LOCHLUICHART WIND FARM EXTENSION II
APPENDIX 5A:
CARBON CALCULATOR RESULTS

INFINERGY

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PAYBACK TIME AND CO2 EMISSIONS

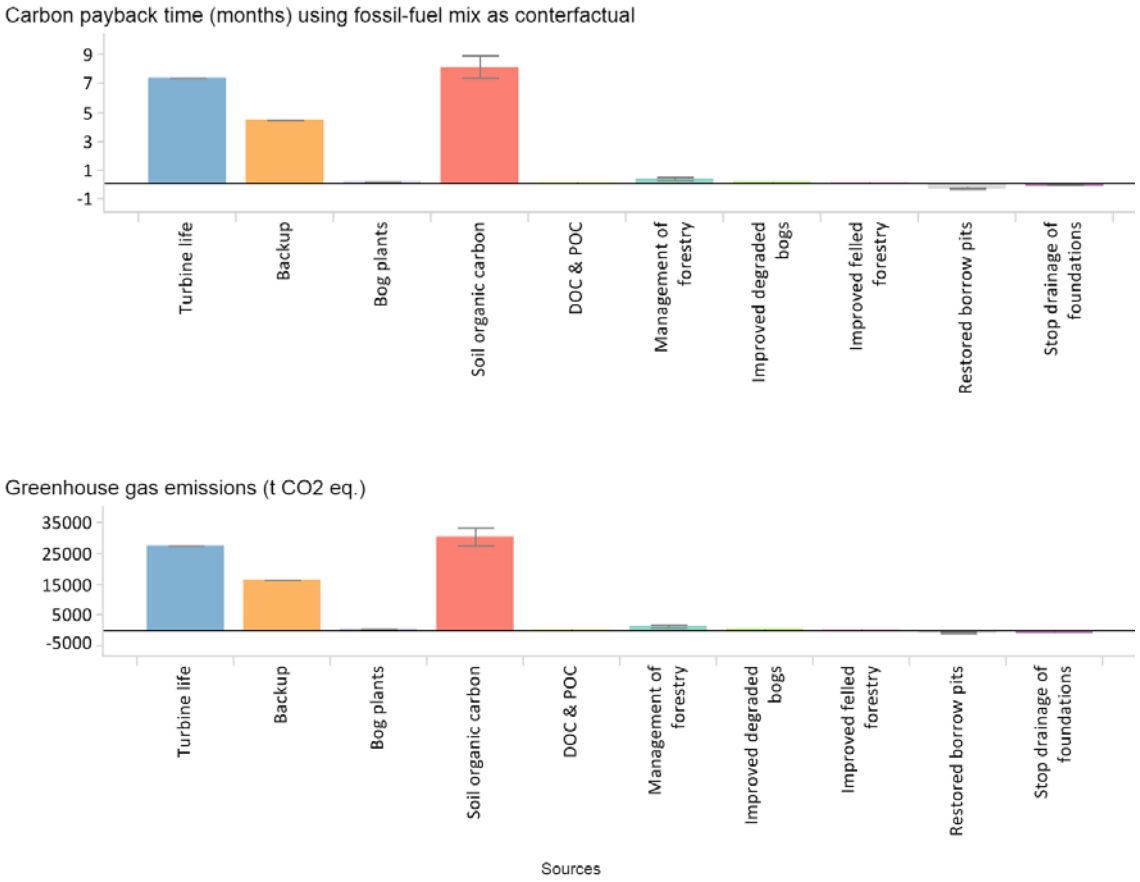
1. Windfarm CO2 emission saving over...	Exp.	Min.	Max.
...coal-fired electricity generation (t CO2 / yr)	88,587	85,982	91,193
...grid-mix of electricity generation (t CO2 / yr)	27,105	26,308	27,902
...fossil fuel-mix of electricity generation (t CO2 / yr)	44,390	43,084	45,696
Energy output from windfarm over lifetime (MWh)	2,412,504	2,341,548	2,483,460

