Technical Appendix 2.3: Carbon Balance Assessment

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1.1 Introduction

1.1.1 This Carbon Balance Assessment has been prepared to assess carbon emissions associated with the Proposed Development. This Technical Appendix should be read in conjunction with **Chapter 2: Description of the Proposed Development (EIAR Volume 2)** and **Chapter 8: Hydrology, Hydrogeology, Geology and Soils (EIAR Volume 2)**.

1.1.2 It is widely recognised that wind farms and other renewable energy developments can significantly reduce carbon emissions over their operational lifetime, when compared to the emissions that would be associated with either the equivalent energy generation from conventional fossil fuel-based power generation or from a 'grid-mix' of power production.

1.1.3 It is also recognised that the construction of the infrastructure and subsequent operation and decommissioning of the Proposed Development would include activities that either directly or indirectly result in carbon dioxide (CO_2) emissions. Emissions of CO_2 associated with the construction of the Proposed Development requiring consideration includes the potential loss of CO_2 from carbon stored within the peat deposits within the Site.

1.1.4 This Carbon Balance Assessment provides an evaluation of the net measure of carbon emissions associated with the Proposed Development, whether produced or otherwise reduced. The assessment has been conducted using an offline version of the Scottish Government's Windfarm Carbon Calculator[1], which is derived from the government's online tool. At the time of this assessment (May 2026), the online version is undergoing redevelopment. The tool quantifies CO_2 emissions associated with the Proposed Development lifecycle and benchmarks them against the emissions that would be produced by alternative electricity generation sources.

1.1.5 This Technical Appendix is supported by the following:

- **Annex 1: Carbon Calculator Results and Charts.**

1.1.6 The carbon calculator tool uses the methodology and approach developed by Nayak et al[2].

1.2 Input Parameters

1.2.1 Information to inform the carbon calculator has been derived from either specific design parameters for the Proposed Development itself or has been based on industry standard information, as outlined in the Scottish Government's Carbon Calculator Technical Guidance[3].

Characteristics of the Proposed Development

1.2.2 The Proposed Development would comprise an onshore wind farm with up to eight turbines and a total estimated installed capacity of over 50 MW. The net capacity factor for the Proposed Development is estimated to be approximately 48%, which has been estimated based on wind data analysis.

1.2.3 The Proposed Development would have an operational life of 40 years from the date of final commissioning (the operational phase).

1.2.4 The CO^2 emissions generated during the life of the Proposed Development, including those created during manufacture and removal, are calculated using default values within the carbon calculator.

1.2.5 The Proposed Development also includes a Battery Energy Storage System (BESS) with an approximate capacity of 25 MW which is not included in the calculations.

Peatland and Environmental Characteristics of the Site

1.2.6 The Site covers an area of approximately 303 hectares (ha) and is located on land east of Sullom Voe Terminal and the Shetland Gas Plant in Shetland, Scotland. Settlements within approximately 1.5 km the Site are limited to scattered dwellings, in areas such as Toft, Brough and Garths Voe. Small settlements such as Firth and Mossbank are located approximately 2.1 km and 2.7 km from the Site, respectively. The Site is within the administrative boundary of Shetland Islands Council (SIC).

1.2.7 The Site comprises an undulating plateau that ranges in elevation from mean high-water level at its northernmost extent by Ay Wick, to approximately 110 m Above Ordnance Datum (AOD) at the Hill of Crooksetter located east of the centre of the Site. The Site comprises a combination of open heather moorland and grassland on peaty soils, which is used for rough grazing.

1.2.8 The Proposed Development is located within an area characterised by a dense network of small, minor watercourses within an extensive peatland landscape. These include both naturally occurring channels and modified drainage ditches established for historical land management (**Figure 8.1: Surface Water Features** and **Figure 8.2: Water Resources (EIAR Volume 3a)**).

1.2.9 Two larger watercourses are located within the Site, including the Aywick Burn and the Burn of Toft. The Aywick Burn flows through the central, northern area of the Site and a larger tributary of the watercourse flows across the north-western extent of the Site in a northerly direction. The north-western tributary forms a confluence with the Aywick burn and discharges to the Yell Sound coastal waterbody. The Burn of Toft is located within the central, eastern area of the Site with a number of associated small tributary streams. Two field drains are located within the south-western Site boundary which drain to a larger drainage watercourse adjacent to the western Site boundary associated with the public highway.

