

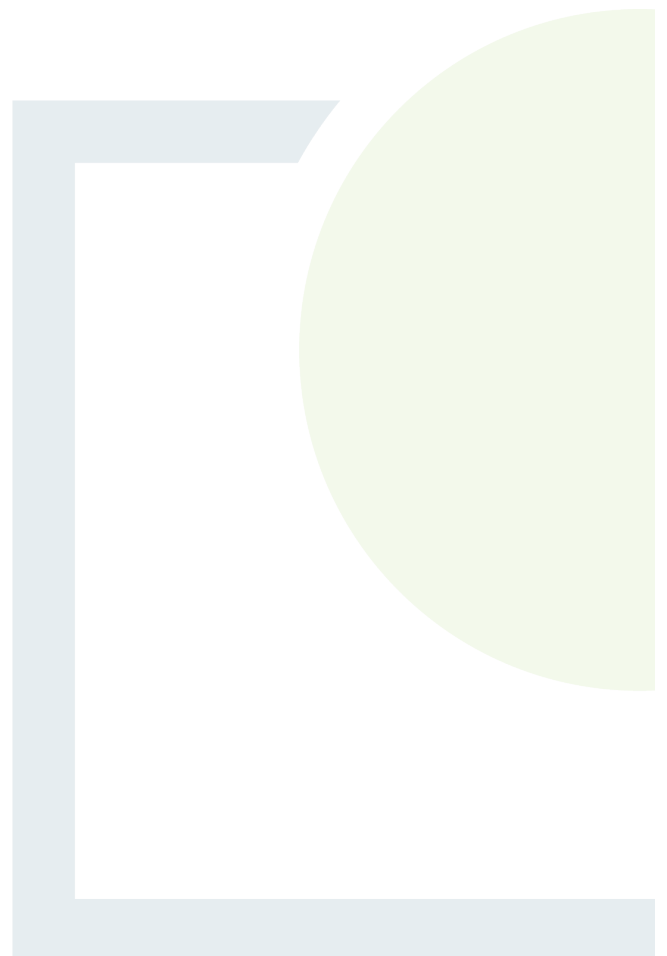


DESIGNING AND DELIVERING
A SUSTAINABLE FUTURE

APPENDIX 10

Air Quality and Climate

Appendix 1.1 – Air and Climate Calculations



APPENDIX 10.1

Air and Climate Calculations

Scottish Government Windfarm Carbon Assessment Tool - Version 2.14.1

27-01-23

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 calculation 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 CO₂ emission saving

2. CO₂ loss due to turbine life

3. CO₂ loss due to backup

4. Loss of CO₂ Fixing Pot.

5. Loss of soil CO₂

5a. Volume of peat removed

5b. CO₂ loss from removed peat

5c. Volume of peat drained

5d. CO₂ loss from drained peat

5e. Emission rates

6. CO₂ loss by DOC & POC loss

7i. Forestry CO₂ loss - simple

7ii. Forestry CO₂ loss - detailed

7a. C sequest. in trees (3PG)

7b. C seq. in soil under trees

7c. Average stand data

7d. Windspeed ratios

8. CO₂ 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:

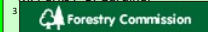
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Note on official version number

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?

Yes ▼

2. Is the soil at the site highly organic?

Yes ▼

i.e. is the soil organo-mineral or organic, (i.e. a peaty gley or peat)?

3. Does windfarm construction require a significant amount of deforestation?

No ▼

i.e. is removal in excess of keyholing the turbines within the forest boundary?

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		Possible range of values			
	Enter expected value here	Record source of data	Enter minimum value here	Record source of data	Enter maximum value here	Record source of data
Windfarm characteristics						
Dimensions						
No. of turbines	11	Fixed				
Lifetime of windfarm (years)	35					
Performance						
Power rating of turbines (turbine capacity) (MW)	6.2					
Capacity factor	Direct input of capacity f _c		Direct input of capacity f _a		Direct input of capacity f _a	
Enter estimated capacity factor (percentage efficiency)	31.0					
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 c _{aj}		Calculate wrt installed c _{aj}		Calculate wrt installed c _{aj}	
Characteristics of peatland before windfarm development						
Type of peatland	Acid b		Acid b		Acid b	
Average annual air temperature at site (°C)	10.7					
Average depth of peat at site (m)	1.50					
C Content of dry peat (% by weight)	60					
Average extent of drainage around drainage features at site (m)						
Average water table depth at site (m)	2.60					
Dry soil bulk density (g cm ⁻³)	0.25					
Characteristics of bog plants						
Time required for regeneration of bog plants after restoration (years)	2					
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha ⁻¹ yr ⁻¹)	0.6					
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					
Average rate of carbon sequestration in timber (tC ha-1 yr-1)	3.60					
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)	1.02					
Grid-mix emission factor (t CO ₂ MWh ⁻¹)	0.204					
Fossil fuel-mix emission factor (t CO ₂ MWh ⁻¹)	0.43					
Borrow pits						
Number of borrow pits	1					
Average length of pits (m)	468					
Average width of pits (m)	190					
Average depth of peat removed from pit (m)	0.00					
Foundations and hard-standing area associated with each turbine						

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% (Dale et al 2004).

Note: Emissions from turbine life. If total emissions for the windfarm are unknown, emissions should be calculated according to turbine capacity. The normal range of CO₂ emissions is 394 to 8147 t CO₂ MW (White & Kulcinski, 2000; White, 2007).

Note: Type of peatland. 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).

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 m³ ha⁻¹ yr⁻¹, compared to the value of 14 m³ ha⁻¹ yr⁻¹ provided by the Forestry Commission. Carbon sequestered for yield class 16 m³ ha⁻¹ yr⁻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) = 1.02 tCO₂e/MWh (Source: [Green Collective](#)) Grid Mix EF = 0.204 tCO₂e/MWh (Source: [SEAI](#), standard factors published annually)

Note: Fossil Fuel-Mix Emission Factor = 0.43 tCO₂e/MWh (Source: [SEAI](#), modelling for a counter-factual scenario suggests gas dominates marginal demand so would be most reflective of a fossil fuel mix)

Method used to calculate CO ₂ loss from foundations and hard-standing	Rectangular with vertical ▼		Rectangular with vertical ▼		Rectangular with vertical ▼		
Average length of turbine foundations (m)	27.5						
Average width of turbine foundations (m)	27.5						
Average depth of peat removed from turbine foundations (m)	1.03						
Average length of hard-standing (m)	88						
Average width of hard-standing (m)	30						
Average depth of peat removed from hard-standing (m)	1.10						
Access tracks							
Total length of access track (m)	18400						
Existing track length (m)	2950						
Length of access track that is floating road (m)	13350						
Floating road width (m)	6						
Floating road depth (m)	0.60						
Length of floating road that is drained (m)	13350						
Average depth of drains associated with floating roads (m)	0.50						
Length of access track that is excavated road (m)	2100						
Excavated road width (m)	6						
Average depth of peat excavated for road (m)	0.20						
Length of access track that is rock filled road (m)	2100						
Rock filled road width (m)	6						
Rock filled road depth (m)	0.8						
Length of rock filled road that is drained (m)	2100						
Average depth of drains associated with rock filled roads (m)	0.50						
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						
Average depth of peat cut for cable trenches (m)	1.00						
Additional peat excavated (not already accounted for above)							
Volume of additional peat excavated (m ³)	12982						
Area of additional peat excavated (m ²)	11019.0						
Peat Landslide Hazard							
Weblink: Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments							
Improvement of C sequestration at site by blocking drains, restoration of habitat etc							
Improvement of degraded bog							
Area of degraded bog to be improved (ha)							
Water table depth in degraded bog before improvement (m)							
Water table depth in degraded bog after improvement (m)							
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)							
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)							
Improvement of felled plantation land							
Area of felled plantation to be improved (ha)							
Water table depth in felled area before improvement (m)							
Water table depth in felled area after improvement (m)							
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)							
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)							
Restoration of peat removed from borrow pits							
Area of borrow pits to be restored (ha)							
Depth of water table in borrow pit before restoration with respect to the restored surface (m)							

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

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

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>.

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 after restoration with respect to the restored surface (m)							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.
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)							
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)							
<u>Early removal of drainage from foundations and hardstanding</u>							
Water table depth around foundations and hardstanding before restoration (m)							Note: <u>Period of time when improvement can be guaranteed</u>. This is assumed to be the lifetime of the windfarm as restoration after windfarm decommissioning is already accounted for in restoration of the site
Water table depth around foundations and hardstanding after restoration (m)							
Time to completion of backfilling, removal of any surface drains, and full restoration of the hydrology (years)							Note: <u>Restoration of site</u>. 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%.
Restoration of site after decomissioning							
Will the hydrology of the site be restored on decommissioning?	Yes		Yes		Yes		Yes No ---
Will you attempt to block any gullies that have formed due to the windfarm?	Not appli▼		Yes▼		Yes▼		
Will you attempt to block all artificial ditches and facilitate rewetting?	Not appli▼		Yes▼		Yes▼		
Will the habitat of the site be restored on decommissioning?	Yes		Yes		Yes		Yes No ---
Will you control grazing on degraded areas?	Yes▼		Yes▼		Yes▼		
Will you manage areas to favour reintroduction of species	Yes▼		Yes▼		Yes▼		

Choice of methodology for calculating emission factors

IPCC default▼

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.

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.).

Click here to move to Payback Time

Click here

Click here to return to Instructions

Click here

Results

PAYBACK TIME AND CO₂ 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.

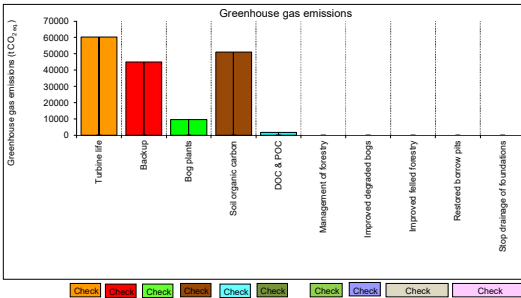
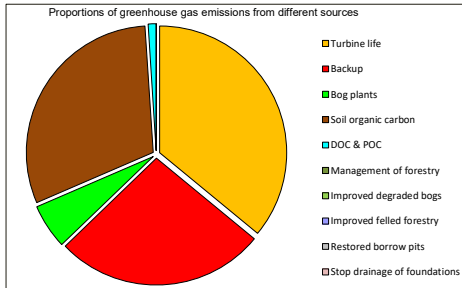
[Click here to return to Input data](#)
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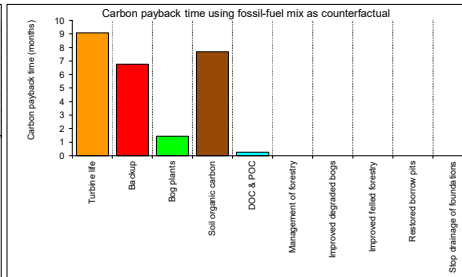
	Exp.
1. Windfarm CO₂ emission saving over...	
...coal-fired electricity generation (tCO ₂ yr ⁻¹)	188908
...grid-mix of electricity generation (tCO ₂ yr ⁻¹)	37782
...fossil fuel - mix of electricity generation (tCO ₂ yr ⁻¹)	79638
Energy output from windfarm over lifetime (MWh)	6482137
Total CO₂ losses due to wind farm (t CO₂ eq.)	
2. Losses due to turbine life (eg. manufacture, construction, decommissioning)	60212
3. Losses due to backup	44957
4. Losses due to reduced carbon fixing potential	9585
5. Losses from soil organic matter	50974
6. Losses due to DOC & POC leaching	1730
7. Losses due to felling forestry	0
Total losses of carbon dioxide	167457
8. Total CO₂ gains due to improvement of site (t CO₂ eq.)	
8a. Change in emissions due to improvement of degraded bogs	0
8b. Change in emissions due to improvement of felled forestry	0
8c. Change in emissions due to restoration of peat from borrow pits	0
8d. Change in emissions due to removal of drainage from foundations & hardstanding	0
Total change in emissions due to improvements	0