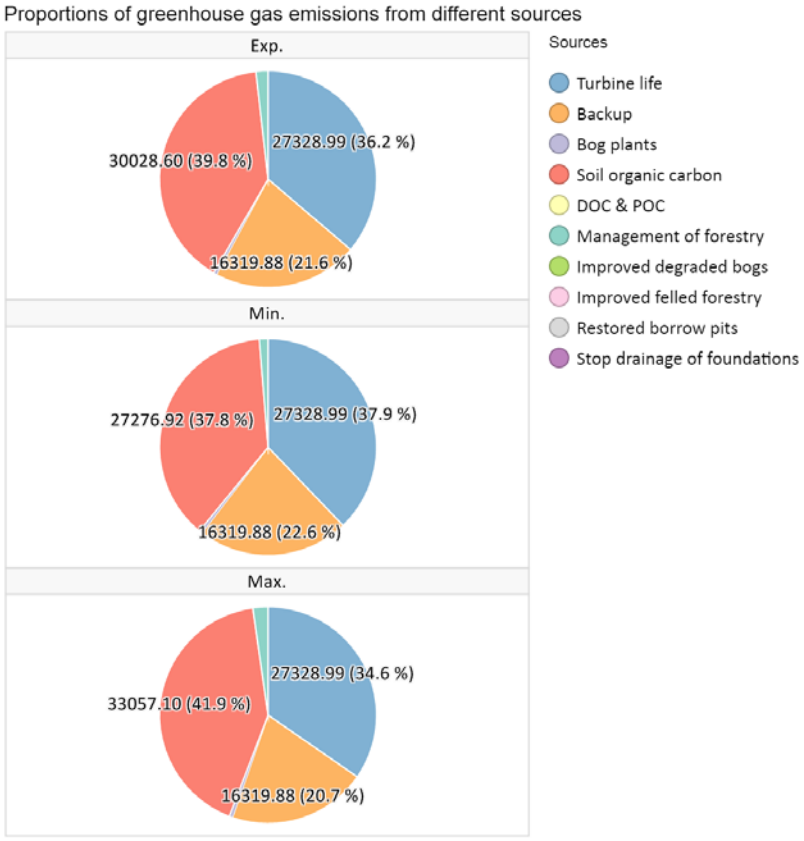
Total CO2 losses due to wind farm (tCO2 eq.)	Exp.	Min.	Max.
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	27,329	27,329	27,329
3. Losses due to backup	16,320	16,320	16,320
4. Lossess due to reduced carbon fixing potential	365	337	394
5. Losses from soil organic matter	30,029	27,277	33,057
6. Losses due to DOC & POC leaching	3	1	21
7. Losses due to felling forestry	1,350	935	1,766
Total losses of carbon dioxide	75,396	72,199	78,888

8. Total CO2 gains due to improvement of site (t CO2 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	-1,108	-1,109	-833
8d. Change in emissions due to removal of drainage from foundations & hardstanding	-163	0	-170
Total change in emissions due to improvements	-1,271	-1,109	-1,003

RESULTS	Exp.	Min.	Max.
Net emissions of carbon dioxide (t CO2 eq.)	74,125	71,196	77,779
Carbon Payback Time			
...coal-fired electricity generation (years)	0.8	0.8	0.9
...grid-mix of electricity generation (years)	2.7	2.6	3
...fossil fuel-mix of electricity generation (years)	1.7	1.6	1.8
Ratio of soil carbon loss to gain by restoration (not used in Scottish applications)	23.63	27.19	29.83
Ratio of CO2 eq. emissions to power generation (g/kWh) (for info. only)	30.73	28.67	33.22

PAYBACK TIME CHARTS


Carbon payback time (months) using fossil-fuel mix as conterfactual
9
7
5
3
1
-1
Turbine life
Backup
Bog plants
Soil organic carbon
DOC & POC
Management of forestry
Improved degraded bogs
Improved felled forestry
Restored borrow pits
Stop drainage of foundations
Greenhouse gas emissions (t CO2 eq.)
35000
25000
15000
5000
-5000
Turbine life
Backup
Bog plants
Soil organic carbon
DOC & POC
Management of forestry
Improved degraded bogs
Improved felled forestry
Restored borrow pits
Stop drainage of foundations
Sources


