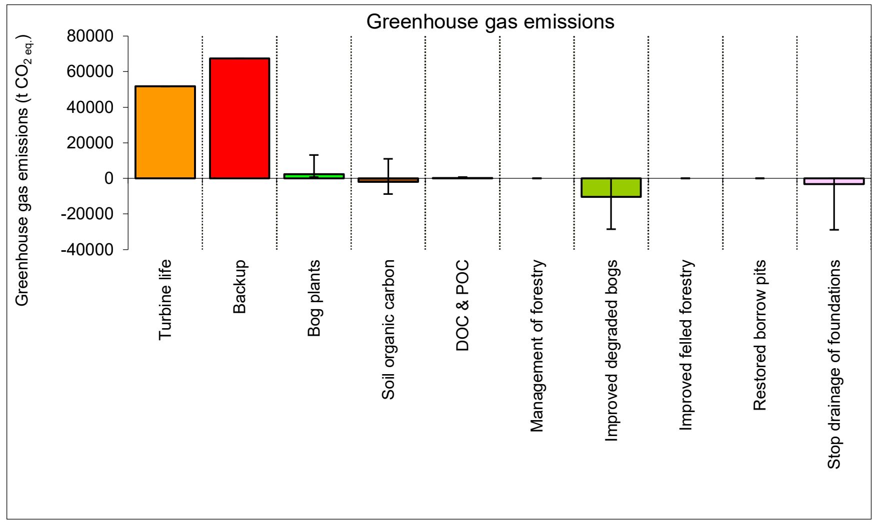
Click here to return to Input data — Click here

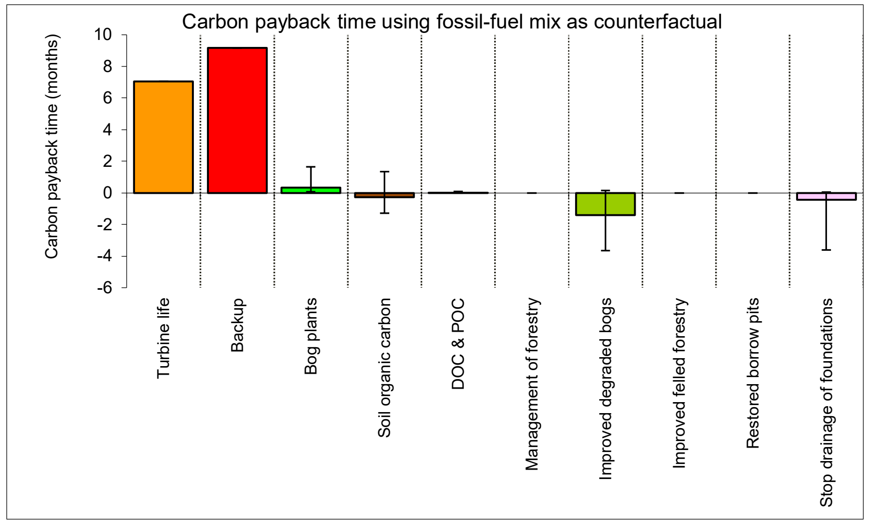
Click here to return to Instructions — Click here

	Exp.	Min.	Max.
1. Windfarm CO_2 emission saving over…			
…coal-fired electricity generation ($tCO_2\ yr^{-1}$)	12807	11527	14088
…grid-mix of electricity generation ($tCO_2\ yr^{-1}$)	54259	48833	59685
…fossil fuel - mix of electricity generation ($tCO_2\ yr^{-1}$)	88412	79571	97254
Energy output from windfarm over lifetime (MWh)	5508563	4957707	6059420
Total CO_2 losses due to wind farm (t CO_2 eq.)			
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	51856	51856	51856
3. Losses due to backup	67490	67490	67490
4. Losses due to reduced carbon fixing potential	2405	668	13131
5. Losses from soil organic matter	-1941	-8704	11044
6. Losses due to DOC & POC leaching	110	0	817
7. Losses due to felling forestry	0	0	0
Total losses of carbon dioxide	119921	111311	144338
8. Total CO_2 gains due to improvement of site (t CO_2 eq.)			
8a. Change in emissions due to improvement of degraded bogs	-10390	0	-28493
8b. Change in emissions due to improvement of felled forestry	0	0	0
8c. Change in emissions due to restoration of peat from borrow pits	0	0	0
8d. Change in emissions due to removal of drainage from foundations & hardstanding	-3124	0	-28966
Total change in emissions due to improvements	-13514	0	-57459

RESULTS	Exp.	Min.	Max.
Net emissions of carbon dioxide (t $CO_{2\ eq.}$)	**106407**	**53852**	**144338**
Carbon Payback Time			
…coal-fired electricity generation (years)	8.3	3.8	12.5
…grid-mix of electricity generation (years)	2.0	0.9	3.0
…fossil fuel - mix of electricity generation (years)	**1.2**	**0.6**	**1.8**
Ratio of soil carbon loss to gain by restoration (TARGET ratio (Natural Resources Wales) < 1.0)	No gains!	No gains!	No gains!
Ratio of CO_2 eq. emissions to power generation (g / kWh) (TARGET ratio by 2030 (electricity generation) < 50 g /kWh)	**19**	**9**	**29**







