TECHNICAL APPENDIX 15.1: CARBON CALCULATOR

Balmeanach Wind Farm

Prepared for: **Balmeanach Wind Farm Limited**

SLR Ref: 428.11223.00001
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BASIS OF REPORT

CONTENTS

1.0 Introduction

SLR has been commissioned by Balmeanach Wind Farm Limited ('the Applicant') to calculate the carbon pay-back period for the proposed Balmeanach Wind Farm (the 'Proposed Development') using the Scottish Government Carbon Calculator Tool[1] in accordance with the associated guidance[2].

The Proposed Development comprises up to 10 turbines and would have an estimated generation capacity of up to 45MW.

The Carbon Calculator Tool has been developed by the Scottish Government to support the process of determining the carbon pay-back period for wind farm developments in Scotland. The carbon payback period is derived by comparing the carbon costs of wind farm developments (particularly during construction) with the carbon savings likely to be achieved through their operation.

The Carbon Calculator Tool v1.7.0 uses 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 & 2011, and Wind Farm and Carbon Savings – Technical Note v.2 2.10.0. Input Parameters).

To calculate the pay-back period, the Scottish Government's Carbon Calculator Tool considers the following carbon saving and carbon loss parameters, as shown in Annex 15.1A:

- carbon emissions savings, based on emissions from different power sources;
- loss of carbon due to production, transportation, erection, operation and decommissioning of the wind farm;
- loss of carbon from backup power generation;
- loss of carbon-fixing potential of peatland;
- loss and/or saving of carbon stored in peatland (by peat removal or changes in drainage); and
- carbon saving due to improvement of habitat.

2.0 Context

By 2030, the Scottish Government aims to have reduced greenhouse gas emissions by at least 75% compared to 1990 levels and generate 50% of Scotland's overall energy consumption from renewable sources, with aims to have decarbonised Scotland's energy system and economy completely by 2050.

Large scale wind farm development in Scotland has raised concerns about the reliability of methods used to calculate the time taken for these proposals to reduce greenhouse gas emissions, largely due to the potential siting of wind farms on peatland which represent large stores of carbon. The implication for carbon emissions is therefore a factor that should be included in the consideration of proposed wind farm development.

[1] Scottish Government Wind Farm Developments on Peat Land: Carbon Calculator Tool v1.7.0 https://informatics.sepa.org.uk/CarbonCalculator/

[2] Calculating Carbon Savings from Wind Farms on Scottish Peatlands – A New Approach (Nayak et al., 2008; Nayak et al., 2010 and Smith et al,. 2011)

3.0 Input Data

The data inputs for the online calculator tool have been extracted from the sources listed below:

- **Chapter 3: Description of the Development** (EIA Report, Volume 2);
- **Technical Appendix 10.1: Peat Landslide and Hazard Risk Assessment (PLHRA)** (EIA Report, Volume 4b); and
- **Technical Appendix 10.2: Peat Management Plan (PMP)** (EIA Report, Volume 4b).

The calculation spreadsheet within the Carbon Calculator Tool (online version reference number 5CE9-7MO7-C1JK v6) allows a range of data to be input in order to utilise expected, minimum and maximum values, where relevant and applicable. The input data is presented within Annex A of this report. However, if several parameters are varied together, this can have the effect of 'cancelling out' a single parameter change. For this reason, the approach for this assessment, has been to include 'maximum values' as those values which would result in the longest (maximum) payback period; and 'minimum values' as those values which would result in the shortest (minimum) payback period. The expected value is based on the most realistic option for the Proposed Development.

4.0 Results

The model calculates carbon emissions savings and losses from the various aspects of the model; and also calculates a payback period based on the three counterfactual emission factors, coal-fired plant, normal grid mix and fossil fuel mix. The counterfactual emission factors are fixed within the calculator tool, the coal-fired and fossil fuel mix emission values are based on DUKES[3] data for which the UK is annually updated. The grid mix emission factor is the list of emission factors used to report on 2016 greenhouse gas emissions as published by DECC[4].