Proportions of greenhouse gas emissions from different sources
Exp.
27328.99 (36.2 %)
30028.60 (39.8 %)
16319.88 (21.6 %)
Min.
27328.99 (37.9 %)
27276.92 (37.8 %)
16319.88 (22.6 %)
Max.
27328.99 (34.6 %)
33057.10 (41.9 %)
16319.88 (20.7 %)
Sources
Turbine life
Backup
Bog plants
Soil organic carbon
DOC & POC
Management of forestry
Improved degraded bogs
Improved felled forestry
Restored borrow pits
Stop drainage of foundations

INPUT DATA

12/12/2018 Reference: 9KMG-8K4M-VHMD v3

Carbon Calculator v1.5.0
Lochluichart Wind Farm Extension II Location: 57.677747 -4.802494
Infinergy

Core input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Windfarm characteristics				
Dimensions				
No. of turbines	9	9	9	Chapter 3
Duration of consent (years)	25	25	25	Chapter 3
Performance				
Power rating of 1 turbine (MW)	3.6	3.6	3.6	Chapter 3
Capacity factor	34	33	35	Chapter 3
Backup				
Fraction of output to backup (%)	5	5	5	Chapter 3
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	PSRA Technical Appendix
Average annual air temperature at site (°C)	1	0.2	1.1	Calculated from climate averages for area.
Average depth of peat at site (m)	0.62	0.61	0.63	PRSA Technical Appendix
C Content of dry peat (% by weight)	50	49	51	Calculated from climate averages for area.
Average extent of drainage around drainage features at site (m)	3.1	3	3.2	Technical estimation - further refined after drainage installed.
Average water table depth at site (m)	0.17	0.16	0.18	Technical estimation - further refined after drainage installed.
Dry soil bulk density ($g\ cm^{-3}$)	0.24	0.23	0.25	Scottish Government Guidance - Guidance on Developments on Peatland - Site Surveys
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	5	4	6	Technical estimation - further refined later.
Carbon accumulation due to C fixation by bog plants in undrained peats ($tC\ ha^{-1}\ yr^{-1}$)	0.24	0.23	0.25	SNH Guidance -Carbon Payback Calculator: Guidelines on Measurements
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	4.09	4.08	4.1	Chapter 11
Average rate of carbon sequestration in timber ($tC\ ha^{-1}\ yr^{-1}$)	3.6	2.5	4.7	Scottish Government and SNH Guidance

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12/12/2018 Reference: 9KMG-8K4M-VHMD v3