Data used in barchart of carbon payback time using fossil-fuel mix as counterfactual

Greenhouse gas emissions

	Exp.	Min	Max
Turbine life	51856	0	0
Backup	67490	0	0
Bog plants	2405	1737	10726
Soil organic carbon	0	6762	12986
DOC & POC	110	110	706
Management of forestry	0	0	0
Improved degraded bogs	0	0	0
Improved felled forestry	0	0	0
Restored borrow pits	0	0	0
Stop drainage of foundations	0	0	0

Data used in barchart of carbon payback time using fossil-fuel mix as counterfactual

	Greenhouse gas emissions			Carbon payback time (months)		
	Exp.	Min.	Max.	Exp.	Min.	Max.
Turbine life	51856	0	0	7	0	0
Backup	67490	0	0	9	0	0
Bog plants	2405	1737	10726	0	0	1
Soil organic carbon	-1941	6762	12986	0	1	2
DOC & POC	110	110	706	0	0	0
Management of forestry	0	0	0	0	0	0
Improved degraded bogs	-10390	-10390	-18103	-1	-2	-2
Improved felled forestry	0	0	0	0	0	0
Restored borrow pits	0	0	0	0	0	0
Stop drainage of foundations	-3124	-3124	-25842	0	0	-3
	106407			14		

Check Check Check Check Check Check Check Check Check Check

Results

PAYBACK TIME AND CO_2 EMISSIONS

Note: The carbon payback time of the windfarm 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.

Click here to return to Input data Click here
Click here to return to Instructions Click here

Windfarm CO_2 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)

Click here to move to Payback Time Click here

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	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Power rating of turbines (turbine capacity) (MW)	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667	6.667
Power of windfarm (MW)	60.003	60.003	60.003	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})	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093
Grid-mix emission factor (t CO_2 MWh^{-1})	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394	0.394
Fossil fuel-mix emission factor (t CO_2 MWh^{-1})	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642

Calculation of capacity factor	1	Direct input of capacity factor		
		Exp	Min	Max
Entered capacity factor (%)		26.2	23.58	28.82

Parameters	*Slope (a)*			*Intercept (b)*		
Partial power curves for different turbines	Exp	Min	Max	Exp	Min	Max
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				#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######	#######
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})	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9	58402.9
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	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max	Exp	Min	Max
Intercept (b)				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		
Direct input of capacity factor																		
Capacity factor(%)	26	24	29	26	24	29	26	24	29	26	24	29	26	24	29	26	24	29

Annual energy output from windfarm (MW yr^{-1})	137714	123943	151485	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		
Windfarm CO_2 emission saving over…																		
…coal-fired electricity generation (tCO_2 yr^{-1})	12807	11526.7	14088.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
…grid-mix of electricity generation (tCO_2 yr^{-1})	54259	48833.4	59685.3	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})	88412	79571.2	97253.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Click here to move to Payback Time Click here

Windfarm CO_2 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, decomissioning) is calculated by comparing the emissions due to turbine life with carbon-savings achieved by the windfarm while displacing electricity generated from coal-fired capacity or grid-mix.

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

	Exp	Min	Max
Direct input of emissions due to turbine life (t CO_2 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})	5762	5762	5762
No. of turbines	9	9	9
Total calculated CO_2 emission of the wind farm due to turbine life (t CO_2 windfarm^{-1})	51856	51856	51856

	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
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
Total CO_2 emissions due to cement used in construction	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.	51856	51856	51856
Additional CO_2 payback time of windfarm due to turbine life (eg. manufacture, contruction, decomissioning)			
…coal-fired electricity generation (months)	49	54	44
…grid-mix of electricity generation (months)	11	13	10
…fossil fuel - mix of electricity generation (months)	7	8	6

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Emissions due to turbine life

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

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

mpa The Concrete Centre

Embodied carbon dioxide (CO_2e) of concretes used in buildings

CONCRETE APPLICATION	Concrete designation	CO_2e ($kgCO_2e/m^3$)[1]			CO_2e ($kgCO_2e$/tonne)[1]		
		CEM I concrete	30% fly ash concrete	50% ggbs concrete	CEM I concrete	30% fly ash concrete	50% ggbs concrete
Blinding, mass fill, strip footings, mass foundations, trench foundations [2]	GEN1	177	128	101	77	55	44
Reinforced Foundations [2]	RC25/30**	316	263	197	133	111	83
Ground floors [2]	RC28/35*	316	261	186	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_2e ($kgCO_2e/m^3$)			CO_2e ($kgCO_2e$/tonne)		
Unreinforced Precast flooring[3]		-			165		
Reinforced precast flooring[3]		-			171		
Average Generic Concrete Block[4]		-			84		

* *includes 30kg/m³ steel reinforcement*

** *includes 100kg/m³ steel reinforcement*

Emissions due to backup power generation

Note: CO_2 loss due to back up is calculated from the extra capacity required for backup of the windfarm given in the input data.

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.