This shows that even if the wind farm is replacing the normal fossil fuel sourced grid mix of electricity generation, the Proposed Development would produce carbon dioxide (CO_2) savings as shown in **Table 4-1**.

Table 4-1
Estimate of CO_2 Emission Savings

Wind Farm CO_2 emission saving over…	Exp.	Min.	Max.
…coal-fired electricity generation (t CO_2/yr)	167,475	165,895	177,745
…grid-mix of electricity generation (t CO_2/yr))	32,322	32,017	34,304
…fossil fuel – mix of electricity generation (t CO_2/yr)	72,205	71,524	76,632
Energy output from Wind Farm over lifetime (MWh)	**6,685,632**	**6,622,560**	**7,095,600**

Table 4-2 and **Table 4-3** present the estimated losses and gains from the various aspects of the wind farm construction and operation. This shows that the improvement of degraded bogs will have a positive impact on carbon capture.

Table 4-2
Estimated CO_2 Losses

Total CO_2 losses due to wind farm (tCO_2 eq.)	Exp.	Min.	Max.
Losses due to turbine life (eg. manufacture, construction, decommissioning)	38,634	38,603	38,666
Losses due to backup	34,059	34,059	34,059
Losses due to reduced carbon fixing potential	1,946	589	10,172
Losses from soil organic matter	36,353	7,893	132,747
Losses due to DOC & POC leaching	33	0	397
Losses due to felling forestry	41,052	38,398	43,472
Total losses of CO_2	**152,077**	**119,541**	**259,514**

[3] Department for Business, Energy & Industrial Strategy, Digest of UK Energy Statistics (DUKES)
[4] Department for Business, Energy & Industrial Strategy, Greenhouse gas reporting – Conversion Factors 2022

Table 4-3
Estimated CO_2 Gains

Total CO_2 gains due to improvement of site (t CO_2 eq.)	Exp.	Min.	Max.
Change in emissions due to improvement of degraded bogs	0	0	0
Change in emissions due to improvement of felled forestry	-3,045	0	-16,369
Change in emissions due to restoration of peat from borrow pits	0	0	-216
Change in emissions due to removal of drainage from foundations & hardstanding	-1,014	0	-13,693
Total change in emissions due to improvements	**-4,059**	**0**	**-30,279**

Table 4-4 demonstrates that the net emissions of CO_2 are estimated at 148,018 tonnes of CO_2, with an estimated payback period of 1.2 to 3.6 years. Therefore, the Proposed Development will produce a reduction in emissions from the electricity grid of around 72,205 tonnes of CO_2 per year (this assumes that the wind farm replaces grid electricity generated from a fossil fuel mix).

Over the 40 year lifetime of the Proposed Development, 2,888,200 tonnes of CO_2 will be displacing fossil fuel mix electricity generation. Given the total net emissions of CO_2 due to the construction of the wind farm, there will be a total net saving of 2,736,123 tonnes of CO_2 over the lifetime of the wind farm.

A summary of the anticipated carbon emissions and carbon payback of the Proposed Development are provided in **Table 4.4**.

Table 4-4
CO_2 Emissions and Payback Time

Results	Exp.	Min.	Max.
Net emissions of carbon dioxide (t $CO_{2\ eq}$) (carbon losses minus carbon gains)	**148,018**	**89,262**	**259,514**
Carbon Payback Time			
…coal-fired electricity generation (years/months)	0.9 years 11 months	0.5 years 6 months	1.6 years 19 months
…grid-mix of electricity generation (years/months)	4.6 years 55 Months	2.6 years 31 months	8.1 years 91 months
…fossil fuel – mix of electricity generation (years/months)	**2.0 years 24 months**	**1.2 years 14 months**	**3.6 years 43 months**
Ratio of CO_2 eq. emissions to power generation (g/kWh) (Target ratio by 2030 (electricity generation) <50 g/kWh)	**22.14**	**12.58**	**39.19**

5.0 Conclusions

The calculations of total CO_2 emission savings and payback time for the Proposed Development indicates that the overall payback period will be around 2.0 years (24 months) when compared to the grid fuel mix of electricity generation. This means that the Proposed Development is anticipated to take around 2.0 years to repay the carbon exchange to the atmosphere (the CO_2 debt) through construction; the site would in effect be in a net gain situation following this time period and can then claim to contribute to national emissions reduction objectives thereafter for its remaining operational life (38 years).