RESULTS

	Exp.
Net emissions of carbon dioxide (t CO₂ eq.)	167457
Carbon Payback Time	
...coal-fired electricity generation (years)	0.9
...grid-mix of electricity generation (years)	4.4
...fossil fuel - mix of electricity generation (years)	2.1
Ratio of soil carbon loss to gain by restoration (TARGET ratio (Natural Resources Wales) < 1.0)	No gain!
Ratio of CO₂ eq. emissions to power generation (g / kWh) (TARGET ratio by 2030 (electricity generation) < 50 g /kWh)	28



[Check](#) [Check](#) [Check](#) [Check](#) [Check](#) [Check](#) [Check](#) [Check](#) [Check](#) [Check](#)



Results

PAYBACK TIME AND CO₂ 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 to return to Instructions](#)

[Click here](#)
[Click here](#)

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

Greenhouse gas emissions	Exp.	Min	Max
Turbine life	60212	60212	0
Backup	44957	44957	0
Bog plants	9585	9585	0
Soil organic carbon	50974	50974	0
DOC & POC	1730	1730	0
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	Exp.	Min.	Max.	Carbon payback time (months)	Exp.	Min.	Max.
Turbine life	60212	60212	-60212	9	60212	60212	-60212
Backup	44957	44957	-44957	7	44957	44957	-44957
Bog plants	9585	9585	-9585	1	9585	9585	-9585
Soil organic carbon	50974	50974	-50974	8	50974	50974	-50974
DOC & POC	1730	1730	-1730	0	1730	1730	-1730
Management of forestry	0	0	0	0	0	0	0
Improved degraded bogs	0	0	0	0	0	0	0
Improved felled forestry	0	0	0	0	0	0	0
Restored borrow pits	0	0	0	0	0	0	0
Stop drainage of foundations	0	0	0	0	0	0	0
	167457			25			

Windfarm CO₂ emission saving

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

[Click here to move to Payback Time](#)

[Click here](#)

[illegible]

Calculation of capacity factor	1	Direct input of capacity factor		
		Exp	Min	Max
Entered capacity factor (%)		31	0	0

Parameters	Slope (a)			Intercept (b)		
<i>Partial power curves for different turbines</i>	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

[illegible][illegible]

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)	188908	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
...grid-mix of electricity generation (tCO ₂ yr ⁻¹)	37782	0	0	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)	79638	0	0	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 CO₂ emission saving

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

Emissions due to turbine life

Note: The carbon payback time of the windfarm due to turbine life (eg. manufacture, construction, 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, decommissioning)?	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)	5325	0	0
No. of turbines	11	0	0
Total calculated CO ₂ emission of the wind farm due to turbine life (t CO ₂ windfarm ⁻¹)	58580	0	0

	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)	5165	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	1632	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

RESULTS			
Losses due to turbine life (eg. manufacture, construction, decomissioning) (t CO ₂ windfarm ⁻¹)	60212	0	0
Additional CO ₂ payback time of windfarm due to turbine life (eg. manufacture, contruction, decomissioning)			
...coal-fired electricity generation (months)	4	0	0
...grid-mix of electricity generation (months)	19	0	0
...fossil fuel - mix of electricity generation (months)	9	0	0

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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



Embodied carbon dioxide (CO₂e) of concretes used in buildings

CONCRETE APPLICATION	Concrete designation	CO ₂ e (kgCO ₂ e/m ³) ¹			CO ₂ e (kgCO ₂ e/tonne) ¹		
		CEM I concret e	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 ₂ e (kgCO ₂ e/m ³)			CO ₂ e (kgCO ₂ e/tonne)		
Unreinforced Precast flooring ³		-			165		
Reinforced precast flooring ³		-			171		
Average Generic Concrete Block ⁴		-			84		

*

includes 30kg/m³ steel reinforcement

**

includes 100kg/m³ steel reinforcement

Emissions due to backup power generation

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

	Expected	Minimum	Maximum
Reserve capacity required for backup			
No. of turbines	11	0	0
Power rating of turbines (turbine capacity) (MW)	6.2	0	0
Power of wind farm (MW h ⁻¹)	68.2	0	0
Rated capacity (MW yr ⁻¹)	597432	0	0
Extra capacity required for backup (%)	5	0	0
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10	0	0
Reserve capacity (MWh yr ⁻¹)	2987	0	0

Carbon dioxide emissions due to backup power generation			
Coal-fired plant emission factor (t CO ₂ MWh ⁻¹)	1.02	0	0
Grid-mix emission factor (t CO ₂ MWh ⁻¹)	0.204	0	0
Fossil fuel- mix emission factor (t CO ₂ MWh ⁻¹)	0.43	0	0
Lifetime of windfarm (years)	35	0	0
Annual emissions due to backup from...			
...coal-fired electricity generation (tCO ₂ yr ⁻¹)	3047	0	0
...grid-mix of electricity generation (tCO ₂ yr ⁻¹)	609	0	0
...fossil fuel - mix of electricity generation (tCO ₂ yr ⁻¹)	1284	0	0

RESULTS			
Total emissions due to backup from...			
...coal-fired electricity generation (tCO ₂)	106642	0	0
...grid-mix of electricity generation (tCO ₂)	21328	0	0
...fossil fuel - mix of electricity generation (tCO ₂)	44957	0	0
Additional CO ₂ payback time of windfarm due to backup			
...coal-fired electricity generation (months)	7	0	0
...grid-mix of electricity generation (months)	7	0	0
...fossil fuel - mix of electricity generation (months)	7	0	0

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Emissions due to backup power generation

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

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

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

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)	242598	0	0
Total area affected by drainage due to windfarm construction (m ²)	80100	0	0
Total area where fixation by plants is lost (m ²)	322698	0	0
Total loss of carbon accumulation			
Carbon accumulation in undrained peats (tC ha ⁻¹ yr ⁻¹)	0.6	0	0
Lifetime of windfarm (years)	35	0	0
Time required for regeneration of bog plants after restoration (years)	100	0	0
Carbon accumulation up to time of restoration (tCO ₂ eq. ha ⁻¹)	297	0	0
RESULTS			
Total loss of carbon accumulation by bog plants			
Total area where fixation by plants is lost (ha)	32	0	0
Carbon accumulation over lifetime of windfarm (tCO ₂ eq. ha ⁻¹)	297	0	0
Total loss of carbon fixation by plants at the site (t CO₂)	9585	0	0
Additional CO₂ payback time of windfarm due to loss of CO₂ fixing potential			
...coal-fired electricity generation (months)	1	0	0
...grid-mix of electricity generation (months)	3	0	0
...fossil fuel - mix of electricity generation (months)	1	0	0

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.

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Emissions due to loss of bog plants

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

Emissions due to loss of soil organic carbon

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

	Expected result	Minimum result	Maximum result
CO₂ loss due to windfarm construction			
☐ CO ₂ loss from removed peat (t CO ₂ equiv)	46064	0	0
☐ CO ₂ loss from drained peat (t CO ₂ equiv)	4910	0	0
RESULTS			
Total CO₂ loss from peat (removed + drained) (t CO₂ equiv)	50974	0	0
Additional CO₂ payback time of windfarm due to loss of soil CO₂			
...coal-fired electricity generation (months)	3	0	0
...grid-mix of electricity generation (months)	16	0	0
...fossil fuel - mix of electricity generation (months)	8	0	0

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Emissions due to loss of soil organic carbon

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

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	Exp	Total Min	Max
Number of borrow pits	1	0	0
Average length of pits (m)	468	0	0
Average width of pits (m)	190	0	0
Average depth of peat removed from pit (m)	0	0	0
Area of land lost in borrow pits (m ²)	88920	0	0
Volume of peat removed from borrow pits (m ³)	0	0	0

Peat removed from turbine foundations	Exp	Total Min	Max	Construction Area 1 Exp	Min	Max	Construction Area 2 Exp	Min	Max	Construction Area 3 Exp	Min	Max	Construction Area 4 Exp	Min	Max	Construction Area 5 Exp	Min	Max
Method used to calculate CO ₂ loss from foundations	Rectangular with vertical walls																	
Calculation method code		1																
No. of turbines	11	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diameter at surface (m)				28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diameter at bottom (m)				28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth of foundations (m)				28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
"Area" of land lost in hard-standing (m ²)	8319	0	0	8319	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Volume of peat removed from foundation area (m ³)	8568.313	0	0	8568.313	0	0	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	11	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diameter at surface (m)				88	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diameter at bottom (m)				30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Depth of hardstanding (m)				88	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
				1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area of land lost in hard-standing (m ²)	29040	0	0	29040	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Volume of peat removed from hardstandingarea (m ³)	31944	0	0	31944	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Peat removed from access tracks	Exp	Total Min	Max
Floating roads			
Length of access track that is floating road (m)	13350	0	0
Floating road width (m)	6	0	0

Floating road depth (m)	0.6	0	0
Area of land lost in floating roads (m ²)	80100	0	0
Volume of peat removed for floating roads	48060	0	0
<u>Excavated roads</u>			
Length of access track that is excavated road (m)	2100	0	0
Excavated road width (m)	6	0	0
Average depth of peat excavated for road (m)	0.2	0	0
Area of land lost in excavated roads (m ²)	12600	0	0
Volume of peat removed for excavated roads	2520	0	0
<u>Rock-filled roads</u>			
Length of access track that is rock filled road (m)	2100	0	0
Rock filled road width (m)	6	0	0
Rock filled road depth (m)	0.8	0	0
Area of land lost in excavated roads (m ²)	12600	0	0
Volume of peat removed for rock-filled roads	10080	0	0
Total area of land lost in access tracks (m ²)	105300	0	0
Total volume of peat removed due to access tracks (m ³)	60660	0	0

Additional peat excavated - (not already accounted for above)			
Volume of additional peat excavated (m ³)	12982	0	0
Area of additional peat excavated (m ²)	11019	0	0

RESULTS		Total	
	Exp	Min	Max
Total volume of peat removed (m ³) due to windfarm construction	114154	0	0
Total area of land lost due to windfarm construction (m ²)	242598	0	0

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

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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.

