Technical Appendix 2.4: Carbon Balance Assessment

Technical Appendix 2.4: Carbon Balance Assessment

2.4.1 Introduction

2.4.1.1 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: Development Description (EIAR Volume 2)** and **Chapter 8: Hydrology, Hydrogeology, and Geology (EIAR Volume 2)**.

2.4.1.2 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.

2.4.1.3 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 that require consideration include the potential loss of CO_2 from carbon stored within the peat deposits within the Site.

2.4.1.4 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 (April 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.

2.4.1.5 This Technical Appendix is supported by the following:

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

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

2.4.2 Input Parameters

2.4.2.1 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

2.4.2.2 The Proposed Development would comprise an onshore wind farm with up to 21 turbines and a total estimated installed capacity of 157.5 MW. The net capacity factor for the Proposed Development is estimated to be approximately 45.6%, which has been estimated based on wind data analysis using published wind atlas data, data collected from the onsite meteorological monitoring mast and LiDAR.

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

2.4.2.4 The CO_2 emissions generated during the lifetime of the Proposed Development, including those created during manufacture and removal of turbines, are calculated using default values within the carbon calculator.

2.4.2.5 The Proposed Development also includes a Battery Energy Storage System (BESS) with an approximate capacity of 50 MW which is not included in the calculations.

Peatland and Environmental Characteristics of the Site

2.4.2.6 The Site covers an area of approximately 2,555 hectares (ha) and is located approximately 1 km north of Leadhills village, and 1.5 km south of Abington village, with the A74 (M) motorway located to the east, as shown on **Figure 1.1 (EIAR Volume 3a)**.

2.4.2.7 The Site predominantly comprises open moorland, much of which is managed for grouse and sheep grazing improved grassland and semi-improved grassland, with areas of forestry located in the valleys, predominantly to the east of the B797.

2.4.2.8 The Site terrain is undulating with multiple hills within the boundary such as Ravengill Dod (499 m AOD), Coom Dod (553 m AOD), Hunt Law (523 m AOD) and Brown Dod (489 m AOD). This landscape is typical of the wider location within the Southern Uplands.

2.4.2.9 The Site lies within the Clyde catchment, with multiple watercourses and waterbodies located within the Site, including tributaries of the River Clyde such as Glengonnar Water through the centre of the Site and Snar Water in the west. Elvan Water runs along the southern Site boundary and the River Clyde lies approximately 1 km to east of the Site boundary at its closest point.

2.4.2.10 The entirety of the Site, including access tracks and proposed turbine locations is shown to be within the River Clyde catchment (SEPA Catchment No. 97). Larger tributaries of the River Clyde, that are located within the Site boundary include Glengonnar Water, Laggen Gill, Kirk Gill, Glencaple Burn, Glenkip burn, Glendorch Burn, and Elvan Water/Shotcluech Water. Multiple unnamed watercourses are also present on the Site, including a number of watercourses which are crossed by existing infrastructure in the form of circular culverts.

2.4.2.11 According to the (BGS) Geology Map Viewer[4], the superficial geology underlying the Site predominantly comprises Devensian Till (Diamicton) and peat deposits. Small areas of Alluvium, comprising clay, silt, sand and gravel, are present in proximity to the burns and watercourses at the Site. There are also small areas of hummocky (moundy) glacial deposits (Diamicton). Large areas of the Site have no superficial deposits mapped. This is shown in **Figure 8.3 (EIAR Volume 3a)**. The underlying bedrock across the Site comprises Portpatrick Formation (Wacke) to the north of Leadhills, Kirkcolm Formation (Wacke) in the northwest portion, and Shinnel Formation (Wacke) in the southeast portion of the Site. There are small areas of Crawford Group (Chert) which is faulted, shown crossing the Site in a northeast to south westerly direction, and this comprises lava, chert, tuff and mudstone succession. This is shown in **Figure 8.4 (EIAR Volume 3a)**.

2.4.2.12 Findings of the peat depth surveys are presented in **Technical Appendix 8.5 (EIAR Volume 4)**. In summary, a total of 897 peat depth probes were taken during the Stage 1 peat survey, 8,118 peat probes during Stage 2. This resulted in a combined peat depth dataset of 9,015 probes. This was

[1] Scottish Government, 2022, Carbon Calculator Tool for Onshore Wind Farms. Available at: [Carbon calculator for wind farms on Scottish peatlands: factsheet - gov.scot]

[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 [Carbon calculator: technical guidance - gov.scot]

[4] British Geological Survey Online Viewer (https://geologyviewer.bgs.ac.uk/)

supplemented by an additional 1,502 peat depth probe data points from historical publicly available peat probing data[5].

2.4.2.13 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 is either absent of peat or, where organic soils are present, they are relatively shallow (less than or equal to 0.5 m in depth for 83% of samples).

