APPENDIX 10-1

CARBON CALCULATIONS

Payback Time

1. Windfarm CO_2 emission saving over...	Exp.	Min.	Max.
...coal-fired electricity generation (t CO_2 / yr)	84,904	84,661	85,146
...grid-mix of electricity generation (t CO_2 / yr)	23,402	23,335	23,469
...fossil fuel-mix of electricity generation (t CO_2 / yr)	41,529	41,410	41,648
Energy output from windfarm over lifetime (MWh)	2,768,598	2,300,573	2,776,508

Total CO_2 losses due to wind farm (tCO_2 eq.)	Exp.	Min.	Max.
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	26,115	25,957	26,273
3. Losses due to backup	17,798	14,832	17,798
4. Lossess due to reduced carbon fixing potential	460	149	779
5. Losses from soil organic matter	524	-2,486	22,638
6. Losses due to DOC & POC leaching	0	0	0
7. Losses due to felling forestry	6,463	5,133	6,919

8. Total CO_2 gains due to improvement of site (t CO_2 eq.)	Exp.	Min.	Max.
8a. Change in emissions due to improvement of degraded bogs	0	0	0
8b. Change in emissions due to improvement of felled forestry	0	0	0
8c. Change in emissions due to restoration of peat from borrow pits	0	0	0
8d. Change in emissions due to removal of drainage from foundations & hardstanding	0	0	0
Total change in emissions due to improvements	0	0	0

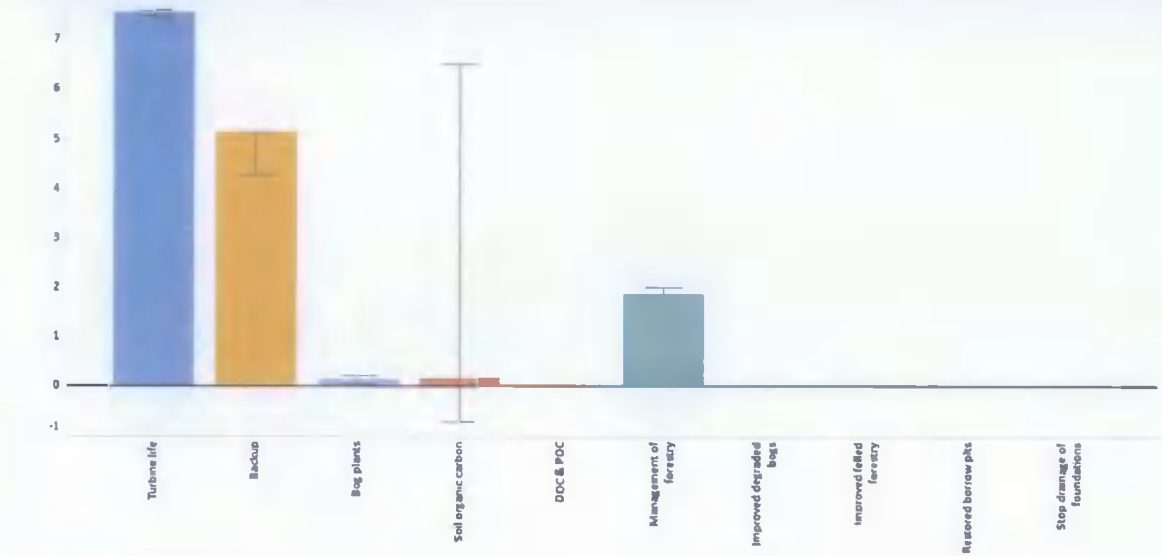
RESULTS	Exp.	Min.	Max.
Net emissions of carbon dioxide (t CO_2 eq.)	51,361	43,586	74,407

Carbon Payback Time			
...coal-fired electricity generation (years)	0.6	0.5	0.9
...grid-mix of electricity generation (years)	2.2	1.9	3.2
...fossil fuel-mix of electricity generation (years)	1.2	1.0	1.8