1.2.10 The Burn of Toft watercourse flows in an easterly direction before discharging into the Yell Sound approximately 3 km east of the Site. Observations taken during the Ramboll May 2025 hydrology walkover survey indicate that the geomorphological development of both larger, ordinary watercourses has been driven by the erosion of underlying peat and flows are strongly influenced by the peat's saturation and microtopography. The low permeability and high storage capacity of the peat supports widespread surface saturation and the presence of numerous bog pools, which act as water storage features and regulate downstream flows. A number of the modified small watercourses across the Site are partially infilled or overgrown with sphagnum moss and other bog vegetation (**Figure 6.3: Phase 1 Habitats and NVC (EIAR Volume 3a)**, which contributes to reduced flow velocities and enhanced water retention.

1.2.11 According to the Scottish Government's Carbon and Peatland Map (2016)[4] the majority of the Site is overlain by Class 1 soils, which are defined as *'nationally important carbon rich soils, deep peat and priority peatland habitat'*, and *'likely to be of high conservation value'*. The underlying bedrock located

[1] Scottish Government (2022). Carbon Calculator Tool for Onshore Wind Farms. Available at: https://www.gov.scot/publications/carbon-calculator-for-wind-farms-on-scottish-peatlands-factsheet/ [Accessed 24/04/2026]

[2] Nayak D.R., Miller D., Nolan A., Smith P., Smith J.U. (2011). Calculating Carbon Savings from Windfarms on Scottish Peat Lands: A New Approach

[3] Scottish Government (2018). Carbon Calculator: Technical Guidance. Available at: https://www.gov.scot/publications/carbon-calculator-technical-guidance/ [Accessed 24/04/2026]

[4] Scotland's Soils (2016). Carbon and peatland 2016 map | Scotland's soils. Available at: https://soils.environment.gov.scot/maps/thematic-maps/carbon-and-peatland-2016-map/. [Accessed 27/04/2016]

in the north-western part of the Site comprises metamorphic psammite and pelite belonging to the Yell Sound Psammite Formation. The formation comprises psammite, variably gneissose; with subsidiary layers or lenses of amphibolite, pelite, quartzite and gneissose semi-pelite. The eastern, central and southern regions of the Site are underlain by unnamed igneous intrusion, late Silurian to early Devonian felsic rock. This is shown on **Figure 8.6: Bedrock Geology (EIAR Volume 3a)**.

1.2.12 There are small areas in the south of the Site that are classified as Class 4 and Class 5 soils. These areas are described as areas unlikely to be associated with peatland habitats or wet and acidic type (Class 4) or peat soil with no peatland vegetation (Class 5) or where no peat soils are recorded. An extract of the Carbon and Peatland Map in relation to the Site is shown on **Figure 8.7: SNH Carbon and Peatland Map 2016 Extract (EIAR Volume 3a)**.

1.2.13 A combined total of 3,242 peat depth probes were taken during the peat surveys, as shown in **Figure 8.8: Peat Depth Contour Plan (EIAR Volume 3a)**. This included 260 peat depth probes during the Stage 1 survey and 2,982 peat depth probes across the two Stage 2 surveys.

1.2.14 The findings of the Stage 1 site-wide low-density peat probing, along with Stage 2 targeted high-density probing and coring surveys found that the majority of the Site to be underlain by areas of deep peat (74 % of peat depth probes recorded peat depths greater than 1 m). The mean peat depths recorded within the developable area of the Site was noted to be between 0.63 m and 2.69 m. The deepest areas of peat were recorded up to 6.0 m in the central part of the Site.

1.2.15 In accordance with the Peatland Survey Guidance[5, 6], peat soil is defined as organic soil exceeding 0.5 m in thickness and containing greater than 60 % organic matter; organic layers of less than or equal to 0.5 m are therefore classified as organo-mineral soils rather than peat.

1.2.16 The definition for deep peat used in this TA comprises areas of soil with a peat layer more than 1 m deep in line with the Joint Nature Conservation Committee (JNCC) report[7] '*Towards an assessment of the state of UK Peatlands*'.

1.2.17 Infrastructure of the Proposed Development has been located away from these deeper peat deposits where practicable, taking into account other environmental and technical constraints, or microsited to reduce potential adverse effects. The peat mitigation hierarchy, as detailed in **Chapter 8: Hydrology, Hydrogeology, Geology and Soils (EIAR Volume 2)**, has been used, whereby consideration has been given to avoiding development on peatland in the first instance. Where this was not possible, as a result of other environmental and technical constraints, commitment is made to implement measures to reduce the likely significant effects on peat, including restoration.