	Expected	Minimum	Maximum
Reserve capacity required for backup			
No. of turbines	9	9	9
Power rating of turbines (turbine capacity) (MW)	6.667	6.667	6.667
Power of wind farm ($MW\ h^{-1}$)	60.003	60.003	60.003
Rated capacity ($MW\ yr^{-1}$)	525626.28	525626.28	525626.28
Extra capacity required for backup (%)	5	5	5
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10	10	10
Reserve capacity ($MWh\ yr^{-1}$)	2628	2628	2628

	Expected	Minimum	Maximum
Carbon dioxide emissions due to backup power generation			
Coal-fired plant emission factor ($t\ CO_2\ MWh^{-1}$)	0.093	0.093	0.093
Grid-mix emission factor ($t\ CO_2\ MWh^{-1}$)	0.394	0.394	0.394
Fossil fuel- mix emission factor ($t\ CO_2\ MWh^{-1}$)	0.642	0.642	0.642
Lifetime of windfarm (years)	40	40	40
Annual emissions due to backup from…			
…coal-fired electricity generation ($tCO_2\ yr^{-1}$)	244	244	244
…grid-mix of electricity generation ($tCO_2\ yr^{-1}$)	1035	1035	1035
…fossil fuel - mix of electricity generation ($tCO_2\ yr^{-1}$)	1687	1687	1687

	Expected	Minimum	Maximum
RESULTS			
Total emissions due to backup from…			
…coal-fired electricity generation (tCO_2)	9777	9777	9777
…grid-mix of electricity generation (tCO_2)	41419	41419	41419
…fossil fuel - mix of electricity generation (tCO_2)	**67490**	**67490**	**67490**
Additional CO_2 payback time of windfarm due to backup			
…coal-fired electricity generation (months)	9	10	8
…grid-mix of electricity generation (months)	9	10	8
…fossil fuel - mix of electricity generation (months)	9	10	8

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: CO_2 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)	152431	152431	152431
Total area affected by drainage due to windfarm construction (m^{-2})	372290	185067	1947734
Total area where fixation by plants is lost (m^2)	524721	337498	2100165
Total loss of carbon accumulation			
Carbon accumulation in undrained peats (tC ha^{-1} yr^{-1})	0.25	0.12	0.31
Lifetime of windfarm (years)	40	40	40
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})	46	20	63
RESULTS			
Total loss of carbon accumulation by bog plants			
Total area where fixation by plants is lost (ha)	52	34	210
Carbon accumulation over lifetime of windfarm (tCO_2 eq. ha^{-1})	46	20	63
Total loss of carbon fixation by plants at the site (t CO_2)	**2405**	**668**	**13131**
Additional CO_2 payback time of windfarm due to loss of CO2 fixing potential			
…coal-fired electricity generation (months)	2	1	11
…grid-mix of electricity generation (months)	1	0	3
…fossil fuel - mix of electricity generation (months)	0	0	2

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.

Click here to move to Payback Time Click here

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), CO_2 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			
Check	CO_2 loss from removed peat (t CO_2 equiv)	-1941	-8704	11044
Check	CO_2 loss from drained peat (t CO_2 equiv)	0	0	0
	RESULTS			
	Total CO_2 loss from peat (removed + drained) (t CO_2 equiv)	**-1941**	**-8704**	**11044**
	Additional CO_2 payback time of windfarm due to loss of soil CO2			
	…coal-fired electricity generation (months)	-2	-9	9
	…grid-mix of electricity generation (months)	0	-2	2
	…fossil fuel - mix of electricity generation (months)	0	-1	1

Click here to move to Payback Time Click here

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), CO_2 loss from removed peat (sheet 5b), % site affected by drainage (sheet 5c), and the CO2 loss from drained peat (sheet 5d).

Volume of Peat Removed

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 as additional peat excavated in the core input sheet.

Peat removed from borrow pits	Total		
	Exp	Min	Max
Number of borrow pits	1	1	1
Average length of pits (m)	359.64	359.64	359.64
Average width of pits (m)	100	100	100
Average depth of peat removed from pit (m)	0.27	0.27	0.27
Area of land lost in borrow pits (m^2)	35964	35964	35964
Volume of peat removed from borrow pits (m^3)	9710.28	9710.28	9710.28

Peat removed from turbine foundations	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
Method used to calculate CO_2 loss from foundations	Rectangular with vertical walls																	
Calculation method code		1																
No. of turbines	9	9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0
Diameter at surface (m)				531	531	531	0	0	0	0	0	0	0	0	0	0	0	0
				1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Diameter at bottom (m)				531	531	531	0	0	0	0	0	0	0	0	0	0	0	0
				1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Depth of foundations (m)				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
"Area" of land lost in hard-standing (m^2)	4779	4779	4779	4779	4779	4779	0	0	0	0	0	0	0	0	0	0	0	0
Volume of peat removed from foundation area (m^3)	10.0359	10.0359	10.0359	10.0359	10.0359	10.0359	0	0	0	0	0	0	0	0	0	0	0	0