CO₂ loss from removed peats

Note: If peat is treated in such a way that it is permanently restored, so that less than 100% of the C is lost to the atmosphere, a lower percentage can be entered in cell C10

	Expected	Minimum	Maximum
CO₂ loss from removed peat			
C Content of dry peat (% by weight)	60	0	0
Dry soil bulk density (g cm ⁻³)	0.25	0.00	0.00
% C contained in removed peat that is lost as CO ₂	100	100	100
Total volume of peat removed (m ³) due to windfarm construction	114154	0	0
CO ₂ loss from removed peat (t CO ₂)	62791	0	0

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

Check

CO₂ loss from undrained peat left in situ			
Total area of land lost due to windfarm construction (ha)	24	0	0
CO ₂ loss from undrained peat left in situ (t CO ₂ ha ⁻¹)	689	0	0
CO ₂ loss from undrained peat left in situ (t CO ₂)	16726	0	0

CO₂ loss attributable to peat removal only			
CO ₂ loss from removed peat (t CO ₂)	62791	0	0
CO ₂ loss from undrained peat left in situ (t CO ₂)	16726	0	0
RESULTS			
CO₂ loss attributable to peat removal only (t CO₂)	46064	0	0

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CO₂ loss from removed peats

Note: If peat is treated in such a way that it is permanently restored, so that less than 100% of the C is lost to the atmosphere, a lower percentage can be entered in cell C10

Volume of peat drained

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

Extent of drainage around each metre of drainage ditch	Exp	Total Min	Max
Average extent of drainage around drainage features at site (m)	0	0	0

Peat affected by drainage around borrow pits	Exp	Total Min	Max
Number of borrow pits	1	0	0
Average length of pits (m)	468	0	0
Average width of pits (m)	190	0	0
Average depth of peat removed from pit (m)	0.0	0.0	0.0
Area affected by drainage per borrow pit (m ²)	0	0	0
Total area affected by drainage around borrowpits (m ²)	0	0	0
Total volume affected by drainage around borrowpits (m ³)	0	0	0

Peat affected by drainage around turbine foundation and hardstanding	Exp	Total Min	Max	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	11	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average length of turbine foundations at base (m)				28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average width of turbine foundations at base(m)				28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average depth of peat removed from turbine foundations (m)				1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average length of hard-standing at base (m)				88	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average width of hard-standing at base (m)				30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average depth of peat removed from hard-standing (m)				1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum depth of drains (m)				1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total length of foundation and hardstanding (m)				116	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total width of foundation and hardstanding (m)				58	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area affected by drainage of foundation and hardstanding area (m ²)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total area affected by drainage of foundation and hardstanding area (m ²)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total volume affected by drainage of foundation and hardstanding area (m ³)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Peat affected by drainage of access tracks	Exp	Total Min	Max
Floating roads			

Length of floating road that is drained (m)	13350	0	0
Floating road width (m)	6.0	0.0	0.0
Average depth of drains associated with floating roads (m)	0.50	0.00	0.00
Area affected by drainage of floating roads (m ²)	80100	0	0
Volume affected by drainage of floating roads (m ³)	20025	0	0
<u>Excavated Road</u>			
Length of access track that is excavated road (m)	2100	0	0
Excavated road width (m)	6	0	0
Average depth of peat excavated for road (m)	0.2	0.0	0.0
Area affected by drainage of excavated roads (m ²)	0	0	0
Volume affected by drainage of excavated roads (m ³)	0	0	0
<u>Rock-filled roads</u>			
Length of rock filled road that is drained (m)	2100	0	0
Rock filled road width (m)	6	0	0
Average depth of drains associated with rock filled roads (m)	0.5	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)	80100	0	0
Total volume affected by drainage of access track (m ³)	20025	0	0

Peat affected by drainage of cable trenches	Exp	Total Min	Max
Length of any cable trench on peat that does not follow access tracks and is lined with a permeable medium (eg. sand) (m)	0	0	0
Average depth of peat cut for cable trenches (m)	1.0	0.0	0.0
Total area affected by drainage of cable trenches (m ²)	0	0	0
Total volume affected by drainage of cable trenches (m ³)	0.00	0.00	0.00

Drainage around additional peat excavated	Exp	Total Min	Max
Volume of additional peat excavated (m ³)	12982.0	0.0	0.0
Area of additional peat excavated (m ²)	11019.0	0.0	0.0
Average depth of excavated peat (m)	1	0	0
Radius of area excavated (m)	59	0	0

Assumption: Area excavated is assumed to be a circle

Radius of excavated and drained area (m)	59	0	0
Total area affected by drainage (m ²)	0	0	0
Total volume affected by drainage (m ³)	0.00	0.00	0.00

assumed to be a circle

RESULTS	Exp	Total Min	Max
Total area affected by drainage due to windfarm (m ²)	80100	0	0
Total volume affected by drainage due to windfarm (m ³)	20025	0	0

Click here to move to 5d. CO2 loss from drained peat

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Volume of peat drained

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

CO₂ loss due to drainage

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

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	Expected	Minimum	Maximum
Drained Land			
Total area affected by drainage due to wind farm construction (ha)	8	0	0
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

Check	Total volume affected by drainage due to wind farm (m ³)	20025	0	0
	C Content of dry peat (% by weight)	60	0	0
	Dry soil bulk density (g cm ⁻³)	0.25	0.00	0.00
	Total GHG emissions from Drained Land (t CO₂ equiv.)	11015	0	0
	Total GHG Emissions from Undrained Land (t CO₂ equiv.)	5831	0	0

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

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

	Flooded period (days year ⁻¹)	0	0	0
	Lifetime of windfarm (years)	35	25	25
	Time required for regeneration of bog plants after restoration (years)	2	0	0
	Methane Emissions from Drained Land			
Check	Rate of methane emission in drained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.000	0.000	0.000
	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.)	0	0	0
	Carbon Dioxide Emissions from Drained Land			
Check	Rate of carbon dioxide emission in drained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	35.20	35.20	35.20
	CO ₂ emissions from drained land (t CO ₂)	10432	0	0
	Total GHG emissions from Drained Land (t CO₂ equiv.)	10432	0	0

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

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

2. Losses if Land is Undrained

	Flooded period (days year ⁻¹)	178	178	178
	Lifetime of windfarm (years)	35	25	25
	Time required for regeneration of bog plants after restoration (years)	2	0	0
	Methane Emissions from Undrained Land			
Check	Rate of methane emission in undrained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.04	0.04	0.04
	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.)	178	0	0
	Carbon Dioxide Emissions from Undrained Land			
Check	Rate of carbon dioxide emission in undrained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	0.00	0.00	0.00
	CO ₂ emissions from undrained land (t CO ₂)	5345	0	0
	Total GHG Emissions from Undrained Land (t CO₂ equiv.)	5523	0	0

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

3. CO₂ Losses due to Drainage

Total GHG emissions from drained land (t CO ₂ equiv.)	10432	0	0
Total GHG emissions from undrained land (t CO ₂ equiv.)	5523	0	0
RESULTS			
Total GHG emissions due to drainage (t CO₂ equiv.)	4910	0	0

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CO₂ loss due to drainage

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

Emission rates from soils

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

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Selected Methodology = IPCC default
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)

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

Selected emission characteristics (IPCC, 1997)

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

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

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

Assumption: CO₂ emissions on drainage of organic soils for upland crops (e.g., grain, vegetables) are 3.667x9.6 (7.9-11.3) t CO₂ 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)	8	0	0
Total volume affected by drainage due to wind farm construction (m ³)	20025	0	0

Soil Characteristics that Determine Emission Rates

Average annual air temperature at the site (°C)	10.7	0	0
Average water table depth at site (m)	2.60	0.00	0.00
Average water table depth of drained land (m)	2.60	#DIV/0!	#DIV/0!

Annual Emission Rates following site specific methodology

Acid bogs

Rate of carbon dioxide emission in drained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	24.48	#DIV/0!	#DIV/0!
Rate of carbon dioxide emission in undrained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	24.48	-2.13	-2.13
Rate of methane emission in drained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.001	#DIV/0!	#DIV/0!
Rate of methane emission in undrained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.00	0.46	0.46

Fens

Rate of carbon dioxide emission in drained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	65.58	#DIV/0!	#DIV/0!
Rate of carbon dioxide emission in undrained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	65.58	0.06	0.06
Rate of methane emission in drained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	-0.003	#DIV/0!	#DIV/0!
Rate of methane emission in undrained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.00	0.55	0.55

Selected emission characteristics following site specific methodology

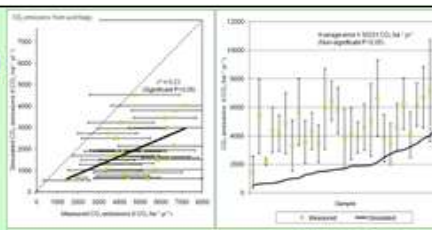
Rate of carbon dioxide emission in drained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	24.48	#DIV/0!	#DIV/0!
Rate of carbon dioxide emission in undrained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	24.48	-2.13	-2.13
Rate of methane emission in drained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.001	#DIV/0!	#DIV/0!
Rate of methane emission in undrained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.00	0.46	0.46

RESULTS

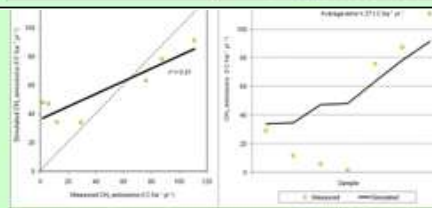
Selected Emission Rates

Rate of carbon dioxide emission in drained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	35.20	35.20	35.20
Rate of carbon dioxide emission in undrained soil (t CO ₂ ha ⁻¹ yr ⁻¹)	0.00	0.00	0.00
Rate of methane emission in drained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.000	0.000	0.000
Rate of methane emission in undrained soil ((t CH ₄ -C) ha ⁻¹ yr ⁻¹)	0.04	0.04	0.04

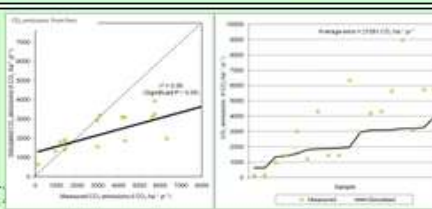
Note: Carbon dioxide emissions from acid bogs. Equation derived by regression analysis against 60 measurements (Nayak et al, 2009). The equation derived was $R_{CO_2} = (3.667/1000) \times ((6700 \times \exp(-0.26 \times \exp(-0.0515 \times ((W \times 100) - 50)))) + ((72.54 \times T) - 800))$ where R_{CO_2} is the annual rate of CO₂ emissions (t CO₂ (ha)⁻¹ yr⁻¹), T = average annual peat temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements ($r^2 = 0.53$, $P > 0.05$). Evaluation against 29 independent experiments shows a significant association ($r^2 = 0.21$; $P > 0.05$) and an average error of 3023 t CO₂ ha⁻¹ yr⁻¹ which is non-significant ($P < 0.05$) (Smith et al, 1997).