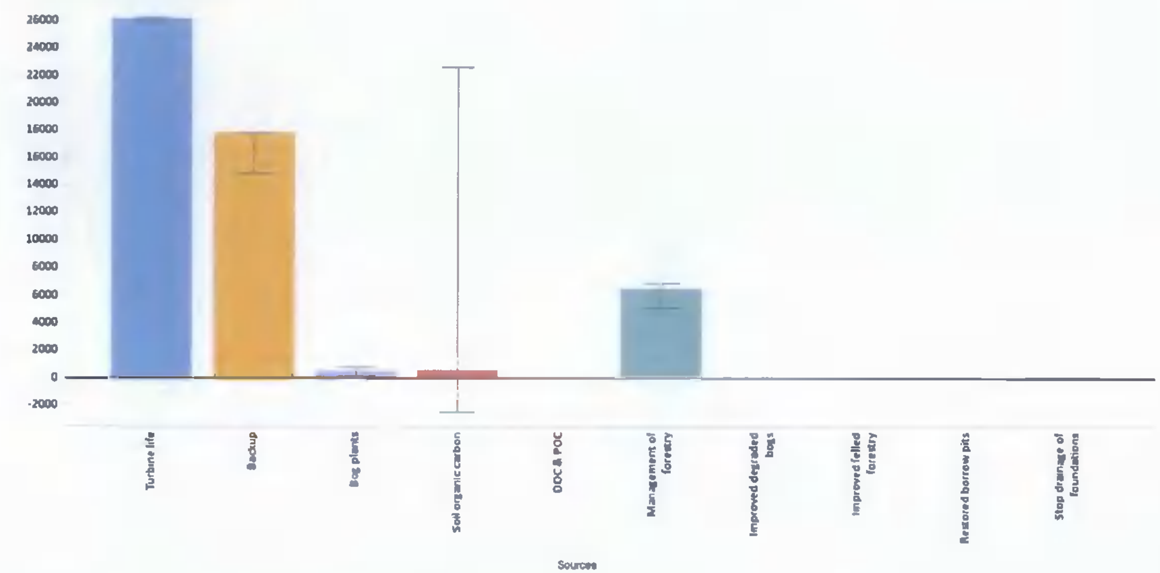
Payback Time - Charts

Edit input | New app

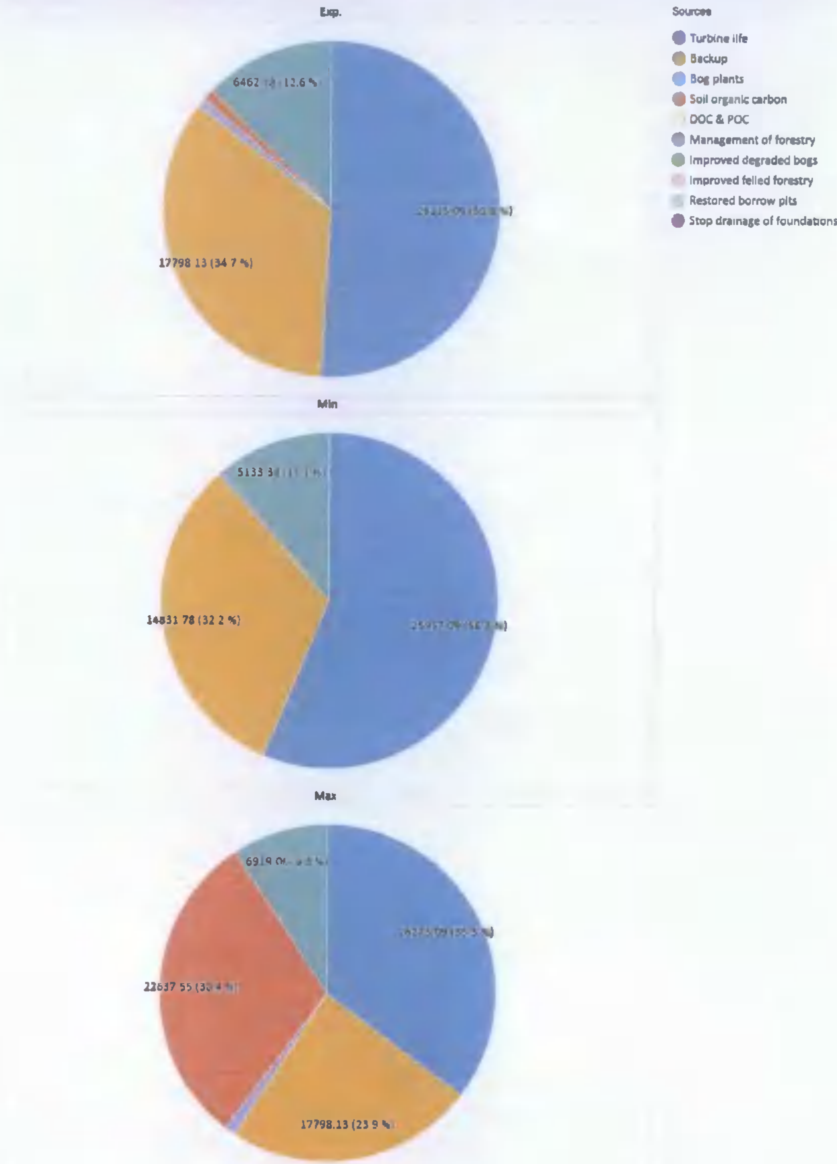
Carbon payback time (months) using fossil-fuel mix as conterfactual