6.0 References

Carbon Calculator Tool v1.7.0. Available at https://informatics.sepa.org.uk/CarbonCalculator/ - accessed March 2023.

Carbon Calculator Tool User Guidance. Available at https://informatics.sepa.org.uk/CarbonCalculator/assets/Carbon_calculator_User_Guidance.pdf

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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://mires-and-peat.net/pages/volumes/map04/map0409.php)

Scottish Peat Resources and their Energy Potential. ETSU B 1204. London: Department of Energy. Birnie R.V., Clayton P., Griffiths P., Hulme P.D., Robertson, R.A., Sloane B.D., and S.A. Ward. (1991).

Peatbogs and Carbon: A Critical Synthesis Lindsey, R. (2010) for RSPB Scotland.

Scottish Natural Heritage (SNH), SEPA, Scottish Government & The James Hutton Institute. (2014). Peat Survey Guidance; Developments on Peatland: Site Surveys.

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Scottish Renewables & SEPA. (2012). Developments on Peatland Guidance on the Assessment of Peat Volumes, Reuse of Excavated Peat and the Minimisation of Waste. http://www.scottishrenewables.com/static/uploads/publications/a4_developments_on_peatland.pdf

Scottish Government. 2020. Update to the Climate Change Plan 2018 – 2032 Securing a Green Recovery on a Path to Net Zero. Available at https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2020/12/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/documents/update-climate-change-plan-2018-2032-securing-green-recovery-path-net-zero/update-climate-change-plan-2018-2032-securing-green-recovery-path-net-zero/govscot%3Adocument/update-climate-change-plan-2018-2032-securing-green-recovery-path-net-zero.pdf - Accessed March 2023.

ANNEX A

Carbon Calculator v1.7.0
Balmeanach Location: 57.400376 -6.470958
Wind 2 Limited

Core input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Windfarm characteristics				
Dimensions				
No. of turbines	10	10	10	EIA Chapter 3: Description of the Development
Duration of consent (years)	40	40	40	EIA Chapter 3: Description of the Development
Performance				
Power rating of 1 turbine (MW)	4.5	4.5	4.5	EIA Chapter 3: Description of the Development
Capacity factor	42.4	42	45	EIA Chapter 3: Description of the Development
Backup				
Fraction of output to backup (%)	5	5	5	Dale et al 2004
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	Peat Survey Site Visit
Average annual air temperature at site (°C)	8.7	5.6	11.7	https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/gf5wbt9v5
Average depth of peat at site (m)	0.663	0.4	2	Peat depth survey
C Content of dry peat (% by weight)	55.5	49	62	Birnie et al. 1991
Average extent of drainage around drainage features at site (m)	10	5	50	Generic Precautionary Values
Average water table depth at site (m)	0.1	0.05	0.3	Typical intact peat values
Dry soil bulk density (g cm^{-3})	0.2	0.15	0.25	Default values taken from Lilly et al. 2010
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	10	10	15	Conservative Estimate
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha^{-1} yr^{-1})	0.25	0.12	0.31	Default
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	77.75	77	78	EIA Chapter 3: Description of the Development
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	3.6	3.4	3.8	Default values taken from Cannell 1999
Counterfactual emission factors				
Coal-fired plant emission factor (t CO2 MWh^{-1})	1.002	1.002	1.002	
Grid-mix emission factor (t CO2 MWh^{-1})	0.19338	0.19338	0.19338	
Fossil fuel-mix emission factor (t CO2 MWh^{-1})	0.432	0.432	0.432	
Borrow pits				
Number of borrow pits	4	4	4	EIA Chapter 3: Description of the Development
Average length of pits (m)	162.5	130	231	EIA Chapter 3: Description of the Development
Average width of pits (m)	82	66	100	EIA Chapter 3: Description of the Development
Average depth of peat removed from pit (m)	0.55	0.2	1.2	PMP
Foundations and hard-standing area associated with each turbine				
Average length of turbine foundations (m)	0	0	0	
Average width of turbine foundations (m)	0	0	0	
Average depth of peat removed from turbine foundations(m)	0	0	0	
Average length of hard-standing (m)	0	0	0	
Average width of hard-standing (m)	0	0	0	
Average depth of peat removed from hard-standing (m)	0	0	0	
Volume of concrete used in construction of the ENTIRE windfarm				
Volume of concrete (m^3)	0	0	0	