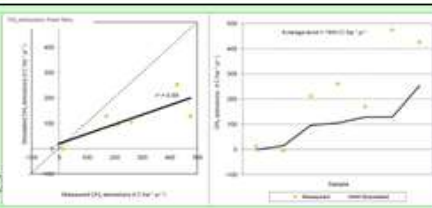
measurements (Nayak et al, 2009). The equation derived was $R_{CH_4} = (1/1000) \times (500 \times \exp(-0.1234 \times (W \times 100))) + ((3.529 \times T) - 36.67))$ where R_{CH_4} is the annual rate of CH₄ emissions (t CH₄-C (ha)⁻¹ yr⁻¹), T = average annual air temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements ($r^2 = 0.54$, $P > 0.05$). Evaluation against 7 independent experiments shows a significant association ($r^2 = 0.81$; $P > 0.05$) and an average error of 27 t CH₄-C ha⁻¹ yr⁻¹ (significance not defined due to lack of replicates - Smith et al, 1997).



Note: Carbon dioxide emissions from fens. Equation derived by regression analysis against 44 measurements (Nayak et al, 2009). The equation derived was $R_{CO_2} = (3.667/1000) \times (16244 \times \exp(-0.175 \times \exp(-0.073 \times ((W \times 100) - 50)))) + (153.23 \times T)$ where R_{CO_2} is the annual rate of CO₂ emissions (t CO₂ (ha)⁻¹ yr⁻¹), T = average annual peat temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements ($r^2 = 0.42$, $P > 0.05$). Evaluation against 18 independent experiments shows a significant association ($r^2 = 0.66$; $P > 0.05$) and an average error of 2108 t CO₂ ha⁻¹ yr⁻¹ (significance not defined due to lack of replicates - Smith et al, 1997).



Note: Methane emissions from fens. Equation derived by regression analysis against experimental data from 35 measurements (Nayak et al, 2009). The equation derived was $R_{CH_4} = (1/1000) \times (-10 + 563.62 \times \exp(-0.097 \times (W \times 100))) + (0.662 \times T)$ where R_{CH_4} is the annual rate of CH₄ emissions (t CH₄-C (ha)⁻¹ yr⁻¹), T = average annual air temperature (°C) and W is the water table depth (m). The equation shows a significant correlation with measurements ($r^2 = 0.41$, $P > 0.05$). Evaluation against 7 independent experiments shows a significant association ($r^2 = 0.69$; $P > 0.05$) and an average error of 164 t CH₄-C ha⁻¹ yr⁻¹ (significance not defined due to lack of replicate - Smith et al, 1997).



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Emission rates from soils

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

Emissions due to loss of DOC and POC

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

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

	Expected	Minimum	Maximum
Total C loss			
Gross CO ₂ loss from restored drained land (t CO ₂)	5087	0	0
Gross CH ₄ loss from restored drained land (t CO ₂ equiv.)	0	0	0
Gross CO ₂ loss from improved land (t CO ₂)			
Degraded Bog	0	0	0
Felled Forestry	0	0	0
Borrow Pits	0	0	0
Foundations & Hardstanding	0	0	0
Gross CH ₄ loss from improved land (t CO ₂ equiv.)			
Degraded Bog	0	0	0
Felled Forestry	0	0	0
Borrow Pits	0	0	0
Foundations & Hardstanding	0	0	0
Conversion factor: CH ₄ -C to CO ₂ equivalents	30.6667	30.6667	30.6667
% total soil C losses, lost as DOC	26	7	40
% DOC loss emitted as CO ₂ over the long term	100	100	100
% total soil C losses, lost as POC	8	4	10
% POC loss emitted as CO ₂ over the long term	100	100	100
Total gaseous loss of C (t C)	1390	0	0
Total C loss as DOC (t C)	361	0	0
Total C loss as POC (t C)	111	0	0

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

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

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

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

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

RESULTS			
Total CO₂ loss due to DOC leaching (t CO₂)	1323	0	0
Total CO₂ loss due to POC leaching (t CO₂)	407	0	0
Total CO₂ loss due to DOC & POC leaching (t CO₂)	1730	0	0
Additional CO₂ payback time of windfarm due to DOC & POC			
...coal-fired electricity generation (months)	0	#DIV/0!	#DIV/0!
...grid-mix of electricity generation (months)	1	#DIV/0!	#DIV/0!
...fossil fuel - mix of electricity generation (months)	0	#DIV/0!	#DIV/0!

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Emissions due to loss of DOC and POC

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

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

Emissions due to forest felling - calculation using simple management data

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 forestry to be felled should be entered as zero.

	Expected	Minimum	Maximum
Emissions due to forestry felling			
Area of forestry plantation to be felled (ha)	0	0	0
Carbon sequestered (tC ha ⁻¹ yr ⁻¹)	3.6	0	0
Lifetime of windfarm (years)	35	0	0
Carbon sequestered over the lifetime of the windfarm (t C ha ⁻¹)	126	0	0
RESULTS			
Total carbon loss due to felling of forestry (t CO₂)	0	0	0
Additional CO₂ payback time of windfarm due to management of forestry			
...coal-fired electricity generation (months)	0	0	0
...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 forest felling - calculation using simple management data

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 forestry to be felled should be entered as zero.

<u>CO₂ loss from forests - calculation using detailed management information</u> Forest carbon calculator (Perks et al, 2009)	
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Forest carbon calculator (Perks et al, 2009)

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Fossil fuel-mix emission factor (t CO ₂ MWh ⁻¹)	0.430	0.000	0.000	0.430	0.000	0.000	0.430	0.000	0.000	0.430	0.000	0.000	0.430	0.000	0.000	0.430	0.000	0.000
Savings in CO ₂ emissions associated with using replanted forestry as a biofuel (t CO ₂)				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distance to nearest biomass power plant (km)	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	0.0	0.0	0.0
Emissions of CO ₂ associated with transportation (t CO ₂ km ⁻¹ t ⁻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	0.00	0.00	0.00	0.00	0.00	0.00
Carbon equivalent of transportation (t CO ₂ eq.)				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fossil fuel equivalent saving (t CO ₂)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

RESULTS																		
Total Carbon loss associated with forest management (t CO ₂)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Additional CO ₂ payback time of windfarm due to management of forestry																		
...coal-fired electricity generation (months)	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
...grid-mix of electricity generation (months)	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
...fossil fuel - mix of electricity generation (months)	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!

CO ₂ loss from forests - calculation using detailed management information
Forest carbon calculator (Perks et al, 2009)

Simplified version of the 3PG model (Xenakis et al, 2008). This version, doesn't require climate data as no explicit environmental modifier is calculated. Instead, it uses a factor (from 0 to 1) representing the total effect of environment on growth. The simplified model requires a value of annual incoming solar radiation, a modifier for the age-related decline in productivity, a light extinction coefficient and specific leaf area.

The model calculates gross primary productivity (GPP) and then net primary production (NPP) through a standard ratio. It allocates NPP to roots, wood and foliage. A soil model calculates the size of old and young carbon pools, respiration losses from these pools and from this net ecosystem productivity (NEP).

The model does not need temp/rain/soilrad data: the impact of the environment at the site is included by adjusting the environmental modifier, based on site yield class and temperature. Light use efficiency (LUE), rather than quantum use efficiency (QYE) is used, making it easier to develop the model for many species even for a grouping such as "conifers" or "deciduous".
Calibration for Sitka Spruce gives QYE = 0.08 (mol/mol) => LUE = 2.21 (kJC/MJ), and for SP QYE = 0.05 (mol/mol) => LUE = 1.37 (kJC/MJ).

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
Accumulated temperature (day-degrees > 5°C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)	(> 1050 deg.C)
Code number	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Major Soil Sub Group	Deep Peat			Deep Peat	Deep Peat	Deep Peat	0	0	0	0	0	0	0	0	0	0	0	0
Code number	2			2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Species	Scots pine			Scots pine	Scots pine	Scots pine	0	0	0	0	0	0	0	0	0	0	0	0
Code number	1			1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Age of forestry when felled for windfarm (yr)	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lifetime of windfarm (years)	35	25	25	35	25	25	35	25	25	35	25	25	35	25	25	35	25	25
Years after felling when replanting occurs	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Age of seedlings on planting (yr)				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Years when replanted forestry will be grown on wind farm site	35			35	25	25	35	25	25	35	25	25	35	25	25	35	25	25

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Parameter	Units	Species		Selected Value				
		Scots Pine	Sitka Spruce	Area 1	Area 2	Area 3	Area 4	Area 5
3PG module								
Average annual photosynthetically active radiation	2880 MJ m ⁻² yr ⁻¹			2880	2880	2880	2880	2880
Light extinction coefficient	0.5 -			0.5	0.5	0.5	0.5	0.5
Specific leaf area	m ² kg ⁻¹ C	6	8	6	8	8	8	8
Leaf longevity	1 yrs	4	7	4	7	7	7	7
Fine root longevity	1 yrs			1	1	1	1	1
Maximum light-use efficiency	kg C MJ ⁻¹ day ⁻¹	0.00152	0.00166	0.00152	0.00166	0.00166	0.00166	0.00166
Total reduction factor for misc environmental effects	-			0.3679	#N/A	#N/A	#N/A	#N/A
Ratio of NPP to GPP	0.47 -			0.47	0.47	0.47	0.47	0.47
Allocation to foliage	0.25 -			0.25	0.25	0.25	0.25	0.25
Coefficient for allocation response to nitrogen	1.00 -			1.00	1.00	1.00	1.00	1.00
Age for 50% reduction in light-use efficiency	100 yrs	100	120	100	120	120	120	120
Initial foliage biomass	0.005 kg C m ⁻²			0.005	0.005	0.005	0.005	0.005
Understorey module								
Understorey LAI	3.00 -			3.00	3.00	3.00	3.00	3.00

Conversion Factors	Quantum yield efficiency (mol mol^{-1}) 0.05	to	Light use efficiency (kgC MJ^{-1}) 0.00130
	Light use efficiency (kgC MJ^{-1}) 0.00135	to	Quantum yield efficiency (mol mol^{-1}) 0.0489
gDM_mol	24		
molPAR_MJ	2.3		

GPP Reduction Factor Lookup Table				
		Accumulated temperature		
		Less than 1050 °C yr ¹	1050 to 1350 °C yr ¹	More than 1350 °C yr ¹
Soil type	Code	1	2	3
Peaty Gley	1	0.3178	0.3551	0.3720
Deep Peat	2	0.3177	0.3569	0.3679

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Gains due to site improvement