Peat removed from hard-standing																		
Method used to calculate CO_2 loss from foundations	Rectangular with vertical walls																	
Calculation method code		1																
No. of turbines	9	9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0
Diameter at surface (m)				40	40	40	0	0	0	0	0	0	0	0	0	0	0	0
				38	38	38	0	0	0	0	0	0	0	0	0	0	0	0
Diameter at bottom (m)				40	40	40	0	0	0	0	0	0	0	0	0	0	0	0
				38	38	38	0	0	0	0	0	0	0	0	0	0	0	0
Depth of hardstanding (m)				0	0.103	0.126	0	0	0	0	0	0	0	0	0	0	0	0
Area of land lost in hard-standing (m^2)	13680	13680	13680	13680	13680	13680	0	0	0	0	0	0	0	0	0	0	0	0
Volume of peat removed from hardstandingarea (m^3)	1559.52	1409.04	1723.68	1559.52	1409.04	1723.68	0	0	0	0	0	0	0	0	0	0	0	0

Peat removed from access tracks	Total		
	Exp	Min	Max
Floating roads			
Length of access track that is floating road (m)	490	490	490
Floating road width (m)	5.5	5.5	5.5
Floating road depth (m)	0	0	0
Area of land lost in floating roads (m^2)	2695	2695	2695
Volume of peat removed for floating roads	0	0	0

Excavated roads			
Length of access track that is excavated road (m)	12150	12150	12150
Excavated road width (m)	5.5	5.5	5.5
Average depth of peat excavated for road (m)	0.125	0.112	0.137
Area of land lost in excavated roads (m^2)	66825	66825	66825
Volume of peat removed for excavated roads	8353.13	7484.4	9155.03
Rock-filled roads			
Length of access track that is rock filled road (m)	0	0	0
Rock filled road width (m)	5	5	5
Rock filled road depth (m)	0	0	0
Area of land lost in excavated roads (m^2)	0	0	0
Volume of peat removed for rock-filled roads	0	0	0
Total area of land lost in access tracks (m^2)	69520	69520	69520
Total volume of peat removed due to access tracks (m^3)	8353.13	7484.4	9155.03

Additional peat excavated - (not already accounted for above)			
Volume of additional peat excavated (m^3)	6102	6102	6102
Area of additional peat excavated (m^2)	28488	28488	28488

RESULTS		**Total**	
	Exp	**Min**	**Max**
Total volume of peat removed (m^3) due to windfarm construction	**25735**	**24715.8**	**26701**
Total area of land lost due to windfarm construction (m^2)	**152431**	**152431**	**152431**

Click here to move to 5b. CO2 loss from removed peat Click here

Click here to move to Payback Time Click here

Volume of Peat Removed

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.

CO_2 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
CO_2 loss from removed peat			
C Content of dry peat (% by weight)	55.5	49	62
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
Check Total volume of peat removed (m^3) due to windfarm construction	25735	24716	26701
CO_2 loss from removed peat (t CO_2)	6914	3198	17787

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 windfarm construction (ha)	15	15	15
CO_2 loss from undrained peat left in situ (t CO_2 ha^{-1})	581	781	442
CO_2 loss from undrained peat left in situ (t CO_2)	8855	11901	6742

CO_2 loss attributable to peat removal only			
CO_2 loss from removed peat (t CO_2)	6914	3198	17787
CO_2 loss from undrained peat left in situ (t CO_2)	8855	11901	6742
RESULTS			
CO_2 loss attributable to peat removal only (t CO_2)	**-1941**	**-8704**	**11044**

Click here to move to 5. Loss of soil CO_2 Click here

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CO_2 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	Total		
	Exp	Min	Max
Average extent of drainage around drainage features at site (m)	10	5	50

Peat affected by drainage around borrow pits	Total		
	Exp	Min	Max
Number of borrow pits	1	1	1
Average length of pits (m)	360	360	360
Average width of pits (m)	100	100	100
Average depth of peat removed from pit (m)	0.3	0.3	0.3
Area affected by drainage per borrow pit (m^2)	9593	4696	55964
Total area affected by drainage around borrowpits (m^2)	9593	4696	55964
Total volume affected by drainage around borrowpits (m^3)	1295	634	7555

Peat affected by drainage around turbine foundation and hardstanding	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
No. of turbines	9	9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0
Average length of turbine foundations at base (m)				531	531	531	0	0	0	0	0	0	0	0	0	0	0	0
Average width of turbine foundations at base(m)				1	1	1	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)				40	40	40	0	0	0	0	0	0	0	0	0	0	0	0
Average width of hard-standing at base (m)				38	38	38	0	0	0	0	0	0	0	0	0	0	0	0
Average depth of peat removed from hard-standing (m)				0.1	0.1	0.1	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)				0.1	0.1	0.1	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)				571	571	571	0	0	0	0	0	0	0	0	0	0	0	0
Total width of foundation and hardstanding (m)				39	39	39	0	0	0	0	0	0	0	0	0	0	0	0
Area affected by drainage of foundation and hardstanding area (m^2)	12600	6200	71000	12600	6200	71000	0	0	0	0	0	0	0	0	0	0	0	0
Total area affected by drainage of foundation and hardstanding area (m^2)	113400	55800	639000	113400	55800	639000	0	0	0	0	0	0	0	0	0	0	0	0
Total volume affected by drainage of foundation and hardstanding area (m^3)	6464	2874	40257	6464	2874	40257	0	0	0	0	0	0	0	0	0	0	0	0