Input data	Expected value	Minimum value	Maximum value	Source of data
Counterfactual emission factors				
Coal-fired plant emission factor (t CO2 MWh^{-1})	0.918	0.918	0.918	
Grid-mix emission factor (t CO2 MWh^{-1})	0.28088	0.28088	0.28088	
Fossil fuel-mix emission factor (t CO2 MWh^{-1})	0.46	0.46	0.46	
Borrow pits				
Number of borrow pits	2	2	2	Borrow Pit Assessment Technical Appendix
Average length of pits (m)	300	300	300	Borrow Pit Assessment Technical Appendix
Average width of pits (m)	150	150	150	Borrow Pit Assessment Technical Appendix
Average depth of peat removed from pit (m)	0.6	0.6	0.6	PSRA Technical Appendix.
Foundations and hard-standing area associated with each turbine				
Average length of turbine foundations (m)	23	23	23	Chapter 3
Average width of turbine foundations (m)	23	23	23	Chapter 3
Average depth of peat removed from turbine foundations(m)	0.5	0.5	0.5	PSRA Technical Appendix.
Average length of hard-standing (m)	50	50	50	Chapter 3
Average width of hard-standing (m)	20	20	20	Chapter 3
Average depth of peat removed from hard-standing (m)	0.6	0.6	0.6	PSRA Technical Appendix.
Volume of concrete used in construction of the ENTIRE windfarm				
Volume of concrete (m^3)	4000	4000	4000	Chapter 3
Access tracks				
Total length of access track (m)	9065	9064	9066	Chapter 3
Existing track length (m)	5065	5065	5065	Chapter 3
Length of access track that is floating road (m).	4000	3999	4001	Chapter 3
Floating road width (m)	5.5	5.5	5.5	Chapter 3
Floating road depth (m)	0.5	0.4	0.6	Chapter 3
Length of floating road that is drained (m)	0.75	0.74	0.76	Chapter 3
Average depth of drains associated with floating roads (m)	0.5	0.5	0.5	Chapter 3
Length of access track that is excavated road (m)	0	0	0	Not applicable
Excavated road width (m)	5	5	5	Not applicable
Average depth of peat excavated for road (m)	0	0	0	Not applicable
Length of access track that is rock filled road (m)	0	0	0	Not applicable
Rock filled road width (m)	5	5	5	Not applicable
Rock filled road depth (m)	0	0	0	Not applicable
Length of rock filled road that is drained (m)	0	0	0	Not applicable
Average depth of drains associated with rock filled roads (m)	0	0	0	Not applicable
Cable trenches				
Length of any cable trench on peat that does not follow access tracks and is lined with a permeable medium (eg. sand) (m)	0	0	0	Not applicable

12/12/2018 Reference: 9KMG-8K4M-VHMD v3

Input data	Expected value	Minimum value	Maximum value	Source of data
Average depth of peat cut for cable trenches (m)	0	0	0	Not applicable
Additional peat excavated (not already accounted for above)				
Volume of additional peat excavated (m^3)	0	0	0	Not applicable
Area of additional peat excavated (m^2)	0	0	0	Not applicable
Peat Landslide Hazard				
Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments	negligible	negligible	negligible	Fixed
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)	0	0	0	Not applicable
Water table depth in degraded bog before improvement (m)	0	0	0	Not applicable
Water table depth in degraded bog after improvement (m)	0	0	0	Not applicable
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	5	5	5	Technical estimation.
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	20	20	20	Technical estimation.
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	0	0	0	Not applicable.
Water table depth in felled area before improvement (m)	0	0	0	Not applicable.
Water table depth in felled area after improvement (m)	0	0	0	Not applicable.
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	2	2	2	Not applicable.
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	20	20	20	Not applicable.
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	4.5	4.5	4.5	Borrow Pit Assessment Technical Appendix
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	2	1	3	Technical average used.
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.1	0	0.11	Technical estimation - refined when restoration taken place.
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	5	5	5	Technical average used.
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	20	20	20	Technical average used.
Early removal of drainage from foundations and hardstanding				
Water table depth around foundations and hardstanding before restoration (m)	1	0.9	1.1	Technical estimation

12/12/2018 Reference: 9KMG-8K4M-VHMD v3

Input data	Expected value	Minimum value	Maximum value	Source of data
Water table depth around foundations and hardstanding after restoration (m)	0.9	0.8	1	Technical estimation
Time to completion of backfilling, removal of any surface drains, and full restoration of the hydrology (years)	0.1	0.1	0.1	Technical estimation.
Restoration of site after decomissioning				
Will the hydrology of the site be restored on decommissioning?	Yes	Yes	Yes	
Will you attempt to block any gullies that have formed due to the windfarm?	Yes	Yes	Yes	Worst case scenario.
Will you attempt to block all artificial ditches and facilitate rewetting?	Yes	Yes	Yes	Worst case scenario
Will the habitat of the site be restored on decommissioning?	No	No	No	
Will you control grazing on degraded areas?	n/a	n/a	n/a	Not applicable to the Development.
Will you manage areas to favour reintroduction of species	No	No	No	Not applicable to the Development.
Methodology				
Choice of methodology for calculating emission factors	Site specific (required for planning applications)			