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

Selected Methodology = IPCC default
Type of peatland = Acid Bog

Improvement of...	Expected result				Minimum result				Maximum result			
	Degraded Bog	Felled Forestry	Borrow Pits	Foundations & Hardstanding	Degraded Bog	Felled Forestry	Borrow Pits	Foundations & Hardstanding	Degraded Bog	Felled Forestry	Borrow Pits	Foundations & Hardstanding
Reduction in GHG emissions due to improvement of site												
1. Description of site												
Period of time when effectiveness of the improvement can be guaranteed (years)	0	0	0	35	0	0	0	25	0	0	0	25
Area to be improved (ha)	0	0	0	0	0	0	0	0	0	0	0	0
Average air temperature at site (°C)	10.7	10.7	10.7	10.7	0	0	0	0	0	0	0	0
Depth of peat drained (m)	1.50	1.50	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth of peat above water table before improvement (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depth of peat above water table after improvement (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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)	0	0	0	0	0	0	0	0	0	0	0	0
Improved period (years)	0	0	0	35	0	0	0	25	0	0	0	25
Methane emissions from improved land												
Site specific methane emission from improved soil on acid bogs (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.501	0.501	0.501	0.501	0.463	0.463	0.463	0.463	0.463	0.463	0.463	0.463
Site specific methane emission from improved soil on fens (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.561	0.561	0.561	0.561	0.554	0.554	0.554	0.554	0.554	0.554	0.554	0.554
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)	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
CH ₄ emissions from improved land (t CO ₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0
Carbon dioxide emissions from improved land												
Site specific CO ₂ emission from improved soil on acid bogs (t CO ₂ ha ⁻¹ yr ⁻¹)	0.72	0.72	0.72	0.72	-2.13	-2.13	-2.13	-2.13	-2.13	-2.13	-2.13	-2.13
Site specific CO ₂ emissions from improved soil on fens (t CO ₂ ha ⁻¹ yr ⁻¹)	6.07	6.07	6.07	6.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
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)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO ₂ emissions from improved land (t CO ₂)	0	0	0	0	0	0	0	0	0	0	0	0
Total GHG emissions from improved land (t CO ₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0
3. Losses without improvement												
Flooded period (days year ⁻¹)	0	0	0	0	0	0	0	0	0	0	0	0
Time required for hydrology and habitat to return to its previous state on restoration (years)	0	0	0	0	0	0	0	0	0	0	0	0
Improved period (years)	0	0	0	35	0	0	0	25	0	0	0	25
Methane emissions from unimproved land												
Site specific methane emission from unimproved soil on acid bogs (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.501	0.501	0.501	0.501	0.463	0.463	0.463	0.463	0.463	0.463	0.463	0.463
Site specific methane emission from unimproved soil on fens (t CH ₄ -C ha ⁻¹ yr ⁻¹)	0.561	0.561	0.561	0.561	0.554	0.554	0.554	0.554	0.554	0.554	0.554	0.554
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)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
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)	0.72	0.72	0.72	0.72	-2.13	-2.13	-2.13	-2.13	-2.13	-2.13	-2.13	-2.13
Site specific CO ₂ emissions from unimproved soil on fens (t CO ₂ ha ⁻¹ yr ⁻¹)	6.07	6.07	6.07	6.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
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)	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20	35.20
CO ₂ emissions from unimproved land (t CO ₂)	0	0	0	0	0	0	0	0	0	0	0	0
Total GHG emissions from unimproved land (t CO ₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0
RESULTS												
4. Reduction in GHG emissions due to improvement of site												
Total GHG emissions from improved land (t CO ₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0
Total GHG emissions from unimproved land (t CO ₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0
Reduction in GHG emissions due to improvement (t CO ₂ equiv.)	0	0	0	0	0	0	0	0	0	0	0	0
Additional CO₂ payback time of windfarm due to site improvement												
...coal-fired electricity generation (months)	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
...grid-mix of electricity generation (months)	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!
...fossil fuel - mix of electricity generation (months)	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!	0	#DIV/0!	#DIV/0!

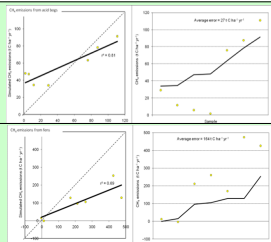
Click here to move to Payback Tim [Click here](#)

Gains due to site improvement

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

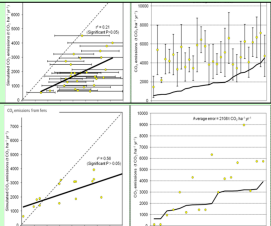
Note: Methane emissions from acid bogs. Equation derived by regression analysis against 57 measurements (Nayak et al, 2009). The equation derived was:
 $R_{CH_4} = (1/1000) \times (500 \times \exp(-0.1234 \times (W \times 100))) + ((3.529 \times T) - 36.67))$
where R_{CH_4} is the annual rate of CH₄ emissions (t CH₄-C (ha)⁻¹ yr⁻¹),
 T = average annual air temperature (°C) and
 W is the water table depth (m).
The equation shows a significant correlation with measurements ($r^2 = 0.54$, $P > 0.05$).
Evaluation against 7 independent experiments shows a significant association ($r^2 = 0.81$; $P > 0.05$) and an average error of 27 t CH₄-C ha⁻¹ yr⁻¹ (significance not defined due to lack of replicates - Smith et al, 1997).

Note: Methane emissions from fens. Equation derived by regression analysis against experimental data from 35 measurements (Nayak et al, 2009). The equation derived was:
 $R_{CH_4} = (1/1000) \times (-10 \times 563.62 \times \exp(-0.097 \times (W \times 100))) + (0.662 \times T)$
where R_{CH_4} is the annual rate of CH₄ emissions (t CH₄-C (ha)⁻¹ yr⁻¹),
 T = average annual air temperature (°C) and
 W is the water table depth (m).
The equation shows a significant correlation with measurements ($r^2 = 0.41$, $P > 0.05$).
Evaluation against 7 independent experiments shows a significant association ($r^2 = 0.69$; $P > 0.05$) and an average error of 164 t CH₄-C ha⁻¹ yr⁻¹ (significance not defined due to lack of replicate-Smith et al, 1997).



$R_{CO_2} = (3.667/1000) \times ((6700 \times \exp(-0.26 \times \exp(-0.0515 \times ((W \times 100) - 50)))) + ((72.54 \times T) - 800))$
where R_{CO_2} is the annual rate of CO₂ emissions (t CO₂ (ha)⁻¹ yr⁻¹),
 T = average annual peat temperature (°C) and
 W is the water table depth (m).
The equation shows a significant correlation with measurements ($r^2 = 0.53$, $P > 0.05$).
Evaluation against 29 independent experiments shows a significant association ($r^2 = 0.21$; $P > 0.05$) and an average error of 3023 t CO₂ ha⁻¹ yr⁻¹ which is non-significant ($P < 0.05$) (Smith et al, 1997).

Note: Carbon dioxide emissions from fens. Equation derived by regression analysis against 44 measurements (Nayak et al, 2009). The equation derived was:
 $R_{CO_2} = (3.667/1000) \times (16244 \times \exp(-0.175 \times \exp(-0.073 \times ((W \times 100) - 50)))) + (153.23 \times T)$
where R_{CO_2} is the annual rate of CO₂ emissions (t CO₂ (ha)⁻¹ yr⁻¹),
 T = average annual 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 CO₂ ha⁻¹ yr⁻¹ (significance not defined due to lack of replicates-Smith et al, 1997).



Note: Methane emissions from acid bogs. As above

Note: Methane emissions from fens. As above

Note: CO₂ emissions from acid bogs. As above

Note: CO₂ emissions from fens. As above

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Frequently Asked Questions

Click here to email question

GENERAL

Syin Yi Phoon (Senior Hydrologist, EnviroCentre Ltd)

Comment: I could see the benefit of protected feature on the all the sheets, but it this means we cannot even copy the equations for testing sensitivity of a parameter without changing the entire sheet. The protection should be removed as it reduces the usefulness of the tool.

Response: Protection of sheets removed

Syin Yi Phoon (Senior Hydrologist, EnviroCentre Ltd)

Comment: We miss the carbon payback table that used to be at the bottom of every carbon gain/loss component. Our clients like to see how quickly they can payback C emitted due to individual components. This is useful in planning and should be replaced.

Response: This feature has been replaced

CORE INPUT DATA

Cameron Mclver (Cameron Ecology Ltd)

Question: The note on “extra capacity required for backup (%)” suggests there is a choice of % capacity or % output – I’m not clear how you know which you have chosen.

Response: The note is misleading. The number that should be entered is the percentage of the actual output of the windfarm (MWh yr⁻¹) that is required for backup. Text has been added to the note to clarify this.

Stephen Lockett (AECOM)

Question:

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

We have reviewed the guidance but are still unsure of what this variable means. We have used a standard input of 100m but the sheet appears to be extremely sensitive to this variable and we have limited confidence on the value chosen. The note in the cell refers to obtaining data on the ground water level but I am unsure how this relates to extent of drainage around drainage features.

Response: Average extent of drainage around each drainage feature can be measured following the method by Stewart and Lance (1991). In order to determine the extent of drainage, the undrained water table depth, and the 95% confidence interval of the measurements are needed.

Possible approach:

1. Install a series of dipwells or boreholes both upslope and downslope from the drainage feature.
2. In the first instance, assume that all dipwells are from undrained areas of the site. This incorrect assumption is used to initialise the iterative process that calculated the water table depth of the undrained soil.
3. For a particular sampling occasion, calculate the mean water table depth and 95% confidence interval from all the available data.
4. Assume all dipwells with water table depths deeper than the calculated mean water table depth plus the 95% confidence interval are within the area that is drained by a ditch and so exclude these from the calculation.
5. Calculate a new mean water table depth and 95% confidence interval using only data from undrained area.
6. Repeat the process until the calculation of the mean water table depth and 95% confidence interval has stabilised, and no further data points need to be excluded. This gives the water table depth of the undrained soil.
7. The distance from the drain to the first dipwell where the water table depth of the undrained soil occurred (to within the 95% confidence interval) can then be assumed to be the total extent of the drainage impact.

Question: Our drainage strategy is to mimic the existing drainage patterns as closely as possible by intercepting surface run-off and discharging at regular intervals downstream of the tracks back onto natural ground. As such, is there an argument this value could be effectively zero?

Response: No – removing water increases the drainage of the site, and this needs to be accounted for. However, if you are following existing drainage patters, it will be easier to determine the extent of drainage because the drains are already established.

Question: For our example site there is a significant difference in pay back when using site specific and IPCC default values (ranging from 3 to 15 years). Would you be able to provide a brief description of what is being ignored when selecting IPCC default?

Response: The IPCC default takes no account of the previous condition of the site. It provides the result for a typical acid bog or fen across Europe. Therefore, if you are working with an unusually pristine peat or a badly drained peat, you would expect the result to be very different to the average.

Tanya Ogilvy (SEPA)

Question:

Response:

5c. Volume of peat drained

Stephen Lockett (AECOM)

Question: Our new drainage will be surface swales above the ground water table so should not have any effect on the ground water table.

Response: If the surface swales will just convey storm water that would not otherwise have percolated into the soil, these swales will have no impact on the water table of the soil profile, but will only impact the water that would have runoff the surface, causing erosion. However, if the swales also reduce the amount of water entering the soil profile, then they could have an impact on the wetness of the soil. This should really be accounted for in the calculation. However, there is nothing to describe this in the carbon calculator, so you would be justified in neglecting this effect but need to indicate this in the notes.

5e. Emission rates from soils

Stephen Lockett (AECOM)

Question:

Rate of carbon dioxide emission

Response:

We would expect the rate of emission in undrained soil to be worse than the rate in drained soil. This is only the case when the ground water level is very shallow. Does the output define ‘drained soil’ as soil which is being drained by our engineering activities and ‘undrained soil’ as excavated soil which was dry to start with?

I think the confusion comes about due to the definition of terms.

The “drained soil” refers to the soil after it has been drained for the windfarm development. The “undrained soil” refers to the soil before it was drained for the development. This doesn’t refer to the status of the site before the development. Agreed, where a “drained site” refers to a site that has already been drained for a number of years, much of the labile carbon would already have been lost, and so losses due to the windfarm construction would be much less than the losses from an “undrained site” where the peat was still in pristine condition.