Greenhouse gas emissions (t CO2 eq.)



Proportions of greenhouse gas emissions from different sources



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Core input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Windfarm characteristics				
Dimensions				
No. of turbines	7	7	7	Chapter 4 - Description
Duration of consent (years)	30	25	30	Chapter 4 - Description
Performance				
Power rating of 1 turbine (MW)	4.3	4.3	4.3	Chapter 4 - Description
Capacity factor	35	34.9	35.1	Chapter 4 - Description
Backup				
Fraction of output to backup (%)	5	5	5	SNH Carbon Calculator Guidance
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10	10	10	Fixed
Total CO2 emission from turbine life ($tCO2\ MW^{-1}$) (eg. manufacture, construction, decommissioning)	Calculate wrt installed capacity	Calculate wrt installed capacity	Calculate wrt installed capacity	
Characteristics of peatland before windfarm development				
Type of peatland	Acid bog	Acid bog	Acid bog	Ch 11 Air & Climate
Average annual air temperature at site (°C)	9.9	5.6	15	Ch 11 Air & Climate
Average depth of peat at site (m)	0.4	0.01	2	Geotechnical & Peat Stability Assessment Report
C Content of dry peat (% by weight)	55	50	60	Default value used
Average extent of drainage around drainage features at site (m)	15	5	20	Drainage Drawings
Average water teble depth at site (m)	0.5	0.1	1	Drainage Drawings
Dry soil bulk density ($g\ cm^{-3}$)	0.1	0.09	0.11	Default value of 0.1 used
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	10	5	15	Best practice in raised bog restoration in Ireland
Carbon accumulation due to C fixation by bog plants in undrained peats ($tC\ ha^{-1}\ yr^{-1}$)	0.25	0.2	0.3	SNH Guidance default value

5. Loss of soil CO2 (a, b)

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

5. Loss of soil C02

	Exp.	Min.	Max.
CO2 loss from removed peat (t CO2 equiv.)	524.28	-2485.82	14336.89
CO2 loss from drained peat (t CO2 equiv.)	0	0	8300.66
RESULTS			
Total CO2 loss from peat (removed + drained) (t CO2 equiv.)	524.28	-2485.82	22637.55
Additional CO2 payback time of windfarm due to loss of soil C...			
...coal-fired electricity generation (months)	0.07	-0.35	3.19
...grid-mix of electricity generation (months)	0.27	-1.28	11.57
...fossil fuel - mix of electricity generation (months)	0.15	-0.72	6.52

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

5b. CO2 loss from removed peat

	Exp.	Min.	Max.
CO2 loss from removed peat (t CO2)	3649.13	297.23	17654.42
CO2 loss from undrained peat left in situ (t CO2)	3124.85	2783.05	3317.53
RESULTS			
CO2 loss atributable to peat removal only (t CO2)	524.28	-2485.82	14336.89

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

5a. Volume of peat removed

	Exp.	Min.	Max.
Peat removed from borrow pits			
Area of land lost in borrow pits (m2)	10500	10500	10500
Volume of peat removed from borrow pits (m3)	4725	105	21000
Peat removed from turbine foundations			
Area of land lost in foundation (m2)	2268	2268	2268
Volume of peat removed from foundation area (m3)	907.2	22.68	4536
Peat removed from hard-standing			
Area of land lost in hard-standing (m2)	17325	17325	17325
Volume of peat removed from hard-standing area (m3)	8662.5	173.25	34650
Peat removed from access tracks			
Area of land lost in floating roads (m2)	500	495	505
Volume of peat removed from floating roads (m3)	500	445.5	555.5
Area of land lost in excavated roads (m2)	5500	5495	5505
Volume of peat removed from excavated roads (m3)	2200	54.95	11010
Area of land lost in rock-filled roads (m2)	0	0	0
Volume of peat removed from rock-filled roads (m3)	0	0	0
Total area of land lost in access tracks (m2)	6000	5990	6010
Total volume of peat removed due to access tracks (m3)	2700	500.45	11565.5
RESULTS			
Total area of land lost due to windfarm construction (m2)	41953	41933	41973
Total volume of peat removed due to windfarm construction (m3)	18094.7	1801.38	72951.5