Input data	Expected value	Minimum value	Maximum value	Source of data
Access tracks				
Total length of access track (m)	9404	9400	9410	EIA Chapter 3: Description of the Development
Existing track length (m)	0	0	0	EIA Chapter 3: Description of the Development
Length of access track that is floating road (m)	0	0	0	EIA Chapter 3: Description of the Development
Floating road width (m)	0	0	0	
Floating road depth (m)	0	0	0	
Length of floating road that is drained (m)	0	0	0	
Average depth of drains associated with floating roads (m)	0	0	0	
Length of access track that is excavated road (m)	9404	9400	9410	EIA Chapter 3: Description of the Development
Excavated road width (m)	6	5	7	EIA Chapter 3: Description of the Development
Average depth of peat excavated for road (m)	0.48	0.4	0.5	PMP
Length of access track that is rock filled road (m)	0	0	0	
Rock filled road width (m)	0	0	0	
Rock filled road depth (m)	0	0	0	
Length of rock filled road that is drained (m)	0	0	0	
Average depth of drains associated with rock filled roads (m)	0	0	0	
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	Unknown
Average depth of peat cut for cable trenches (m)	0	0	0	Unknown
Additional peat excavated (not already accounted for above)				
Volume of additional peat excavated (m^3)	19158	19150	19160	PMP TA3.2
Area of additional peat excavated (m^2)	33900	33899	33901	PMP TA3.2
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	Currently unspecified
Water table depth in degraded bog before improvement (m)	0.3	0.1	0.5	Typical degraded peat values
Water table depth in degraded bog after improvement (m)	0.1	0.05	0.3	Typical intact peat values
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	10	5	15	Estimated by hydrologist
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	15	10	20	Typical values
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	77.75	77	77.8	Currently unspecified
Water table depth in felled area before improvement (m)	0.3	0.1	0.5	Typical degraded peat values
Water table depth in felled area after improvement (m)	0.1	0.05	0.3	Typical intact peat values
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	10	5	15	Estimated by hydrologist
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	15	10	20	Typical values
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	5.14	5.14	5.14	EIA
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	0.3	0.1	0.5	Typical degraded peat values

Input data	Expected value	Minimum value	Maximum value	Source of data
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.1	0.05	0.3	Typical intact peat values
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	5	2	10	Estimated by hydrologist
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	5	5	5	Typical values
Early removal of drainage from foundations and hardstanding				
Water table depth around foundations and hardstanding before restoration (m)	0.3	0.1	0.5	Typical degraded peat values
Water table depth around foundations and hardstanding after restoration (m)	0.1	0.05	0.3	Typical intact peat values
Time to completion of backfilling, removal of any surface drains, and full restoration of the hydrology (years)	2	1	5	Estimated by hydrologist
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	EIA Chapter 3: Description of the Development
Will you attempt to block all artificial ditches and facilitate rewetting?	Yes	Yes	Yes	EIA Chapter 3: Description of the Development
Will the habitat of the site be restored on decommissioning?	No	No	No	
Will you control grazing on degraded areas?	No	No	No	EIA Chapter 3: Description of the Development
Will you manage areas to favour reintroduction of species	Yes	Yes	Yes	EIA Chapter 3: Description of the Development
Methodology				
Choice of methodology for calculating emission factors	Site specific (required for planning applications)			