2.4.2.14 In accordance with the Peatland Survey Guidance[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.

2.4.2.15 Based on this definition, 83% of samples recorded organic layers of less than or equal to 0.5 m or were absent of peat. Further, approximately 97% of the peat depth probes recorded peat depths less than or equal to 1 m depth.

2.4.2.16 The peat depth survey results for the Site are summarised as follows:

- 697 no. samples (8.6%) located on land with no peat present;
- 6,044 no. samples (74.5%) located on land with > 0.05 m and ≤0.5 m depth of peat or organo-mineral soil;
- 1,118 no. samples (13.8%) located on land with >0.5 m and ≤1.0 m depth of peat;
- 184 no. samples (2.3%) located on land with >1.0 m and ≤1.5 m depth of peat;
- 45 no. samples (0.6%) located on land with >1.5 m and ≤2.0 m depth of peat; and
- 30 no. samples (0.4%) located on land with >2.0 m and >4.0 m depth of peat.

2.4.2.17 The maximum peat depth recorded during the Stage 2 surveys was 3.7 m and the average (mean) was 0.36 m. The maximum and mean peat depth of the entire data set including data outside the Proposed Development was 5.4 m and 0.37 m respectively. The peat depth interpolated contours are shown on **Figure 8.6 (EIAR Volume 3a)**.

2.4.2.18 Most of the infrastructure of the Proposed Development has been located in areas where the peat depth is expected to be absent or 0.5 m or less. This includes all of the turbines and their associated hardstanding areas, with the exception of turbines T6 and T10, where the peat depth is expected to be up to 0.51 m and 0.53 m respectively. 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.

2.4.2.19 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.

2.4.2.20 Peatland Condition Assessment (PCA) (detailed within **Technical Appendix 6.2, EIAR Volume 4**) surveys undertaken for the Proposed Development have shown the peatland within the Study Area to comprise a patchwork of modified and degraded blanket bog, with widespread evidence of historic drainage and localised areas of actively eroding peatland (**Figure 6.5, EIAR Volume 3a**). No peatland within the Study Area was classified as near-natural as part of the PCA. The PCA data nevertheless identifies clear potential for peatland restoration opportunities within the Site, particularly through reprofiling and re-wetting of modified and eroding areas. These findings have informed proposals included in the Outline Biodiversity Enhancement and Management Plan (OBEMP) (**Technical Appendix 6.7, EIAR Volume 4**).

2.4.2.21 The mean annual temperature was derived based on the mean annual air temperature for Abington over a five-year period between 2020 – 2024[7]. The mean annual air temperature for Abington was found to be 6.9°C, with minimum and maximum values of -4°C and 18°C respectively. However, 0°C and 15°C have been used as the minimum and maximum values in the carbon calculator as these are the maximum and minimum values allowed.

2.4.2.22 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. A minimum value of 19% has also been used as per tool limitations.

2.4.2.23 Generic hydrological parameters 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.

2.4.2.24 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'[8] have been used. Therefore, the expected value is 10 m, while minimum is 5 m and maximum 50 m.

2.4.2.25 The peat across the Site is generally moderately to strongly decomposed, with peat core data indicating intermediate peat grading into amorphous peat at depth (see **Technical Appendix 8.5, EIAR Volume** 4). This is supported by Von Post classifications typically ranging from H5 to H8, together with low fine fibre content and low-to-moderate coarse fibre content within the catotelmic layers. On this basis, the peat is expected to have a moderate dry bulk density. Therefore, in the absence of site-specific laboratory-derived bulk density measurements, an average dry soil bulk density of 0.14 g/cm^3 was adopted in the carbon calculator, with minimum and maximum values of 0.10 g/cm^3 and 0.20 g/cm^3 respectively.

2.4.2.26 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

2.4.2.27 The most recent counterfactual emission factors for three methods of energy generation have been used in the carbon calculator. These are 0.207 tCO_2 MWh^{-1} CO_2 emissions for grid mix, 0.945 tCO_2 MWh^{-1} for coal, and 0.424 tCO_2 MWh^{-1} for fossil fuel mix[9].

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[5] Data was taken from the Harryburn wind farm consent application, which was submitted in 2018. Available online: https://www.energyconsents.scot/ApplicationDetails.aspx?cr=EC00005277, access 26.03.2026

[6] Scottish Government, Scottish Natural Heritage, SEPA. (2017). Peatland Survey. Guidance on Developments on Peatland. Available at: https://www.gov.scot/publications/peatland-survey-guidance

[7] Abington Weather Averages - South Lanarkshire, GB

[8] Carbon calculator: technical guidance ; https://www.gov.scot/publications/carbon-calculator-technical-guidance/

[9] Digest of UK Energy Statistics (DUKES) 2025 - GOV.UK

Proposed Development

2.4.2.28 In line with standard carbon calculator practice, 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.

2.4.2.29 The net capacity factor of the wind turbine generators is estimated to be approximately 45.6%, which has been estimated based on wind data analysis.