1.2.18 For the calculation of carbon balance, only peat depths from areas designated for the Proposed Development's permanent infrastructure were included. Minimum and maximum expected peat depths were calculated as one standard deviation below and above the mean peat depth. It should be noted that the assessment of peat/soil depth assumes peat exists to the full depth of the probed depth value, with potential for an over estimation dependant on the underlying organic material/clay present.

1.2.19 Peatland Condition Assessment (PCA) (see **Chapter 6: Ecology (EIAR Volume 2)**) surveys undertaken for the Proposed Development show the condition of the peatland habitat to be very variable across the Study Area, on a continuum from very wet, high quality blanket bog in Near-Natural condition to Modified and Drained bog. There were widespread degraded areas that were Actively Eroding.

1.2.20 The mean annual temperature was derived based on the mean annual air temperature for Lerwick over a 30-year period between 1991 – 2020[8]. The mean annual air temperature for Lerwick was found to be 9.8°C, with minimum and maximum values of 1.8°C and 14.7°C respectively. These minimum and maximum values have been used in this TA.

1.2.21 An average and maximum carbon content of dry peat (% by weight) value of 65% has been used as this is the default value in the carbon calculator.

1.2.22 Generic hydrological parameters[3] have been used for average groundwater table depth for the Site. A value of 0.3 m has been used as the expected value. A 'maximum' value of 0.5 m has been used to represent areas of intact peat (the higher the water table the longer the payback period), and a 'minimum' value of 0.1 m has been used to represent areas of eroded peat.

1.2.23 The extent of drawdown on drainage features due to excavations onsite is variable and can extend between 2 m and 50 m horizontally around the feature. Site-specific values are not available, so the standard values from 'Windfarm Carbon Calculator Web Tool, User Guidance'[3] have been used. Therefore, the expected value is 10 m, minimum is 5 m and maximum 50 m.

1.2.24 The peat is expected to have a low dry bulk density because it is fibrous and intermediate rather than amorphous (see **Chapter 8: Hydrology, Hydrogeology, Geology and Soils (EIAR Volume 2)**). Therefore, in the absence of Site specific dry bulk density values, an average dry soil bulk density (g/cm3) of 0.2 g/cm3 was included in the calculator, with minimum and maximum values of 0.1 g/cm3 and 0.3 g/cm3 respectively.

1.2.25 For vegetation restoration, it has been assumed that five years is a reasonable time period for regeneration of most bog plants based on the Site elevation, location and current conditions, with minimum and maximum values of 2 and 10 years. The carbon accumulation rate for peatland has been derived based on the carbon calculator guidance[3], 0.25 tC ha-1 yr-1, with the accumulation rates of 0.12 tC ha-1 yr-1 and 0.31 tC ha-1 yr-1 adopted as the minimum and maximum values respectively.

Counterfactual Emission Factors

1.2.26 The most recent counterfactual emission factors for three methods of energy generation have been used in the carbon calculator. These are 0.207 tCO2 MWh-1 CO2 emissions for grid mix, 0.945 tCO2 MWh-1 for coal, and 0.424 tCO2 MWh-1 for fossil fuel mix.

Proposed Development

1.2.27 In line with standard carbon calculator practice[3], the BESS has not been included as part of the calculation. The Scottish Government's carbon calculator scope captures onshore wind infrastructure and peat/land disturbance only and includes no energy storage module.

1.2.28 The net capacity factor of the wind turbine generators is estimated to be approximately 48%, which has been estimated based on wind data analysis.

1.2.29 For the purposes of this assessment, the turbine foundations were assumed to remain unchanged regardless of their location within the Site. The calculation was based on a central excavation of approximately 22 m diameter and an approximate depth of 3-5 m subject to prevailing ground conditions. Based on the peat probing survey results, the mean peat depth at the turbine footprint is

[5] Scottish Government, Scottish Natural Heritage, SEPA. (2017). Peatland Survey. Guidance on Developments on Peatland, online version only. Available at: https://www.gov.scot/binaries/content/documents/govscot/publications/advice-and-guidance/2018/12/peatland-survey-guidance/documents/peatland-survey-guidance-2017/peatland-survey-guidance-2017/govscot:document/Guidance+on+developments+on+peatland+-+peatland+survey+-+2017.pdf [Accessed 27/04/2026]