Forestry input data

N/A

Construction input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Balmeanach				
Number of turbines in this area	10	10	10	EIA Chapter 3: Description of the Development
Turbine foundations				
Depth of hole dug when constructing foundations (m)	0.75	0.4	1	PMP
Aproximate geometric shape of whole dug when constructing foundations	Circular	Circular	Circular	EIA Chapter 3: Description of the Development
Diameter at bottom	25	25	25	
Diameter at surface	25	25	25	
Hardstanding				
Depth of hole dug when constructing hardstanding (m)	0.68	0.4	1	PMP
Aproximate geometric shape of whole dug when constructing hardstanding	Rectangular	Rectangular	Rectangular	EIA Chapter 3: Description of the Development
Length at surface	68	68	68	
Width at surface	38	38	38	
Length at bottom	68	68	68	
Width at bottom	38	38	38	
Piling				
Is piling used?	No	No	No	EIA Chapter 3: Description of the Development
Volume of Concrete				
Volume of concrete used (m^3) in the entire area	4000	3900	4100	BPA

Payback Time and CO_2 emissions • 5CE9-7MO7-C1JK v6

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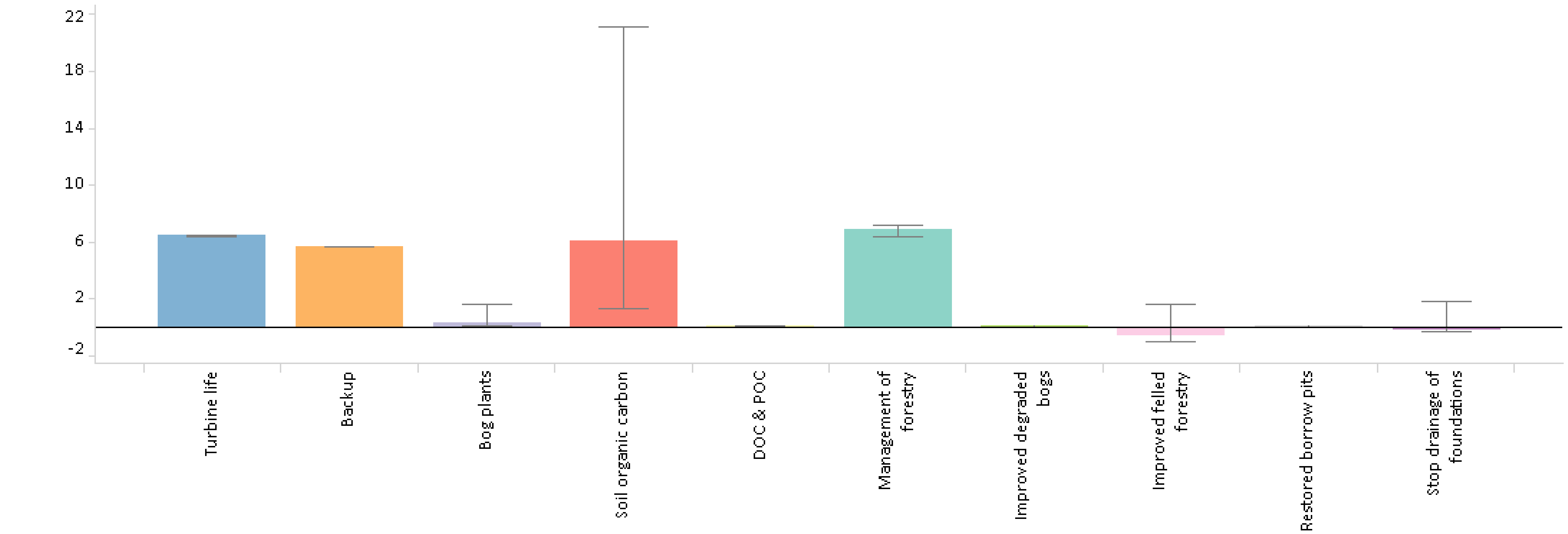
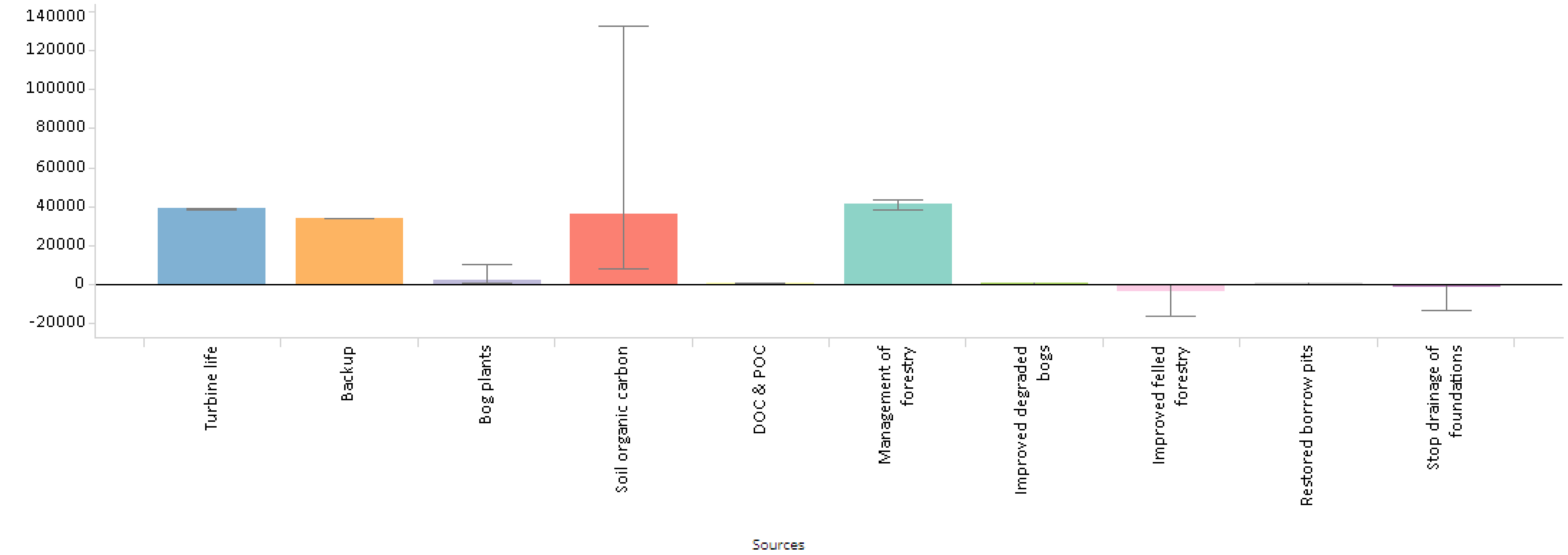
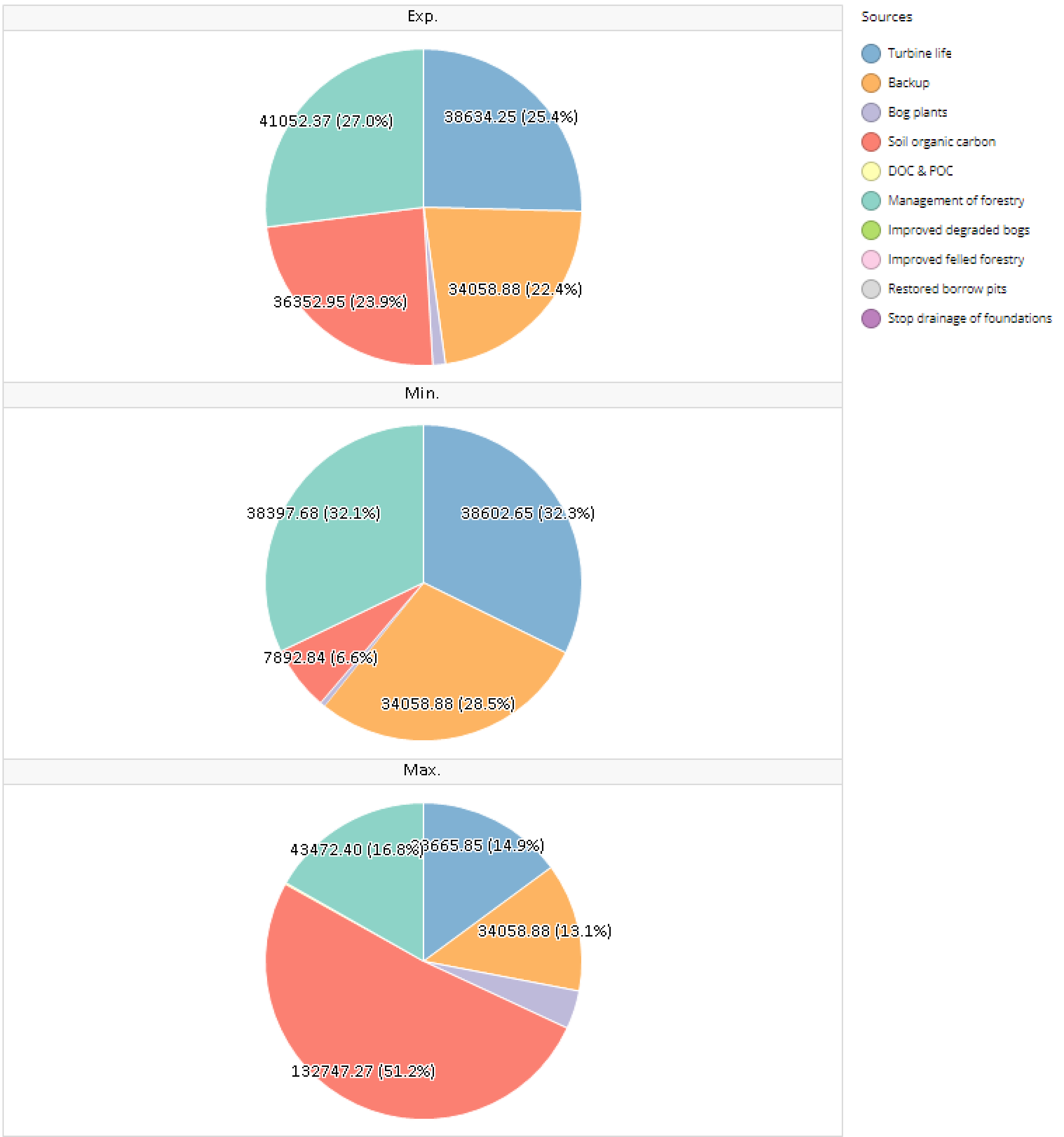
Carbon payback time (months) using fossil-fuel mix as conterfactual