Peat affected by drainage of access tracks	Total		
	Exp	Min	Max
Floating roads			
Length of floating road that is drained (m)	0	0	0
Floating road width (m)	5.5	5.5	5.5

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)	12150	12150	12150
Excavated road width (m)	6	6	6
Average depth of peat excavated for road (m)	0.1	0.1	0.1
Area affected by drainage of excavated roads (m^2)	243000	121500	1215000
Volume affected by drainage of excavated roads (m^3)	15188	6804	83228
Rock-filled roads			
Length of rock filled road that is drained (m)	0	0	0
Rock filled road width (m)	5	5	5
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^2)	0	0	0
Total area affected by drainage of access track (m^2)	243000	121500	1215000
Total volume affected by drainage of access track (m^3)	15188	6804	83228

Peat affected by drainage of cable trenches	**Total**		
	Exp	**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	**Total**		
	Exp	**Min**	**Max**
Volume of additional peat excavated (m^3)	6102.0	6102.0	6102.0
Area of additional peat excavated (m^2)	28488.0	28488.0	28488.0
Average depth of excavated peat (m)	0	0	0
Radius of area excavated (m)	95	95	95
Radius of excavated and drained area (m)	105	100	145
Total area affected by drainage (m^2)	6297	3070	37770
Total volume affected by drainage (m^3)	1348.87	657.61	8090.19

Assumption: Area excavated is assumed to be a circle

RESULTS	Total		
	Exp	Min	Max
Total area affected by drainage due to windfarm (m^2)	372290	185067	1947734
Total volume affected by drainage due to windfarm (m^3)	24295.2	10969.33	139129.8

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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.

CO_2 loss due to drainage

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).

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	Expected	Minimum	Maximum
Drained Land			
Total area affected by drainage due to wind farm construction (ha)	37	19	195
Will the hydrology of the site be restored on decommissioning?	Yes	Yes	Yes
Will the habitat of the site be restored on decommissioning?	Yes	Yes	Yes

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

		Expected	Minimum	Maximum
Check	Total volume affected by drainage due to wind farm (m^3)	24295	10969	139130
	C Content of dry peat (% by weight)	56	49	62
	Dry soil bulk density ($g\ cm^{-3}$)	0.13	0.07	0.29
	Total GHG emissions from Drained Land (t CO_2 equiv.)	6527	1419	92681
	Total GHG Emissions from Undrained Land (t CO_2 equiv.)	6527	1419	92681

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

		Expected	Minimum	Maximum
	Flooded period (days $year^{-1}$)	0	0	0
	Lifetime of windfarm (years)	40	40	40
	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})	0.008	-0.013	0.151
	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.)	464	-324	49558
	Carbon Dioxide Emissions from Drained Land			
Check	Rate of carbon dioxide emission in drained soil (t CO_2 ha^{-1} yr^{-1})	11.37	17.74	3.42
	CO_2 emissions from drained land (t CO_2)	21163	14773	36596
	Total GHG emissions from Drained Land (t CO_2 equiv.)	21627	14449	86154

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

		Expected	Minimum	Maximum
	Flooded period (days $year^{-1}$)	178	178	178
	Lifetime of windfarm (years)	40	40	40
	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})	0.01	-0.01	0.15
	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.)	464	-324	49558
	Carbon Dioxide Emissions from Undrained Land			
Check	Rate of carbon dioxide emission in undrained soil (t CO_2 ha^{-1} yr^{-1})	11.37	17.74	3.42
	CO_2 emissions from undrained land (t CO_2)	21163	14773	36596
	Total GHG Emissions from Undrained Land (t CO_2 equiv.)	21627	14449	86154

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

3. CO_2 Losses due to Drainage

	Expected	Minimum	Maximum
Total GHG emissions from drained land (t CO_2 equiv.)	21627	14449	86154
Total GHG emissions from undrained land (t CO_2 equiv.)	21627	14449	86154

RESULTS **Total GHG emissions due to drainage (t CO_2 equiv.)**	**0**	**0**	**0**

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CO_2 loss due to drainage

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).

Emission rates from soils

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).

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

Calculations following IPCC default methodology

Emission characteristics of acid bogs (IPCC, 1997)

	Expected	Minimum	Maximum
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)

	Expected	Minimum	Maximum
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)

	Expected	Minimum	Maximum
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

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

	Expected	Minimum	Maximum
Total area affected by drainage due to wind farm construction (ha)	37	19	195
Total volume affected by drainage due to wind farm construction (m^3)	24295	10969	139130

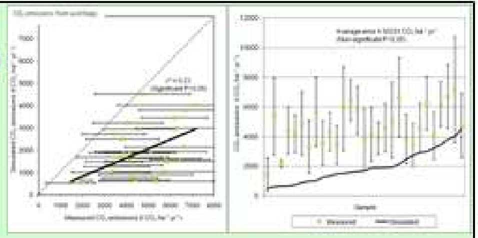
Soil Characteristics that Determine Emission Rates

	Expected	Minimum	Maximum
Average annual air temperature at the site (°C)	9.2	6.5	11.89
Average water table depth at site (m)	0.30	0.50	0.10
Average water table depth of drained land (m)	0.30	0.50	0.10