Forestry input data

N/A

12/12/2018 Reference: 9KMG-8K4M-VHMD v3

Construction input data

N/A

1 WINDFARM CO2 EMISSION

	Exp.	Min.	Max.
Capacity factor (%)	34	33	35

	Exp.	Min.	Max.
Annual energy output from windfarm (MW/yr)			
RESULTS			
Emissions saving over coal-fired electricity generation (tCO_2/yr)	88,587	85,982	91,193
Emissions saving over grid-mix of electricity generation (tCO_2/yr)	27,105	26,308	27,902
Emissions saving over fossil fuel - mix of electricity generation (tCO_2/yr)	44,390	43,084	45,696

2 CO2 LOSS DUE TO TURBINE LIFE

	Exp.	Min.	Max.
Emissions due to turbine from energy output (t CO_2)	2896	2896	2896
Emissions due to cement used in construction (t CO_2)	1264	1264	1264

	Exp.	Min.	Max.
Losses due to turbine life (manufacture, construction, etc.) (t CO_2)	27329	27329	27329
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)	12	12	12
...fossil fuel - mix of electricity generation (months)	7	8	7

3 CO2 LOSS DUE TO BACKUP

	Exp.	Min.	Max.
Reserve energy (MWh/yr)	14,191	14,191	14,191
Annual emissions due to backup from fossil fuel-mix of electricity generation (tCO_2/yr)	653	653	653
RESULTS			
Total emissions due to backup from fossil fuel-mix of electricity generation (tCO_2)	16,320	16,320	16,320

4 LOSS OF CO2 FIXING POTENTIAL

	Exp.	Min.	Max.
Area where carbon accumulation by bog plants is lost (ha)	13.82	13.78	13.87
Total loss of carbon accumulation up to time of restoration (tCO_2 eq./ha)	26	24	28
RESULTS			
Total loss of carbon fixation by plants at the site (t CO_2)	365	337	394
Additional CO2 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

5 LOSS OF SOIL CO2

5. Loss of soil CO_2	Exp.	Min.	Max.
CO_2 loss from removed peat (t CO_2 equiv.)	29612.3	26904.7	32583.3
CO_2 loss from drained peat (t CO_2 equiv.)	416.35	372.26	473.82
RESULTS			
Total CO_2 loss from peat (removed + drained) (t CO_2 equiv.)	30028.6	27276.9	33057.1
Additional CO_2 payback time of windfarm due to loss of soil CO_2			
...coal-fired electricity generation (months)	4.07	3.81	4.35
...grid-mix of electricity generation (months)	13.29	12.44	14.22
...fossil fuel - mix of electricity generation (months)	8.12	7.6	8.68

5a. Volume of Peat Removed	Exp.	Min.	Max.
Peat removed from borrow pits			
Area of land lost in borrow pits (m2)	90000	90000	90000
Volume of peat removed from borrow pits (m3)	54000	54000	54000
Peat removed from turbine foundations			
Area of land lost in foundation (m2)	4761	4761	4761
Volume of peat removed from foundation area (m3)	2380.5	2380.5	2380.5
Peat removed from hard-standing			
Area of land lost in hard-standing (m2)	9000	9000	9000
Volume of peat removed from hard-standing area (m3)	5400	5400	5400
Peat removed from access tracks			
Area of land lost in floating roads (m2)	22000	21994.5	22005.5
Volume of peat removed from floating roads (m3)	11000	8797.8	13203.3
Area of land lost in excavated roads (m2)	0	0	0
Volume of peat removed from excavated roads (m3)	0	0	0
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)	22000	21994.5	22005.5
Total volume of peat removed due to access tracks (m3)	11000	8797.8	13203.3
RESULTS			
Total area of land lost due to windfarm construction (m2)	125761	125756	125767
Total volume of peat removed due to windfarm construction (m3)	72780.5	70578.3	74983.8