[6] The Scottish Government (2017), Peat Landslide Hazard and Risk Assessments - Best Practice Guide for Proposed Electricity Generation Developments Available at: https://www.gov.scot/publications/peat-landslide-hazard-risk-assessments-best-practice-guide-proposed-electricity/ [Accessed 27/04/2026]

[7] Joint Nature Conservation Committee, 2011. Towards an assessment of the state of UK Peatlands, JNCC report No. 445 187_jncc445.pdf

[8] Met Office (2022). Lerwick (S. Screen) (Shetland Islands) Location-specific long-term averages. [online] Available at: https://www.metoffice.gov.uk/research/climate/maps-and-data/location-specific-long-term-averages/gfxnj5fx4. [Accessed 27/04/2026]

estimated to be 1.17 m. The minimum and maximum expected peat depths are 0.66 m and 1.74 m respectively.

1.2.30 The proposed turbine permanent area of the hardstandings and laydowns total 26,205 m^2, with the same excavation footprint. Based on the peat probing survey results, the mean peat depth at the turbine hardstandings is calculated as 1.17 m. For the purposes of the carbon calculator, minimum and maximum depths recorded around hardstandings of 0.66 m and 1.74 m respectively are used.

1.2.31 A total of 7.5 km of new excavated permanent access tracks (of a total footprint of 63,534 m^2) would be created during construction of the Proposed Development. The proposed width of the excavated access track is 5 m on straight sections and a maximum of 7.5 m on bends with 0.5 m wide shoulders on each side. The minimum and maximum expected peat depths along the access tracks are 1.26 m and 1.87 m respectively with the mean of 1.55 m used.

1.2.32 Floating track has been considered as part of the design process to minimise disturbance and excavation of peat in these sections but has not been possible due to the undulating topography of the Site. However, these would be considered further at detailed design stage post-consent, once detailed ground investigation has been undertaken and the design further refined. However, floating track has not been considered within this TA.

1.2.33 A substation compound (of a total footprint of approximately 5,000 m^2) and BESS compound (total footprint of approximately 5,000 m^2) have been considered in the carbon balance assessment. The mean, minimum, and maximum peat depths at this location are 0.95 m, 2.10 m, and 0.14 m respectively.

1.2.34 The potential peat excavation volume associated with the borrow pit has also been considered (approximately 3,435 m^2 footprint). The mean peat depth of the borrow pit is 0.45 m. The minimum, and maximum expected peat depths are 0.4 m, and 1.01 m respectively.

1.2.35 Temporary infrastructure such as construction compounds, and cable trenches are not expected to result in a permanent displacement of peat.

1.2.36 Peat excavation volumes have been estimated based on the interpolated peat depth survey information and outlined in **Technical Appendix 8.5: Outline Peat Management Plan (EIAR Volume 4)**.

1.2.37 The Peat Landslide Hazard Risk Assessment (PLHRA) is detailed in **Technical Appendix 8.6 (EIAR Volume 4)**. It is assumed that measures have been taken to limit damage so carbon losses due to peat landslide fixed as 'negligible' in the online carbon calculator.

Opportunities for Carbon Sequestration

Any local improvements to carbon sequestration, such as areas of peatland habitat restoration, would result in a reduction in the net carbon emissions from the Proposed Development. Much of the peatland on the Site was in a Modified condition as a result of artificial change. There is ambition, as a part of the Proposed Development, to restore and enhance the peat condition in line with the Near-Natural condition peat also found on Site. These are summarised as part of **Technical Appendix 6.5: Outline Biodiversity Enhancement and Habitat Management Plan** and **Technical Appendix 8.5: Outline Peat Management Plan (EIAR Volume 4)**.

1.2.38 Drainage implemented during the construction phase of the Proposed Development would be removed prior to operation, and has been assumed to be temporary in duration. For the purposes of the carbon calculator the expected value for completion of backfilling, removal of any surface drains, and restoration of the hydrology is 0.25 years, and the minimum and maximum are assumed to be 0.1 year and 3 years respectively.

1.2.39 It has been assumed that at the end of its operation (40 years), the Proposed Development would be decommissioned. In this case, it has been assumed that access tracks constructed would remain in situ, drainage channels and gullies in peat would be blocked, and turbine infrastructure removed.