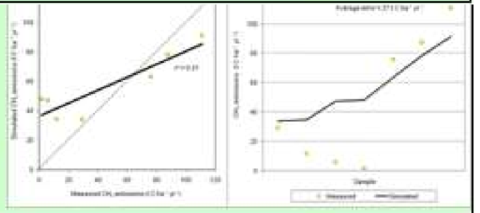
Annual Emission Rates following site specific methodology

	Expected	Minimum	Maximum
Acid bogs			
Rate of carbon dioxide emission in drained soil (t CO_2 ha^{-1} yr^{-1})	11.37	17.74	3.42
Rate of carbon dioxide emission in undrained soil (t CO_2 ha^{-1} yr^{-1})	11.37	17.74	3.42
Rate of methane emission in drained soil ((t CH_4-C) ha^{-1} yr^{-1})	0.008	-0.013	0.151
Rate of methane emission in undrained soil ((t CH_4-C) ha^{-1} yr^{-1})	0.01	-0.01	0.15
Fens			
Rate of carbon dioxide emission in drained soil (t CO_2 ha^{-1} yr^{-1})	32.90	53.61	8.83
Rate of carbon dioxide emission in undrained soil (t CO_2 ha^{-1} yr^{-1})	32.90	53.61	8.83
Rate of methane emission in drained soil ((t CH_4-C) ha^{-1} yr^{-1})	0.027	-0.001	0.211
Rate of methane emission in undrained soil ((t CH_4-C) ha^{-1} yr^{-1})	0.03	0.00	0.21

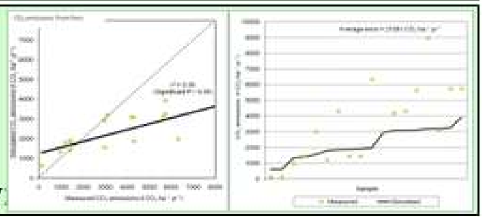
Note: Carbon dioxide emissions from acid bogs. Equation derived by regression analysis against 60 measurements (Nayak et al, 2009). The equation derived was
R_{CO2} = (3.667/1000) x ((6700 x exp(-0.26 x exp(-0.0515 × ((*W*x100)-50)))) + ((72.54 × *T*) - 800))
where R_{CO2} is the annual rate of CO_2 emissions (t CO_2 (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 (r^2 =0.53 P > 0.05).
Evaluation against 29 independent experiments shows a significant association (r^2 = 0.21; P>0.05) and an average error of 3023 t CO_2 ha^{-1} yr^{-1} which is non-significant (P<0.05) (Smith et al, 1997).



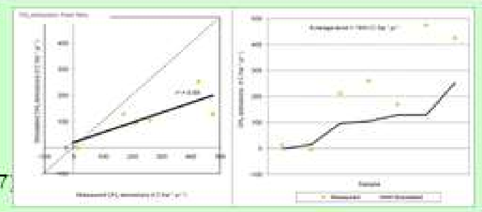
measurements (Nayak et al, 2009). The equation derived was
R_{CH4} = (1/1000) x (500 × exp(-0.1234 × (Wx100)) + ((3.529 × *T*) - 36.67))
where R_{CH4} is the annual rate of CH_4 emissions (t CH_4-C (ha)$^{-1}$ yr^{-1}),
T = average annual air temperature (°C) and
W is the water table depth (m).
The equation shows a significant correlation with measurements (r^2 = 0.54, P > 0.05).
Evaluation against 7 independent experiments shows a significant association (r^2 = 0.81; P>0.05) and an average error of 27 t CH_4-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_{CO2} = (3.667/1000) x (16244 x exp(-0.175 x exp(-0.073 x ((*W*x100)-50)))+(153.23 x *T*))
where R_{CO2} is the annual rate of CO_2 emissions (t CO_2 (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 (r^2 = 0.42, P > 0.05).
Evaluation against 18 independent experiments shows a significant association (r^2 = 0.56; P>0.05) and an average error of 2108 t CO_2 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_{CH4} = (1/1000) x (-10+563.62 x exp(-0.097 x (*W* x 100))+(0.662 x *T*))
where R_{CH4} is the annual rate of CH_4 emissions (t CH_4-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 (r^2 = 0.41, P >0.05).
Evaluation against 7 independent experiments shows a significant association (r^2 = 0.69; P>0.05) and an average error of 164 t CH_4-C ha^{-1} yr^{-1} (significance not defined due to lack of replicate-Smith et al, 1997)



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})	11.37	17.74	3.42
Rate of carbon dioxide emission in undrained soil (t CO_2 ha^{-1} yr^{-1})	11.37	17.74	3.42
Rate of methane emission in drained soil ((t CH_4-C) ha^{-1} yr^{-1})	0.008	-0.013	0.151
Rate of methane emission in undrained soil ((t CH_4-C) ha^{-1} yr^{-1})	0.01	-0.01	0.15

RESULTS

Selected Emission Rates

	Expected	Minimum	Maximum
Rate of carbon dioxide emission in drained soil (t CO_2 ha^{-1} yr^{-1})	11.37	17.74	3.42
Rate of carbon dioxide emission in undrained soil (t CO_2 ha^{-1} yr^{-1})	11.37	17.74	3.42
Rate of methane emission in drained soil ((t CH_4-C) ha^{-1} yr^{-1})	0.008	-0.013	0.151
Rate of methane emission in undrained soil ((t CH_4-C) ha^{-1} yr^{-1})	0.01	-0.01	0.15

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Emission rates from soils

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).