5. Loss of soil CO_2 (c,d,e)

Volume of peat drained

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

5c. Volume of peat drained

	Exp.	Min.	Max.
Total area affected by drainage around borrow pits (m2)	10950	3250	15400
Total volume affected by drainage around borrow pits (m3)	2463.75	16.25	15400
Peat affected by drainage around turbine foundation and hardstanding			
Total area affected by drainage of foundation and hardstanding area (m2)	34860	10220	49280
Total volume affected by drainage of foundation and hardstanding area (m3)	8715	51.1	49280
Peat affected by drainage of access tracks			
Total area affected by drainage of access track(m2)	33000	10990	44040
Total volume affected by drainage of access track(m3)	6600	54.95	44040
Peat affected by drainage of cable trenches			
Total area affected by drainage of cable trenches(m2)	0	0	0
Total volume affected by drainage of cable trneches(m3)	0	0	0
Drainage around additional peat excavated			
Total area affected by drainage (m2)	4777.33	1434.21	6688.56
Total volume affected by drainage (m3)	896.77	244.33	1372.01
RESULTS			
Total area affected by drainage due to windfarm (m2)	83587.33	25894.21	115408.56

CO_2 loss due to drainage

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

5d. CO2 loss from drained peat

	Exp.	Min.	Max.
Calculations of C Loss from Drained Land if Site is NOT Restored after Decomissioning			
Total GHG emissions from Drained Land (t CO2 equiv.)	3766.26	60.49	26642.51
Total GHG emissions from Undrained Land (t CO2 equiv.)	3766.26	60.49	18341.85
Calculations of C Loss from Drained Land if Site IS Restored after Decomissioning			
Losses if Land is Drained			
CH4 emissions from drained land (t CO2 equiv.)	-7.05	-40.27	259.1
CO2 emissions from drained land (t CO2)	6233.01	1758.84	12990.88
Total GHG emissions from Drained Land (t CO2 equiv.)	3766.26	60.49	26642.51
Losses if Land is Undrained			
CH4 emissions from undrained land (t CO2 equiv.)	-7.05	-40.27	1389.64
CO2 emissions from undrained land (t CO2)	6233.01	1758.84	7732.22
Total GHG emissions from Undrained Land (t CO2 equiv.)	3766.26	60.49	18341.85
RESULTS			
Total GHG emissions due to drainage (t CO2 equiv.)	0	0	8300.66

Emission rates from soils

Nota, CO2 losses are calculated using two approaches: IPCC default methodology and more sita 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

5e. Emission rates from soils

	Exp.	Min.	Max.
Calculations following IPCC default methodology			
Flooded period (days/year)	178	178	178
Annual rate of methane emission (t CH4-C/ha year)	0.04	0.04	0.04
Annual rate of carbon dioxide emission (t CO2/ha year)	35.2	35.2	35.2

7. Forestry CO2 loss

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

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

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

	Exp.	Min.	Max.
Area of forestry plantation to be felled (ha)	16.32	16	17
Carbon sequestered (t C ha-1 yr-1)	3.6	3.5	3.7
Lifetime of windfarm (years)	30	25	30
Carbon sequestered over the lifetime of the windfarm (t C ha-1)	108	87.5	111
RESULTS			
Total carbon loss due to felling of forestry (t CO2)	6462.78	5133.38	6919.06
Additional CO2 payback time of windfarm due to management of forestry			
...coal-fired electricity generation (months)	0.91	0.73	0.98
...grid-mix of electricity generation (months)	3.31	2.64	3.54
...fossil fuel - mix of electricity generation (months)	1.87	1.49	1.99