5b. CO_2 loss from removed peat	Exp.	Min.	Max.
CO_2 loss from removed peat (t CO_2)	32023.7	29165.6	35055.3
CO_2 loss from undrained peat left in situ (t CO_2)	2411.45	2260.91	2471.96
RESULTS			
CO_2 loss atributable to peat removal only (t CO_2)	29612.3	26904.7	32583.3

6 CO2 LOSS BY DOC & POC LOSS

	Exp.	Min.	Max.
Gross CO_2 loss from restored drained land (t CO_2)	0	0	0
Gross CH_4 loss from restored drained land (t CO_2 equiv.)	0	0	0
Gross CO_2 loss from improved land (t CO_2)	0	0	0
Gross CH_4 loss from improved land (t CO_2 equiv.)	113.49	93.58	471.64
Total gaseous loss of C (t C)	2.78	2.29	11.53
Total C loss as DOC (t C)	0.72	0.16	4.61
Total C loss as POC (t C)	0.22	0.09	1.15
RESULTS			
Total CO_2 loss due to DOC leaching (t CO_2)	2.65	0.59	16.92
Total CO_2 loss due to POC leaching (t CO_2)	0.81	0.34	4.23
Total CO_2 loss due to DOC & POC leaching (t CO_2)	3.46	0.92	21.15
Additional CO_2 payback time of windfarm due to DOC & POC			
...coal-fired electricity generation (months)	0	0	0
...grid-mix of electricity generation (months)	0	0	0
...fossil fuel - mix of electricity generation (months)	0	0	0

7 FORESTRY CO2 LOSS

	Exp.	Min.	Max.
Area of forestry plantation to be felled (ha)	4.09	4.08	4.1
Carbon sequestered (t C ha-1 yr-1)	3.6	2.5	4.7
Lifetime of windfarm (years)	25	25	25
Carbon sequestered over the lifetime of the windfarm (t C ha-1)	90	62.5	117.5
RESULTS			
Total carbon loss due to felling of forestry (t CO_2)	1349.71	935.01	1766.43
Additional CO_2 payback time of windfarm due to management of forestry			
...coal-fired electricity generation (months)	0.18	0.13	0.23
...grid-mix of electricity generation (months)	0.6	0.43	0.76
...fossil fuel - mix of electricity generation (months)	0.36	0.26	0.46

8 CO2 GAIN – SITE IMPROVEMENT

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)	15	15	15
Selected annual rate of methane emissions (t CH_4-C ha-1 yr-1)	0.467	0.464	0.467
CH_4 emissions from improved land (t CO_2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO_2 ha-1 yr-1)	-1.859	-2.072	-1.832
CO_2 emissions from improved land (t CO_2 equiv.)	0	0	0
Total GHG emissions from improved land (t CO_2 eqiv.)	0	0	0
3. Losses without improvement			
Improved period (years)	15	15	15
Selected annual rate of methane emissions (t CH_4-C ha-1 yr-1)	0.467	0.464	0.467
CH_4 emissions from improved land (t CO_2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO_2 ha-1 yr-1)	-1.859	-2.072	-1.832
CO_2 emissions from unimproved land (t CO_2 equiv.)	0	0	0
Total GHG emissions from unimproved land (t CO_2 eqiv.)	0	0	0
RESULTS			
4. Reduction in GHG emissions due to improvement of site			
Reduction in GHG emissions due to improvement (t CO_2 equiv.)	0	0	0

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)	18	18	18
Selected annual rate of methane emissions (t CH_4-C ha-1 yr-1)	0.467	0.464	0.467
CH_4 emissions from improved land (t CO_2 equiv.)	0	0	0
Selected annual rate of carbone dioxide emissions (t CO_2 ha-1 yr-1)	-1.859	-2.072	-1.832
CO_2 emissions from improved land (t CO_2 equiv.)	0	0	0