Emissions due to loss of DOC and POC

Note: Note, CO_2 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	2791	0	9050
Felled Forestry	0	0	0
Borrow Pits	0	0	0
Foundations & Hardstanding	839	0	9200
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)	89	0	446
Total C loss as DOC (t C)	23	0	179
Total C loss as POC (t C)	7	0	45

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 CO_2

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 CO_2

	Expected	Minimum	Maximum
RESULTS			
Total CO_2 loss due to DOC leaching (t CO_2)	**84**	**0**	**653**
Total CO_2 loss due to POC leaching (t CO_2)	**26**	**0**	**163**
Total CO_2 loss due to DOC & POC leaching (t CO_2)	**110**	**0**	**817**
Additional CO_2 payback time of windfarm due to DOC & POC			
…coal-fired electricity generation (months)	0	0	1
…grid-mix of electricity generation (months)	0	0	0
…fossil fuel - mix of electricity generation (months)	0	0	0

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Emissions due to loss of DOC and POC

Note: Note, CO_2 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, 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).

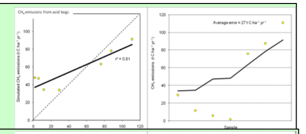
Selected Methodology = **Site specific (required for planning applications)**
Type of peatland = **Acid Bog**

Reduction in GHG emissions due to improvement of site	**Expected result**				**Minimum result**				**Maximum result**			
Improvement of…	**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)	30	0	30	40	30	0	30	40	30	0	30	40
Area to be improved (ha)	88	0	0	11	0	0	0	0	88	0	0	64
Average air temperature at site (°C)	9.2	9.2	9.2	9.2	6.5	6.5	6.5	6.5	11.89	11.89	11.89	11.89
Depth of peat drained (m)	0.46	0.46	0.27	0.46	0.46	0.46	0.27	0.46	0.46	0.46	0.27	0.46
Depth of peat above water table before improvement (m)	0.30	0.00	0.00	0.30	0.10	0.00	0.00	0.10	0.46	0.00	0.00	0.46
Depth of peat above water table after improvement (m)	0.10	0.00	0.00	0.10	0.30	0.00	0.00	0.30	0.05	0.00	0.00	0.05
2. Losses with improvement												
Flooded period (days $year^{-1}$)	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)	15	0	30	5	5	0	30	5	30	0	30	5
Improved period (years)	15	0	0	35	25	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})	0.141	0.496	0.496	0.141	-0.001	0.486	0.486	-0.001	0.275	0.505	0.505	0.275
Site specific methane emission from improved soil on fens (t CH_4-C ha^{-1} yr^{-1})	0.210	0.560	0.560	0.210	0.025	0.558	0.558	0.025	0.345	0.561	0.561	0.345
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
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
Selected annual rate of methane emission (t CH_4-C ha^{-1} yr^{-1})	0.141	0.496	0.496	0.141	-0.001	0.486	0.486	-0.001	0.275	0.505	0.505	0.275
CH_4 emissions from improved land (t CO_2 equiv.)	2791	0	0	839	0	0	0	0	9050	0	0	9200
Carbon dioxide emissions from improved land												
Site specific CO_2 emission from improved soil on acid bogs (t CO_2 ha^{-1} yr^{-1})	2.70	0.32	0.32	2.70	10.65	-0.40	-0.40	10.65	1.98	1.03	1.03	1.98
Site specific CO_2 emissions from improved soil on fens (t CO_2 ha^{-1} yr^{-1})	7.32	5.23	5.23	7.32	31.38	3.71	3.71	31.38	7.17	6.74	6.74	7.17
IPCC annual rate of carbon dioxide emission on acid bogs (t CO_2 ha^{-1} yr^{-1})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IPCC annual rate of carbon dioxide emission on fens (t CO_2 ha^{-1} yr^{-1})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Selected annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	2.70	0.32	0.32	2.70	10.65	-0.40	-0.40	10.65	1.98	1.03	1.03	1.98
CO_2 emissions from improved land (t CO_2)	1826	0	0	549	0	0	0	0	2229	0	0	2266
Total GHG emissions from improved land (t CO_2 equiv.)	**4617**	**0**	**0**	**1388**	**0**	**0**	**0**	**0**	**11280**	**0**	**0**	**11467**
3. Losses without improvement												
Flooded period (days $year^{-1}$)	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)	15	0	30	5	5	0	30	5	30	0	30	5
Improved period (years)	15	0	0	35	25	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})	0.008	0.496	0.496	0.008	0.132	0.486	0.486	0.132	0.007	0.505	0.505	0.007
Site specific methane emission from unimproved soil on fens (t CH_4-C ha^{-1} yr^{-1})	0.027	0.560	0.560	0.027	0.208	0.558	0.558	0.208	0.004	0.561	0.561	0.004
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
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
Selected annual rate of methane emission (t CH_4-C ha^{-1} yr^{-1})	0.008	0.496	0.496	0.008	0.132	0.486	0.486	0.132	0.007	0.505	0.505	0.007
CH_4 emissions from unimproved land (t CO_2 equiv.)	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})	11.37	0.32	0.32	11.37	1.98	-0.40	-0.40	1.98	18.08	1.03	1.03	18.08
Site specific CO_2 emissions from unimproved soil on fens (t CO_2 ha^{-1} yr^{-1})	32.90	5.23	5.23	32.90	5.80	3.71	3.71	5.80	53.72	6.74	6.74	53.72
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
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
Selected annual rate of carbon dioxide emission (t CO_2 ha^{-1} yr^{-1})	11.37	0.32	0.32	11.37	1.98	-0.40	-0.40	1.98	18.08	1.03	1.03	18.08
CO_2 emissions from unimproved land (t CO_2)	15007	0	0	4512	0	0	0	0	39773	0	0	40433
Total GHG emissions from unimproved land (t CO_2 equiv.)	**15007**	**0**	**0**	**4512**	**0**	**0**	**0**	**0**	**39773**	**0**	**0**	**40433**
RESULTS **4. Reduction in GHG emissions due to improvement of site**												
Total GHG emissions from improved land (t CO_2 equiv.)	4617	0	0	1388	0	0	0	0	11280	0	0	11467
Total GHG emissions from unimproved land (t CO_2 equiv.)	15007	0	0	4512	0	0	0	0	39773	0	0	40433
Reduction in GHG emissions due to improvement (t CO_2 equiv.)	**10390**	**0**	**0**	**3124**	**0**	**0**	**0**	**0**	**28493**	**0**	**0**	**28966**
Additional CO_2 payback time of windfarm due to site improvement												
…coal-fired electricity generation (months)	**-10**	**0**	**0**	**-3**	**0**	**0**	**0**	**0**	**-24**	**0**	**0**	**-25**
…grid-mix of electricity generation (months)	**-2**	**0**	**0**	**-1**	**0**	**0**	**0**	**0**	**-6**	**0**	**0**	**-6**
…fossil fuel - mix of electricity generation (months)	**-1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-4**	**0**	**0**	**-4**