Worksheet 5e calculates the rate of emissions of CO2 and CH4 for the soil

1. when drained (ie dry soil);
2. when undrained (ie wet soil).

In a drained (dry) soil, we expect high rates of CO2 emissions and low rates of CH4 emissions.

In an undrained (wet) soil, we expect high rates of CH4 emissions and low rates of CO2 emissions.

These rates are then used in sheet 5d to calculate the net GHG emissions (in CO2 equivalents) attributable to the windfarm development. This is taken as the difference between the losses following drainage for the development and the losses that were occurring before the soil was drained for the development. Because the net emissions are usually higher in the drained (dry) soil than in the undrained (wet) soil, the net emissions due to draining the site usually come out as positive. If we were to compare a “drained site” and an “undrained site” in sheet 5d, the net CO2 emissions calculated for the drained site would be much less than for the undrained site because a smaller volume of soil is being further drained by the development.

CHANGES IN VERSION 2.1.0			
Worksheet	Cells	Change	Thanks to...
Core input data	C31, E31, F31	Redundant input for soil pH removed	Ffion Causer, Natural Power
Forestry input data		Different areas of forestry included	N/A
Construction input data		Different areas of construction included	
1. Windfarm CO2 emission savings		Different areas of forestry included	
2. CO2 loss due to turbine life		Different areas of construction included	
5a. Volume of peat removed		Different areas of construction included	
7ii. Forestry CO2 loss - detail		Different areas of forestry included	
7a. C sequest. in trees (3PG)		Different areas of forestry included	
7d. Wind speed ratios		Different areas of forestry included	

CHANGES IN VERSION 2.2.0			
Worksheet	Cells	Change	Thanks to...
Construction input data	C28, C29....	"Volume cement..." changed to "Volume concrete..."	Marianne Brownlee, Arcus Renewable Energy Consulting Ltd
1. Windfarm CO2 emission saving	F49	=IF(F19=1,365*24*F11*F10*G21/100,SUM(I49,L49,O49,R49,U49)) changed to =IF(D19=1,365*24*F11*F10*G21/100,SUM(I49,L49,O49,R49,U49))	Cameron Mclver, Cameron Ecology Ltd

CHANGES IN VERSION 2.3.0			
Worksheet	Cells	Change	Thanks to...
5a. Volume of peat removed	F23	=IF('Core input data'!C48=1,'Core input data'!C51,'Construction input data'!D17) changed to =IF('Core input data'!C48=1,'Core input data'!C49,'Construction input data'!D17)	Stuart McGowan, Golder Associates
5a. Volume of peat removed	G23,H23	Similar to above	
5a. Volume of peat removed	F24	=IF('Core input data'!C48=1,'Core input data'!C52,'Construction input data'!D18) changed to =IF('Core input data'!C48=1,'Core input data'!C50,'Construction input data'!D18)	
5a. Volume of peat removed	G24,H24	Similar to above	

CHANGES IN VERSION 2.4.0			
Worksheet	Cells	Change	Thanks to...
5c. Volume of peat drained	F33	=(C9+F31+C9)*(C9+F32+C9)-(F31*F32) changed to =IF(F23>0,(C9+F31+C9)*(C9+F32+C9)-(F31*F32),0)	Stuart McGowan, Golder Associates
5c. Volume of peat drained	G33-T33	Similar to above	

CHANGES IN VERSION 2.5.0			
Worksheet	Cells	Change	Thanks to...
7ii. Forestry CO2 loss - detail	F55	=F50*F53/F54 changed to =IF(F50>0,F50*F53/F54,0)	Jenny Sneddon, AMEC
7ii. Forestry CO2 loss - detail	G55-T55	Similar to above	
7ii. Forestry CO2 loss - detail	F46	=IF(F35="Yes", F44*F45, 0) changed to =IF(F35="Yes",IF(F39>0, F44*F45, 0),0)	
7ii. Forestry CO2 loss - detail	G46-T46	Similar to above	
7ii. Forestry CO2 loss - detail	F63	=(F57*'Core input data'!\$E41)-F62 changed to =IF(F55>0,(F57*'Core input data'!\$C41)-F62,0)	
7ii. Forestry CO2 loss - detail	G63-T63	Similar to above	
7ii. Forestry CO2 loss - detail	G38	=Forestry input data'!\$F39 changed to =Forestry input data'!\$H39	
7ii. Forestry CO2 loss - detail	J38,M38,P38,S38	Similar to above	
7ii. Forestry CO2 loss - detail	H38	=Forestry input data'!\$H39 changed to =Forestry input data'!\$F39	
7ii. Forestry CO2 loss - detail	K38,N38,Q38,T38	Similar to above	
7ii. Forestry CO2 loss - detail	D66	=D17+D24+D32-D47-D63 changed to =D17+D24+D32-E47-E63	
7ii. Forestry CO2 loss - detail	G66, J66, M66, P66, S66	Similar to above	
7ii. Forestry CO2 loss - detail	E66	=E17+E24+E32-E47-E63 changed to =E17+E24+E32-D47-D63	
7ii. Forestry CO2 loss - detail	H66, K66, N66, Q66, T66	Similar to above	
5c. Volume of peat drained	C54	=Core input data'!C68 changed to =Core input data'!C70	SEPA

5c. Volume of peat drained	D54, E54	Similar to above
5c. Volume of peat drained	D48	=Core input data!C\$65 changed to =Core input data!E\$65
5c. Volume of peat drained	E48	Similar to above
5c. Volume of peat drained	G33	=IF(G23>0,(\$C9+G31+\$C9)*(\$C9+G32+\$C9)-(G31*G32),0) changed to =IF(G23>0,(\$d9+G31+\$d9)*(\$d9+G32+\$d9)-(G31*G32),0)
5c. Volume of peat drained	J33,M33,P33,S33	Similar to above
5c. Volume of peat drained	H33	=IF(H23>0,(\$C9+H31+\$C9)*(\$C9+H32+\$C9)-(H31*H32),0) changed to =IF(H23>0,(\$eg+H31+\$eg)*(\$eg+H32+\$eg)-(H31*H32),0)
5c. Volume of peat drained	J33,M33,P33,S33	Similar to above

CHANGES IN VERSION 2.6.0

Worksheet	Cells	Change	Thanks to...
Payback Time and CO2 emissions	D33	=D\$31/D9 changed to =D\$31/E9	Sarah Lister, Natural Power
Payback Time and CO2 emissions	D34, D35	Similar to above	
Payback Time and CO2 emissions	E33	=E\$31/E9 changed to =E\$31/D9	
Payback Time and CO2 emissions	E34, E35	Similar to above	
Payback Time and CO2 emissions	D31	=D19+D25 changed to =D19+E25	
Payback Time and CO2 emissions	E31	=E19+E25 changed to =E19+D25	
6. CO2 loss by DOC & POC loss	C11	Contents deleted	Ffion Causer, Natural Power
6. CO2 loss by DOC & POC loss	D11, E11	Similar to above	
6. CO2 loss by DOC & POC loss	C26	=(C9+C12+C13+C14+C15+(C10+C17+C18+C19+C20)/C21)/3.66 changed to =((C9+C12+C13+C14+C15)/3.66)+(((C10+C17+C18+C19+C20)/C21)*(12/16))	
6. CO2 loss by DOC & POC loss	D26, E26	Similar to above	SEPA
Do I need to use this tool		Wording changed to clarify that the tool SHOULD be used with highly organic soils, but COULD also be used with sites undergoing drainage or deforestation	
Core input data	C12	Set to 25 and fixed to comply with planning applications for Section 36 (planning period = 25 years)	
Core input data	Row 25	Average depth of peat at site not used - therefore removed	
1. Windfarm CO2 emission saving	D48	Set to AVERAGE(G48,J48,M48,P48,S48) to ensure a value is provided	Sarah Lister, Natural Power
1. Windfarm CO2 emission saving	E37	24*365*\$D11 changed to 24*365*E11	
1. Windfarm CO2 emission saving	F37-U37	Similar to above	
5e. Emission rates from soils	C34	=C28/(C27*10000) changed to =MAX(C28/(C27*10000),C33)	Ffion Causer, Natural Power
5e. Emission rates from soils	D34, E34	Similar to above	

CHANGES IN VERSION 2.7.0

Worksheet	Cells	Change	Thanks to...
8. CO2 gain - site improvement	C63	=-12*C61/'1. Windfarm CO2 emission saving!\$D54 changed to =-12*C60/'1. Windfarm CO2 emission saving!\$D54	Sarah Lister, Natural Power
	D63-N63	Similar to above	
	C64	=-12*C62/'1. Windfarm CO2 emission saving!\$D54 changed to =-12*C60/'1. Windfarm CO2 emission saving!\$D54	
	D64-N64	Similar to above	
Core input data	C74	Volume of additional peat excavated added to make the calculation more generalised	Rob McCall, Countryside Council for Wales
	E74, G74	Similar to above	
	C75	Area of additional peat excavated added to make the calculation more generalised	
	E75, G75	Similar to above	
5a. Volume of peat removed	Row 64 - 67	Extra lines added to show the additional peat excavated in this sheet	
	C70	=C14+C27+C39+C62 changed to =C14+C27+C39+C62+C65	
	D70, E70	Similar to above	
Core input data	C71	=C13+F26+F38+C61 changed to =C13+F26+F38+C61+C66	Sarah Lister, Natural Power
	B72	"Depth of cable trenches" change to "Average depth of peat cut for cable trenches (m)" to avoid overestimation of peat affected by cable trenches in shallow peats	
Core input data	Row 91	New input: Water table depth in borrow pit before restoration	
	Row 95	New input: Water table depth around foundations and hardstanding before restoration	
8. CO2 gain - site improvement	Row 15	Deleted	
	C15 (previously C16)	=Core input data!C45 changed to =Core input data!C91	
	I15, M15	Similar to above	
	D15 (previously D16)	=Core input data!C50 changed to =Core input data!C95	

5d. CO2 loss from drained peat	J15, N15	Similar to above	University of Aberdeen
	C43	=C8*(C35+C36)*((C42*C34))/365 changed to =C8*(C35+C36)*((C42*(365-C34)))/365	
	D43, E43	Similar to above	

CHANGES IN VERSION 2.7.2

Worksheet	Cells	Change	Comment	Thanks to...
8. CO2 gain - site improvement	C13	=Core input data!C8o changed to =IF('Core input data!C81>'Core input data!C82,'Core input data!C8o,o)		Ffion Causer, Natural Power
	G13, K13	Similar to above		
	D13	=Core input data!C85 changed to =IF('Core input data!C86>'Core input data!C87,'Core input data!C85,o)		
	H13,L13	Similar to above		
	E13	=Core input data!C9o changed to =IF('Core input data!C91>'Core input data!C92,'Core input data!C9o,o)		
	I13, M13	Similar to above		
	F13	=5c. Volume of peat drained!C34/10000 changed to =IF('Core input data!C95>'Core input data!C96,'5c. Volume of peat drained!C34/10000,o)		
	J13, N13	Similar to above		