1.3 Results

1.3.1 The estimated total carbon losses as calculated by the online carbon calculator, as shown in **Table 2.4.1**, summarises the following information:

- Losses due to turbine life: Embodied/lifecycle emissions from manufacture, transport, construction, operation, and decommissioning;
- Losses due to backup: Fossil-generation used to balance wind variability. It is assumed that back up capacity is derived from conventional fossil fuel generation;
- Losses due to reduced carbon fixing potential: Lower CO2 uptake where vegetation is covered or affected by drainage;
- Losses from soil organic matter: CO2 released as disturbed/drained peat oxidises; and
- Losses from Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC) leaching: Carbon washed into watercourses that later oxidises to CO2;

1.3.2 The carbon losses calculated are independent of the generation mix used to calculate the overall carbon balance.

1.3.3 The Expected CO_2 Losses scenario presents anticipated carbon losses based on the mean input parameters detailed in **Section 2.4.2**. The Minimum Value Losses scenario shows expected carbon losses using minimum input parameters, while the Maximum Value CO^2 Losses scenario reflects expected carbon losses based on maximum input parameters.

Table 2.4.1: Total Carbon Losses

Source	Expected CO2 Losses (tCO2)	Minimum Value CO2 Losses (tCO2)	Maximum Value CO2 Losses (tCO2)
Losses due to turbine life	48,209	44,846	50,078
Losses due to backup	41,302	0	42,788
Losses due to reduced carbon fixing potential	1,134	334	6,244
Losses from soil organic matter	52,632	13,924	140,004
Losses from DOC and PCO leaching	1,528	46	26,029
Losses due to forestry felling	0	0	0
Total losses of carbon dioxide	144,806	59,150	265,142

1.3.4 The expected total carbon payback time for the Proposed Development, based on the carbon losses compared to electricity generation from traditional sources such as coal, mixed generation, and fossil fuel mixed generation, as determined by the online carbon calculator, is shown in **Table 2.4.2**.

1.3.5 The Minimum Value 0% Balancing Capacity indicates that no additional balancing is required, with generation matching demand. The Maximum Value 5% Balancing Capacity accounts for up to 5% additional capacity to manage variability, including mechanisms like energy storage or backup generators.

Table 2.4.2: Carbon Payback Period				
Source	**Counterfactual Emission Factors ($tCO2\ MWh^{-1}$)**	**Carbon Payback Period (Years)**		
		Expected Value	**Minimum Value 0% Balancing Capacity**	**Maximum Value 5% Balancing Capacity**
Coal fired generation	0.945	0.7	0.1	1.3
Grid mix generation	0.207	3.0	0.7	5.9
Fossil fuel mix generation	0.424	1.5	0.3	2.9

1.4 Summary

1.4.1 The carbon assessment indicates that the carbon emission payback time for the Proposed Development would be:

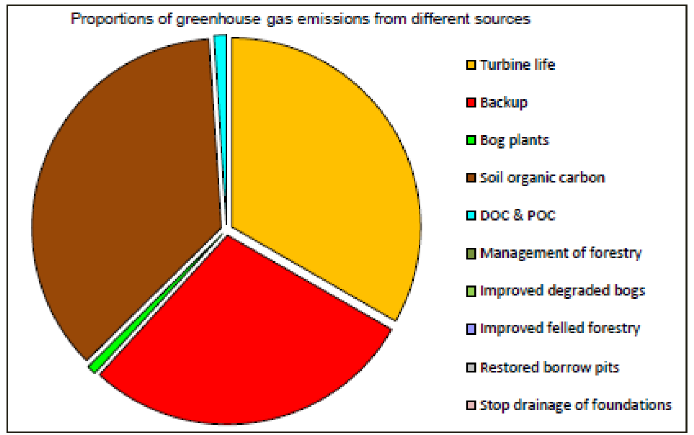
- Between 0.3 and 2.9 years, if compared against a fossil fuel mix generation, with an expected value of 1.5 years; and
- Between 0.7 and 5.9 years based on a grid mix generation, with an expected value of 3 years.

1.4.2 In conclusion, the Proposed Development would deliver a significant net beneficial impact in terms of the total CO^2 emissions offset given the expected operational life of 40 years.