Note: Methane emissions from acid bogs. Equation derived by regression analysis against 57 measurements (Nayak et al, 2009). The equation derived was

R_{CH4} = (1/1000) x (500 × exp(-0.1234 × (Wx100)) + ((3.529 × T) - 36.67))

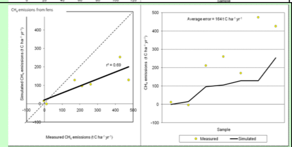
where R_{CH4} is the annual rate of CH_4 emissions (t CH_4-C $(ha)^{-1}$ yr^{-1}),
T = average annual air temperature (°C) and
W is the water table depth (m).
The equation shows a significant correlation with measurements (r^2 = 0.54, P > 0.05).
Evaluation against 7 independent experiments shows a significant association (r^2 = 0.81; P>0.05) and an average error of 27 t CH_4-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

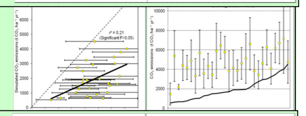
R_{CH4} = (1/1000) x (-10+563.62 x exp(-0.097 x (W x 100))+(0.662 x T))

where R_{CH4} is the annual rate of CH_4 emissions (t CH_4-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 (r^2 = 0.41, P >0.05).
Evaluation against 7 independent experiments shows a significant association (r^2 = 0.69; P>0.05) and an average error of 164 t CH_4-C ha^{-1} yr^{-1} (significance not defined due to lack of replicate-Smith et al, 1997)



R_{CO2} = (3.667/1000) x ((6700 x exp(-0.26 x exp(-0.0515 × ((Wx100)-50)))) + ((72.54 × T) - 800))

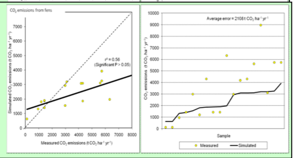
where R_{CO2} is the annual rate of CO_2 emissions (t CO_2 $(ha)^{-1}$ yr^{-1}),
T = average annual peat temperature (°C) and
W is the water table depth (m).
The equation shows a significant correlation with measurements (r^2 =0.53 P > 0.05).
Evaluation against 29 independent experiments shows a significant association (r^2 = 0.21; P>0.05) and an average error of 3023 t CO_2 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_{CO2} = (3.667/1000) x (16244 x exp(-0.175 x exp(-0.073 x ((Wx100)-50)))+(153.23 x T))

where R_{CO2} is the annual rate of CO_2 emissions (t CO_2 $(ha)^{-1}$ yr^{-1}),
T = average annual peat temperature (°C) and
W is the water table depth (m).
The equation shows a significant correlation with measurements (r^2 = 0.42, P > 0.05).
Evaluation against 18 independent experiments shows a significant association (r^2 = 0.56; P>0.05) and an average error of 2108 t CO_2 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: CO_2 emissions from acid bogs. As above

Note: CO_2 emissions from fens. As above

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Gains due to site improvement

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).

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