8. CO2 gain - site improvement

Gains due to site improvement

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

Degraded Bog

	Exp.	Min.	Max.
1. Description of site			
Area to be improved (ha)	0	0	0
Depth of peat above water table before improvement (m)	0	0	0
Depth of peat above water table after improvement (m)	0	0	0
2. Losses with improvement			
Improved period (years)	0	0	0
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.498	0.483	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.508	-0.635	1.865
CO2 emissions from improved land (t CO2 equiv.)	0	0	0
Total GHG emissions from improved land (t CO2 eqiv.)	0	0	0
3. Losses without improvement			

Felled Forestry

	Exp.	Min.	Max.
1. Description of site			
Area to be improved (ha)	0	0	0
Depth of peat above water table before improvement (m)	0	0	0
Depth of peat above water table after improvement (m)	0	0	0
2. Losses with improvement			
Improved period (years)	0	0	0
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.498	0.483	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.508	-0.635	1.865
CO2 emissions from improved land (t CO2 equiv.)	0	0	0
Total GHG emissions from improved land (t CO2 eqiv.)	0	0	0
3. Losses without improvement			

Borrow Pits

	Exp.	Min.	Max.
1. Description of site			
Area to be improved (ha)	0	0	0
Depth of peat above water table before improvement (m)	0	0	0
Depth of peat above water table after improvement (m)	0	0	0
2. Losses with improvement			
Improved period (years)	0	0	0
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.498	0.483	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.508	-0.635	1.865
CO2 emissions from improved land (t CO2 equiv.)	0	0	0
Total GHG emissions from improved land (t CO2 eqiv.)	0	0	0
3. Losses without improvement			

Foundations & Hardstanding

	Exp.	Min.	Max.
1. Description of site			
Area to be improved (ha)	0	0	0
Depth of peat above water table before improvement (m)	0	0	0
Depth of peat above water table after improvement (m)	0	0	0
2. Losses with improvement			
Improved period (years)	30	25	30
Selected annual rate of methane emissions (t CH4-C ha-1 yr-1)	0.498	0.483	0.516
CH4 emissions from improved land (t CO2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO2 ha-1 yr-1)	0.508	-0.635	1.865
CO2 emissions from improved land (t CO2 equiv.)	0	0	0
Total GHG emissions from improved land (t CO2 eqiv.)	0	0	0
3. Losses without improvement			

3. CO2 loss backup

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

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

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

	Exp.	Min.	Max.
Reserve energy (MWh/yr)	13,184	13,184	13,184
Annual emissions due to backup from fossil fuel-mix of electricity generation (tCO2/yr)	593	593	593
RESULTS			
Total emissions due to backup from fossil fuel-mix of electricity generation (tCO2)	17,798	14,832	17,798

1. CO2 emission saving

Emissions due to turbine life

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

Capacity factor calculated from forestry data

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

Capacity factor - Direct input

	Exp.	Min.	Max.
Capacity factor (%)	35.0	34.9	35.1

	Exp.	Min.	Max.
Annual energy output from windfarm (MW/yr)			
RESULTS			
Emissions saving over coal-fired electricity generatio...	84,904	84,661	85,146
Emissions saving over grid-mix of electricity generati...	23,402	23,335	23,469
Emissions saving over fossil fuel - mix of electricity g...	41,529	41,410	41,648

2. CO_2 loss turbine life

Emissions due to turbine life

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

Calculation of emissions with relation to installed capacity

	Exp.	Min.	Max.
Emissions due to turbine frome energy output (t CO_2)	3550	3550	3550
Emissions due to cement used in construction (t CO_2)	1264	1106	1422

Direct input of emissions due to turbine life

	Exp.	Min.	Max.
Emissions due to turbine life (tCO_2/windfarm)			

RESULTS

	Exp.	Min.	Max.
Losses due to turbine life (manufacture, construction, etc.) (t CO_2)	26115	25957	26273
Additional CO_2 payback time of windfarm due to turbine life			
...coal-fired electricity generation (months)	4	4	4
...grid-mix of electricity generation (months)	13	13	13
...fossil fuel - mix of electricity generation (months)	8	8	8

4. Loss CO_2 fixing pot.

Emissions due to loss of bog plants

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

	Exp.	Min.	Max.
Area where carbon accumulation by bog plants is lost (ha)	12.55	6.78	15.74
Total loss of carbon accumulation up to time of restoration (tCO_2 eq./ha)	37	22	50
RESULTS			
Total loss of carbon fixation by plants at the site ($t CO_2$)	460	149	779
Additional CO_2 payback time of windfarm due to loss of CO_2 fixing potential			
...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