Annex 1: Carbon Calculator Assessment Results and Charts

1. Windfarm CO_2 emission saving over…			
…coal-fired electricity generation (tCO_2 yr^{-1})	220929	206624	228876
…grid-mix of electricity generation (tCO_2 yr^{-1})	48394	45260	50135
…fossil fuel - mix of electricity generation (tCO_2 yr^{-1})	99126	92707	102691
Energy output from windfarm over lifetime (MWh)	9351475	8745984	9687859
Total CO_2 losses due to wind farm (t CO_2 eq.)			
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	48209	44846	50078
3. Losses due to backup	41302	0	42788
4. Losses due to reduced carbon fixing potential	1134	334	6244
5. Losses from soil organic matter	52632	13924	140004
6. Losses due to DOC & POC leaching	1528	46	26029
7. Losses due to felling forestry	0	0	0
Total losses of carbon dioxide	144806	59150	265142
8. Total CO_2 gains due to improvement of site (t CO_2 eq.)			
8a. Change in emissions due to improvement of degraded bogs	0	0	-14327
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	-58
8d. Change in emissions due to removal of drainage from foundations & hardstanding	-936	408	-12105
Total change in emissions due to improvements	-936	408	-26489

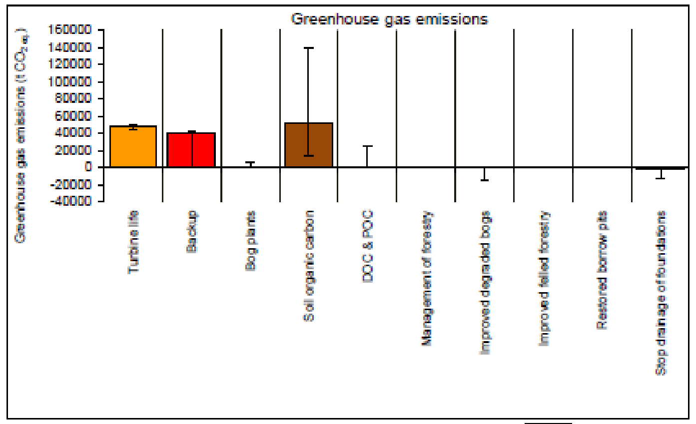
RESULTS	*Exp.*	*Min.*	*Max.*
Net emissions of carbon dioxide (t $CO_{2\ eq.}$)	143870	32661	265550
Carbon Payback Time			
…coal-fired electricity generation (years)	0.7	0.1	1.3
…grid-mix of electricity generation (years)	3.0	0.7	5.9
…fossil fuel - mix of electricity generation (years)	1.5	0.3	2.9
Ratio of soil carbon loss to gain by restoration (TARGET ratio (Natural Resources Wales) < 1.0)	No gains!	-0.5	No gains!
Ratio of CO_2 eq. emissions to power generation (g / kWh) (TARGET ratio by 2030 (electricity generation) < 50 g /kWh)	15	3	30

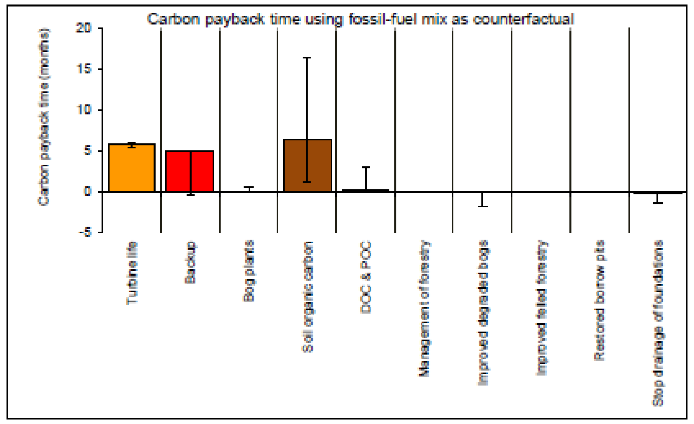


Data used in barchart of carbon payback time using fossil-fuel mix as counterfactual

Greenhouse gas emissions

	Exp.	*Min*	*Max*
Turbine life	48209	3364	1869
Backup	41302	41302	1486
Bog plants	1134	800	5110
Soil organic carbon	52632	38708	87372
DOC & POC	1528	1482	24500
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	48209	3364	1869	6	0	0
Backup	41302	41302	1486	5	5	0
Bog plants	1134	800	5110	0	0	1
Soil organic carbon	52632	38708	87372	6	5	10
DOC & POC	1528	1482	24500	0	0	3
Management of forestry	0	0	0	0	0	0
Improved degraded bogs	0	0	-14327	0	0	-2
Improved felled forestry	0	0	0	0	0	0
Restored borrow pits	0	0	-58	0	0	0
Stop drainage of foundations	-936	-1344	-11169	0	0	-1
	143870			17		

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Results

PAYBACK TIME AND CO_2 EMISSIONS

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

Click here to return to Input data — Click here

Click here to return to Instructions — Click here