CHANGES IN VERSION 2.8.0

Worksheet	Cells	Change	Comment	Thanks to...
5c. Volume of peat drained	Rows 67 - 76	Inserted rows to included additional excavated peat in volume of peat drained	Include additional excavated peat in volume of peat drained	Susana Sebastian, SEPA
	C67-C68; D67-D68; E67-E68	Title lines		
	C69	=Core input data!C74		
	D69,E69	Similar to above		
	C70	=Core input data!C75		
	D70,E70	Similar to above		
	C71	=IF(C70>0,C69/C70,o)		
	D71,E71	Similar to above		
	C72	=SQRT(C70/PI())		
	D72,E72	Similar to above		
	C73	=C72+C9		
	D73,E73	Similar to above		
	C74	=(PI()*C73*C73)-C7o		
	D74,E74	Similar to above		
	C75	=C74*C71		
	D75,E75	Similar to above		
	C79	=C18+C34+C57+C64 changed to =C18+C34+C57+C64+C74		
	D79,E79	Similar to above		
	C8o	=C19+C35+C58+C65 changed to =C19+C35+C58+C65+C75		
	D8o,E8o	Similar to above		
7ii. Forestry CO2 loss - detail	F62	=F6o*F61 changed to =F6o*F61*F55	Calculation of emissions associated to the transport of wood to biomass plant should account for number of trips to plant	Susana Sebastian, SEPA
Forestry input data	G62-T62	Similar to above		
Core input data	C23	Units changed from g CO2 km ⁻¹ to g CO2 km ⁻¹ t ⁻¹		
8. CO2 gain - site improvement	Row 25	Insert input for average depth of peat at site	Limit improvements following restoration to the depth of the peat	Susana Sebastian, SEPA
	Row 15	Insert average depth of peat at site		
	C15	=Core input data!C25		
	D15-N15 (excl. E15, I15 & M15)	Similar to above		
	E15	=Core input data!C46		
	I15,M15	Similar to above		
	C16	Core input data!C82 changed to =IF('Core input data!C82<C15,'Core input data!C82,C15)		

	D16-N16 C17 D17-N17 C21 D21-N21	Similar to above ='Core input data'!C83 changed to =IF('Core input data'!C83<C15,'Core input data'!C83,C15) Similar to above C12-C20 changed to =IF(C12-C20>0,C12-C20,0) Similar to above		
Core input data 8. CO2 gain - site improvement	Rows 85, 91, 97 C12 D12-N12 (excl. E12, I12 & M12)	Insert period of time when the improvement can be guaranteed to work (years) ='Core input data'!C12 changed to =IF('Core input data'!C85 Similar to above	Improvements in C sequestration should continue for as long as the improvement can be guaranteed.	Rob McCall, NRW
Payback Time and CO2 emissions	Row 37 C37 D637,E37	Insert ratio of soil carbon loss to gain by restoration =IF(C26<0,-(C17+C18)/C26,0) Similar to above	Include calculation of ratio of soil losses to gains	Rob McCall, NRW
Payback Time and CO2 emissions	Row 38 C38 D637,E37	Insert ratio of C emissions to power generation =((C20+C26)*1000000)/(C12*1000) Similar to above	Include calculation of C emissions to power generation	Susana Sebastian, SEPA
5. Loss of soil CO2 5e. Emission rates from soils	D11 E11 D31 E31 D33 E33	=D8+D9 changed to =MIN(D8+D9,E8+E9) =E8+E9 changed to =MAX(D8+D9,E8+E9) ='Core input data'!E24 changed to =IF('Core input data'!G24 ='Core input data'!G24 changed to =IF('Core input data'!E24 ='Core input data'!E28 changed to =IF('Core input data'!G28 ='Core input data'!G28 changed to =IF('Core input data'!E28	Correct use of minimum and maximum wrt water table depth at very low depths	Peter Batten
8. CO2 gain - site improvement	G17 H17-J17 K17 L17-N17	=IF('Core input data'!E83<G15,'Core input data'!E83,G15) changed to =IF('Core input data'!G83<G15,'Core input data'!G83,G15) Similar to above =IF('Core input data'!G83<K15,'Core input data'!G83,K15) changed to =IF('Core input data'!E83<K15,'Core input data'!E83,K15) Similar to above	Correct use of minimum and maximum depth of water table after restoration	Jo Smith, University of Aberdeen
8. CO2 gain - site improvement	G12 H12-J12 K12 L12-N12	=IF('Core input data'!E85 changed to =IF('Core input data'!G85 Similar to above ='Core input data'!G85 changed to =IF('Core input data'!E85 Similar to above	Correct use of min/max period when restoration can be restored	Jo Smith, University of Aberdeen
8. CO2 gain - site improvement	C34 D34-N34 C53 D53-N53	=IF('Core input data'!\$C\$112=2,'8. CO2 gain - site improvement'!C30,'8. CO2 gain - site improvement'!C32) changed to =IF('Core input data'!\$C\$112=2,IF('Core input data'!\$C\$23=1,C30,C31),IF('Core input data'!\$C\$23=1,C32,C33)) Similar to above =IF('Core input data'!\$C\$112=2,'8. CO2 gain - site improvement'!C49,'8. CO2 gain - site improvement'!C51) changed to =IF('Core input data'!\$C\$112=2,IF('Core input data'!\$C\$23=1,C49,C50),IF('Core input data'!\$C\$23=1,C51,C52)) Similar to above	Correct selection of emission factor when soil type is fen	Elizabeth Keen, Peter Brett Associates LLP

CHANGES IN VERSION 2.9.0

Worksheet	Cells	Change	Comment	Thanks to...
Core input data	B94 B95	"Water table depth in borrow pit before restoration (m)" changed to "Depth of water table in borrow pit before restoration with respect to the restored surface (m)" "Water table depth in borrow pit after restoration (m)" changed to "Depth of water table in borrow pit after restoration with respect to the restored surface (m)"	Confusing wording as water table depth may always be entered as zero.	Clare Wharmby - Carbon Forecast
8. CO2 gain - site improvement	C47 D47-N47	=(23*16/12)*C13*C40*C46*(C19/365) changed to =(23*16/12)*C13*C40*C46*(C38/365) Similar to above	Error in formula using the improved flooded period instead of the unimproved flooded period	Elizabeth Keen - Peter Brett Associates
7c. Average stand data	Rows 13-29 Rows 168-86	Stand data extended from 17 year to 0 years Similar to above	If forest stand is less than 17 years old, the calculations fail	Brenda Park - AMEC
7ii. Forestry CO2 loss - detail	F31	=IF (F29>0,IF(F27="Deep Peat",(VLOOKUP(F29,7c. Average stand data'!\$D\$87:\$G\$118,3)),(VLOOKUP(F29,7c. Average stand data'!\$D\$30:\$G\$63,3))))),0) changed to =IF(F29>0,IF(F27="Deep Peat",(VLOOKUP(F29,7c. Average stand data'!\$D\$68:\$G\$118,3)),		

7ii. Forestry CO2 loss - detail	G31-T31	Similar to above		
	G35	=IF('Forestry input data'!\$F\$33=1,"Yes", "No") changed to =IF('Forestry input data'!\$D\$33=1,"Yes", "No")	Use of felled wood as biofuel not correctly read in min and max calculations	Jo Smith - University of Aberdeen
7ii. Forestry CO2 loss - detail	H35,J35,K35,M35,N35,P35,Q35,S35,T35	Similar to above		
	F16	=7a. C sequest. in trees (3PG)!\$F\$24 changed to =IF(F12>0,7a. C sequest. in trees (3PG)!\$F\$24,0)	Avoid #NA	Claire Frost - AECOM
Forestry input data	G16-T16	Similar to above		
	Note: Emissions from felling and timber removal.	"the emissions are 6657 g CO ₂ m ⁻³ " changed to "the emissions are 6675 g CO ₂ m ⁻³ "		Jonathon Davison - Mott MacDonald
Forestry input data	Note: Emissions associated with transportation	"3933000 g CO ₂ km ⁻¹ (range 3850000 – 4015000 g CO ₂ km ⁻¹ - average = 39.33 g CO ₂ km ⁻¹ t ⁻¹)" changed to "39.33 g CO ₂ km ⁻¹ t ⁻¹ (range 38.5 – 40.15 g CO ₂ km ⁻¹ t ⁻¹ - average = 39.33 g CO ₂ km ⁻¹ t ⁻¹)"		Jonathon Davison - Mott MacDonald
Payback Time and CO2 emissions	C37	=IF(C26<0,-(C17+C18)/C26,"No gains!")	Ensure no restoration is highlighted as no gains rather than appearing	Sarah Lister, Natural Power
	D637,E37	Similar to above		
Payback Time and CO2 emissions	C38	=((12/44)*(C20+C26)*1000000)/(C12*1000)	Express ratio as CO2 rather than C emissions to power generation	Sarah Lister, Natural Power
	D637,E37	Similar to above		

CHANGES IN VERSION 2.10.0

Worksheet	Cells	Change	Comment	Thanks to...
8. CO2 gain - site improvement	K13	=IF('Core input data'!G82>'Core input data'!G83,'Core input data'!G81,0) changed to =IF('Core input data'!G82>'Core input data'!E83,'Core input data'!G81,0)	Change to correct test for improvement in restored area.	Sarah Lister, Natural Power
	L13-N13	Similar to above		
	G13	=IF('Core input data'!E82>'Core input data'!E83,'Core input data'!E81,0) changed to =IF('Core input data'!E82>'Core input data'!G83,'Core input data'!E81,0)		
Payback Time and CO2 emissions	H13-J13	Similar to above		
	B22	"8a. Gains due to improvement of degraded bogs" changed to "8a. Change in emissions due to improvement of degraded bogs"	Confusion over labelling of "gains" due to restoration and improvement	Sarah Lister, Natural Power
	B23 - B26	Similar to above		
1. Windfarm CO2 emission saving	D38	=((D20+D26)*1000000)/(D12*1000) changed to =(D32*1000)/(E12)	Error in min / max calculation	Peter Batten
	C38, E38	Similar to above		
	H39	=('Forestry input data'!\$F28 changed to =G39	The power curve code for Min and Max were not correctly retrieved, because the dropdowns located in the tab Forestry Input Data cells F28 and H28 do not have any value associated to them.	Carlos Ruiz, SEPA
	I39-U39	Similar to above		
	H40	=OFFSET(\$D\$24,H39,1) changed to =OFFSET(\$D\$24,H39,2)	Column in offset incorrectly specified	
	I40-U40	Similar to above		
	H44	=OFFSET(\$D\$24,H39,4) changed to =OFFSET(\$D\$24,H39,5)	Column in offset incorrectly specified	
	I40-U40	Similar to above		
	G49	=24*365*G11*G10*G48/100 changed to =IF(G10<=0,0,24*365*G11*G10*G48/100)		
	H48-U49	Similar to above	Incorrect calculation of annual energy output when less than 5 areas of forestry included.	