Greenhouse gas emissions (t CO2 eq.)



Proportions of greenhouse gas emissions from different sources



Payback Time and CO_2 emissions • 5CE9-7MO7-C1JK v6

1. Windfarm CO2 emission saving over...	Exp.	Min.	Max.
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5. Losses from soil organic matter	36,353	7,893	132,747
6. Losses due to DOC & POC leaching	33	0	397
7. Losses due to felling forestry	41,052	38,398	43,472
Total losses of carbon dioxide	152,077	119,541	259,514

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
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8c. Change in emissions due to restoration of peat from borrow pits	0	0	-216
8d. Change in emissions due to removal of drainage from foundations & hardstanding	-1,014	0	-13,693
Total change in emissions due to improvements	-4,059	0	-30,279

RESULTS	Exp.	Min.	Max.
Net emissions of carbon dioxide (t CO2 eq.)	148,018	89,262	259,514
Carbon Payback Time			
...coal-fired electricity generation (years)	0.9	0.5	1.6
...grid-mix of electricity generation (years)	4.6	2.6	8.1
...fossil fuel-mix of electricity generation (years)	2.0	1.2	3.6
Ratio of soil carbon loss to gain by restoration (not used in Scottish applications)	8.96	0.26	No gains!
Ratio of CO2 eq. emissions to power generation (g/kWh) (for info. only)	22.14	12.58	39.19