Total GHG emissions from improved land (t CO_2 eqiv.)	0	0	0
3. Losses without improvement			
Improved period (years)	18	18	18
Selected annual rate of methane emissions (t CH_4-C ha-1 yr-1)	0.467	0.464	0.467
CH_4 emissions from improved land (t CO_2 equiv.)	0	0	0
Selected annual rate of carbon dioxide emissions (t CO_2 ha-1 yr-1)	-1.859	-2.072	-1.832
CO_2 emissions from unimproved land (t CO_2 equiv.)	0	0	0
Total GHG emissions from unimproved land (t CO_2 eqiv.)	0	0	0
RESULTS			
4. Reduction in GHG emissions due to improvement of site			
Reduction in GHG emissions due to improvement (t CO_2 equiv.)	0	0	0

Borrow Pits	**Exp.**	**Min.**	**Max.**
1. Description of site			
Area to be improved (ha)	4.5	4.5	4.5
Depth of peat above water table before improvement (m)	0.6	0.6	0.6
Depth of peat above water table after improvement (m)	0.1	0.11	0
2. Losses with improvement			
Improved period (years)	15	15	15
Selected annual rate of methane emissions (t CH_4-C ha-1 yr-1)	0.112	0.093	0.467
CH_4 emissions from improved land (t CO_2 equiv.)	113.488	93.579	471.641
Selected annual rate of carbon dioxide emissions (t CO_2 ha-1 yr-1)	0.527	0.659	-1.832
CO_2 emissions from improved land (t CO_2 equiv.)	18.231	22.784	-63.369
Total GHG emissions from improved land (t CO_2 eqiv.)	131.719	116.363	408.272
3. Losses without improvement			
Improved period (years)	15	15	15
Selected annual rate of methane emissions (t CH_4-C ha-1 yr-1)	-0.033	-0.036	-0.032
CH_4 emissions from improved land (t CO_2 equiv.)	0	0	0
Selected annual rate of carbon dioxide emissions (t CO_2 ha-1 yr-1)	18.365	18.152	18.391
CO_2 emissions from unimproved land (t CO_2 equiv.)	1239.62	1225.26	1241.41
Total GHG emissions from unimproved land (t CO_2 eqiv.)	1239.62	1225.26	1241.41
RESULTS			
4. Reduction in GHG emissions due to improvement of site			
Reduction in GHG emissions due to improvement (t CO_2 equiv.)	1107.9	1108.89	833.141

Foundations and Hardstanding	**Exp.**	**Min.**	**Max.**
1. Description of site			
Area to be improved (ha)	0.682	0	0.705
Depth of peat above water table before improvement (m)	0.62	0.61	0.63
Depth of peat above water table after improvement (m)	0.62	0.61	0.63
2. Losses with improvement			
Improved period (years)	24.9	24.9	24.9
Selected annual rate of methane emissions (t CH_4-C ha-1 yr-1)	-0.033	-0.036	-0.033
CH_4 emissions from improved land (t CO_2 equiv.)	-8.355	0	-8.553
Selected annual rate of carbon dioxide emissions (t CO_2 ha-1 yr-1)	18.687	18.317	18.864
CO_2 emissions from improved land (t CO_2 equiv.)	162.552	0	169.665
Total GHG emissions from improved land (t CO_2 eqiv.)	154.197	0	161.112
3. Losses without improvement			
Improved period (years)	24.9	24.9	24.9
Selected annual rate of methane emissions (t CH_4-C ha-1 yr-1)	-0.033	-0.036	-0.033
CH_4 emissions from improved land (t CO_2 equiv.)	0	0	0
Selected annual rate of carbon dioxide emissions (t CO_2 ha-1 yr-1)	18.687	18.317	18.864
CO_2 emissions from unimproved land (t CO_2 equiv.)	317.28	0	331.165
Total GHG emissions from unimproved land (t CO_2 eqiv.)	317.28	0	331.165
RESULTS			
4. Reduction in GHG emissions due to improvement of site			
Reduction in GHG emissions due to improvement (t CO_2 equiv.)	163.083	0	170.052