2. CO2 loss due to turbine life	C19-T19	0.173 changed to 0.316		The emission rate of 173kg/m3 is the rate for "mass foundations". However foundations for wind turbines are reinforced, so the rate is changed to that for Reinforced Foundations, and revised to the new emission rate, from the Table 7 in http://www.concretecentre.com/sustainability/energy_efficiency/embodied_co2.aspx Direct input of emissions includes cement already	Carlos Ruiz, SEPA
	C23	=IF('Core input data'!\$C\$20=1,\$C9+C20,\$C13+C20) changed to =IF('Core input data'!\$C\$20=1,\$C9,\$C13+C20)			
5a. Volume of peat removed	D23-E23	Similar to above		Error in formula	Carlos Ruiz, SEPA
	F26	=F20*((F23*F24)+(F22*(F21-F23)/2)+(F21*(F22-F24)/2)+((F21-F23)*(F22-F24))/2) changed to =IF(F25>0,(F20*(F25/3 * (F21*F22 + F23*F24 + SQRT(F21*F22*F23*F24))))/F25,0)			
5c. Volume of peat drained	G26-T26	Similar to above			Carlos Ruiz, SEPA
	C34	=C33*C23 changed to =F34+I34+L34+O34+R34			
	D34-T34	Similar to above			
	C55	=('Core input data'!C70 changed to =C52*(C9+C9)			
	D55-E55	Similar to above			
	C73 D73-E73	=C72+C9 changed to =IF(C70>0,C72+C9,0) Similar to above			
5d. CO2 loss from drained peat	C43	=C8*(C35+C36)*((C42*(365-C34))/365 changed to =C8*(C35+C36)*(((C42*C34)/365)+(C29*(365-C34)/365))	Accounts for emissions during both flooded and unflooded times of the year in an undrained soil	Protection against unusual conditions that result in incorrect order for min and max calculations	Carlos Ruiz, SEPA
	D43,E43 C40	Similar to above =C8*(C35+C36)*C39*((C38*C34))/365 changed to =C8*(C35+C36)*C39*(((C38*C34)/365)+(C25*(365-C34)/365))			
	D40,E40 D50	Similar to above =D47-D48 changed to =IF(D47-D48<E47-E48,D47-D48,E47-E48)			
	E50	Similar to above			
5e. Emission rates from soils	D31	=('Core input data'!G24 changed to =('Core input data'!E24	Correction from previous min/max change		Carlos Ruiz, SEPA
	E31	=('Core input data'!E24 changed to =('Core input data'!G24			
Core input data	C103 E103, G103, C107, E107, G107	=IF(C105=2,IF(C106=2,2,1),1) changed to =IF(C105>1,IF(C106>1,2,1),1) Similar to above			Carlos Ruiz, SEPA
7a. C sequest. in trees (3PG)	E24	=AVERAGE(F24,I24,L24,O24,R24) changed to =AGGREGATE(1,6,F24,I24,L24,O24,R24)	Correction to avoid error when some areas of forestry are not filled.		Carlos Ruiz, SEPA
	F24, G24, E25-G25, E26-G26	Similar to above			
	F25 G25-T25	=VLOOKUP(F15,\$C62:\$AQ212,9,TRUE) changed to =VLOOKUP(F15,\$B62:\$AQ212,10,TRUE) Similar to above	Correction to formula so that it looks in the age column		
	F26	=SUM(OFFSET(((INDIRECT(ADDRESS(MATCH(F19,\$B62:\$B112,0)+61,9,4))))),0,1, F19,1)) changed to =SUM(OFFSET(((INDIRECT(ADDRESS(MATCH(F18,\$B62:\$B112,0)+61,9,4))))),0,1, F19,1))	Change to correct lookup of net primary production of replanted forestry		
	G26-T26	Similar to above			
7d. Wind speed ratios	Insert row 9	Years after planting when felling occurs	Changes to calculate final height of		Carlos Ruiz, SEPA

	C9	=Forestry input data!D41		
	D9-Q9	Similar to above		replanted forestry by accounting for years after felling when replanting occurs and age of seedlings as well as lifetime of windfarm - previously only accounted for lifetime of windfarm.
	Insert row 10	Age of seedlings on plant (yr)		
	C10	=Forestry input data!D42		
	D10-Q10	Similar to above		
	C21	=VLOOKUP(C11,'7c. Average stand data'!\$D\$30:\$H\$63,2,TRUE) changed to =VLOOKUP(C11-C9+C10,'7c. Average stand data'!\$D\$30:\$H\$63,2,TRUE)		
	D21-Q21	Similar to above		
	C22	=OFFSET('7c. Average stand data'!\$D30,C8-'7c. Average stand data'!\$D30+C11,1,1) changed to =IF(C8+C11<=50,OFFSET('7c. Average stand data'!\$D30,C8-'7c. Average stand data'!\$D30+C11,1,1),OFFSET('7c. Average stand data'!\$D30,C8-'7c. Average stand data'!\$D30+C11-50+C10-C9,1,1))	Change to allow for normal harvesting of forestry during the lifetime of the windfarm	
	D22-Q22	Similar to above		
	C52	=IF((0.75+0.03*(LN(C43/C44)))*C44*POWER(C18/C44,0.8)+C46<C49,(0.75+0.03*(LN(C43/C44)))*C44*POWER(C18/C44,0.8)+C46,C49) changed to =IF((0.75+0.03*(LN(C42/C44)))*C44*POWER(C18/C44,0.8)+C46<C49,(0.75+0.03*(LN(C42/C44)))*C44*POWER(C18/C44,0.8)+C46,C49)	Changes to correct formula for height of new internal boundary layer over forest - previously used roughness of group in gap instead of roughness of ground in forested area	
	D52-Q52	Similar to above		
	C54	=IF((0.75+0.03*LN(C44/C43))*C45*POWER(C19/C21,0.8)+C47<C49,(0.75+0.03*LN(C44/C45))*C45*POWER(C19/C45,0.8)+C47,C49) changed to =IF((0.75+0.03*LN(C44/C45))*C45*POWER(C19/C45,0.8)+C47<C49,(0.75+0.03*LN(C44/C45))*C45*POWER(C19/C45,0.8)+C47,C49)	Changes to correct the calculation of height of boundary layer in replanted area	
	D54-Q54	Similar to above		
Construction input data	C13	"Depth of hole dug when constructing foundations (m)" changed to "Average depth of peat removed when constructing foundations (m)"	Changes in wording to improve clarity of input data	Carlos Ruiz, SEPA
	C20, C34, C41, C55, C62, C76, C83, C97, C104	Similar to above		
1. Windfarm CO2 emission saving	H17	=Core input data!\$C\$41 changed to =Core input data!\$E\$41	Correction of error	Carlos Ruiz, SEPA
	D48	=AVERAGE(G48,J48,M48,P48,S48) changed to =AGGREGATE(1,6,G48,J48,M48,P48,S48)	Changes to average capacity factor only over forestry areas that have valid data	Jo Smith, University of Aberdeen
	E48,F48	Similar to above		
2. CO2 loss due to turbine life	D9	=Core input data!E21*D12*Core input data!E14*1. Windfarm CO2 emission saving!D48/100 changed to =Core input data!E21*D12*Core input data!E14*1. Windfarm CO2 emission saving!E48/100	Changed so that minimum and maximum emission factors are used	Carlos Ruiz, SEPA
	E9	Similar to above		
Forestry input data	F31	Dropdown menu linked to cell D31	Change to set soil type in forestry areas of exp., min and max to same value	Carlos Ruiz, SEPA
	H31	Similar to above		
	F50	Dropdown menu linked to cell D50		
	H50	Similar to above		
	F69	Dropdown menu linked to cell D69		
	H69	Similar to above		
	F88	Dropdown menu linked to cell D88		
	H88	Similar to above		
	F107	Dropdown menu linked to cell D107		
	H107	Similar to above		
7ii. Forestry CO2 loss - detail	F37	=7a. C sequest. in trees (3PG)!\$F\$25 changed to =7a. C sequest. in trees (3PG)!F\$25	Change to correctly reference different forestry areas	Carlos Ruiz, SEPA
	G37-T37	Similar to above		
	F52	=7a. C sequest. in trees (3PG)!\$F19 changed to =7a. C sequest. in trees (3PG)!F19		
	G52-T52	Similar to above		
	F53	=7a. C sequest. in trees (3PG)!F26 changed to =7a. C sequest. in trees (3PG)!\$F26		
	G53-T53	Similar to above		
	I38	=Forestry input data!\$D39 changed to =Forestry input data!\$D58	Change to refer to different forestry areas	
	J38-T38	Similar to above		
	D61	=Forestry input data!\$D23/1000000 changed to =Forestry input data!\$F23/1000000	Change to reference the correct cell	

	G61,J61,M61,P61,S61 E61 H61,K61,N61,Q61,T61 G63 H83-T63	Similar to above ='Forestry input data!\$D23/1000000 changed to ='Forestry input data!\$H23/1000000 Similar to above =IF(G55>0,(G57*'Core input data!\$C41)-G62,o) changed to =IF(G55>0,(G57*'Core input data!\$E41)-G62,o) Similar to above		
Core input data	E23 G23	Menu linked to cell C23 Similar to above	Change to allow only one soil type	Carlos Ruiz, SEPA
8. CO2 gain - site improvement	D62 E62-N62;D63-N63;D64-N64	=-12*D60/'1. Windfarm CO2 emission saving!\$D53 changed to =-12*D60/'1. Windfarm CO2 emission saving!\$E53 Similar to above	Change to allow use of different counterfactual emission factors	Carlos Ruiz, SEPA

CHANGES IN VERSION 2.11.0

Worksheet	Cells	Change	Comment	Thanks to...
5e. Emission rates from soils	D21 E21 D22,E22,D23,E23	=IF('Core input data!D23=1,D11,D16) changed to =IF('Core input data!C23=1,D11,D16) =IF('Core input data!E23=1,D11,D16) changed to =IF('Core input data!C23=1,D11,D16) Similar to above		Peter Batten

CHANGES IN VERSION 2.12.0

Worksheet	Cells	Change	Comment	Thanks to...
Core input data	C27,E27,G27	Cell validated to be between 0.01 and 1000	Avoids incorrect entry of zero for extent of drainage	Carlos Ruiz, SEPA
Payback and CO2 emissions	C37 D37 E37	=IF(C26>0,(C17+C18)/C26,"No gains!") changed to =IF(C26>0,(C17+C18)/C26,"No gains!") =IF(D26<0,-(D17+D18)/D26,"No gains!") changed to Similar to D37	Error introduced by change in sign of C26 Error introduced by change in sign of D26 plus correction in use of minimum and maximum values	 Alexa Morrison, RSPB
2. CO2 loss due to turbine life	C9,D9,E9	= 'Core input data!C21*C12*'Core input data!C14*'1. Windfarm CO2 emission saving!D48/100 to = 'Core input data!C21*C12*'Core input data!C14	Corrected to remove dependence on capacity factor	Clare Wharmby

CHANGES IN VERSION 2.13.0

CHANGES MADE BY SEPA - REPLICATED IN VERSION 2.14

CHANGES IN VERSION 2.14.0

Worksheet	Cells	Change	Comment	Thanks to...
5a. Volume of peat removed	F37 G37,H37 I37 J37 - T37	=IF(\$C\$31=1,'Core input data!C54,'Construction input data!D13) -> =IF(\$C\$31=1,'Core input data!C54,'Construction input data!D20) Similar to above =IF(\$C\$31=1,0,'Construction input data!\$D34) -> =IF(\$C\$31=1,0,'Construction input data!D41) Similar to above	Correction to use depth of hardstanding instead of depth of foundations	Clare Wharmby - Carbon Forecast