2.4.2.30 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 32 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 foundations is estimated to be 0.34 m. The minimum and maximum expected peat depths are 0.21 m and 0.47 m respectively.

2.4.2.31 The proposed permanent area of the turbine hardstandings and laydowns totals 42,336 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 0.34 m. For the purposes of the carbon calculator, minimum and maximum depths of the hardstandings are 0.21 m and 0.47 m respectively are used.

2.4.2.32 A total of 30.5 km of access tracks would be required as part of the Proposed Development, 25.3 km of which would be new excavated access tracks (of a total footprint of 213,500 m^2). The proposed width of the excavated access track is 6 m with 0.5 m wide shoulders on each side. The minimum and maximum expected peat depths are 0.20 and 0.50 m respectively, with a mean of 0.35 m.

2.4.2.33 Approximately 4.68 km of upgraded existing track is proposed as part of the Proposed Development.

2.4.2.34 Approximately 0.57 km of floating track is also proposed as part of the Proposed Development, traversing an area underlain by deeper peat. The minimum and maximum expected peat depths are 1.24 and 2.77 m respectively, with a mean of 2.00 m.

2.4.2.35 No forestry is proposed to be felled as a result of the Proposed Development.

2.4.2.36 A Substation Compound (of a total footprint of approximately 9,600 m^2) has been considered in the carbon balance assessment. The mean, minimum, and maximum peat depths at this location are 0.34 m, 0.23 m and 0.45 m respectively.

2.4.2.37 The BESS Compound (of a total footprint of approximately 10,500 m^2) has been included in the carbon balance assessment. The mean, minimum, and maximum peat depths at this location are 0.34 m, 0.20 m, and 0.48 m respectively.

2.4.2.38 The potential peat excavation volume associated with the four borrow pit search areas has also been considered (approximately 81,500 m^2 footprint). The mean peat depth across all borrow pits is 0.27 m. The minimum, and maximum expected peat depths are 0.13 m, and 0.40 m respectively.

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

2.4.2.40 Peat excavation volumes have been estimated based on the interpolated peat depth survey information and outlined in the Outline Peat Management Plan (**Technical Appendix 8.6, EIAR Volume 4**).

2.4.2.41 The Peat Landslide Hazard Risk Assessment (PLHRA) is detailed in **Technical Appendix 8.7 (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

2.4.2.42 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. Given the absence/ shallow depth, and potentially modified condition of the peat at the Site as a result of artificial drainage, there are opportunities, as part of the Proposed Development, to restore and enhance the peat condition. These are summarised as part of the Outline Biodiversity Enhancement Management Plan (OBEMP) (**Technical Appendix 6.7, EIAR Volume 4**) and Outline Peat Management Plan (OPMP) (**Technical Appendix 8.5, EIAR Volume 4**).

2.4.2.43 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.

2.4.2.44 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.

2.4.3 Results

2.4.3.1 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 CO_2 uptake where vegetation is covered or affected by drainage;
- Losses from soil organic matter: CO_2 released as disturbed/drained peat oxidises;
- Losses from Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC) leaching: Carbon washed into watercourses that later oxidises to CO_2; and
- Losses due to forestry felling: Emissions and foregone sequestration from tree removal.

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

2.4.3.3 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 CO_2 Losses (tCO_2)	Minimum Value CO_2 Losses (tCO_2)	Maximum Value CO_2 Losses (tCO_2)
Losses due to turbine life	137,342	137,342	137,342
Losses due to backup	116,999	0	116,999
Losses due to reduced carbon fixing potential	3,937	1,186	20,680
Losses from soil organic matter	25,949	-15,231	90,353

Table 2.4.1: Total Carbon Losses			
Source	**Expected CO_2 Losses (tCO_2)**	**Minimum Value CO_2 Losses (tCO_2)**	**Maximum Value CO_2 Losses (tCO_2)**
Losses from DOC and PCO leaching	18	23	30186
Losses due to forestry felling	0	0	0
Total losses of carbon dioxide	284,244	123,320	395,560

2.4.3.4 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**.

2.4.3.5 The Minimum Value 0% Balancing Capacity indicates no additional balancing is required, with generation perfectly 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 (tCO_2 MWh^{-1})**	**Carbon Payback Period (years)**		
		Expected Value	**Minimum Value 0% Balancing Capacity**	**Maximum Value 5% Balancing Capacity**
Coal fired generation	0.945	0.5	0.1	0.7
Grid mix generation	0.207	2.2	0.5	3.0
Fossil fuel mix generation	0.424	**1.1**	**0.2**	**1.5**

2.4.4 Summary

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

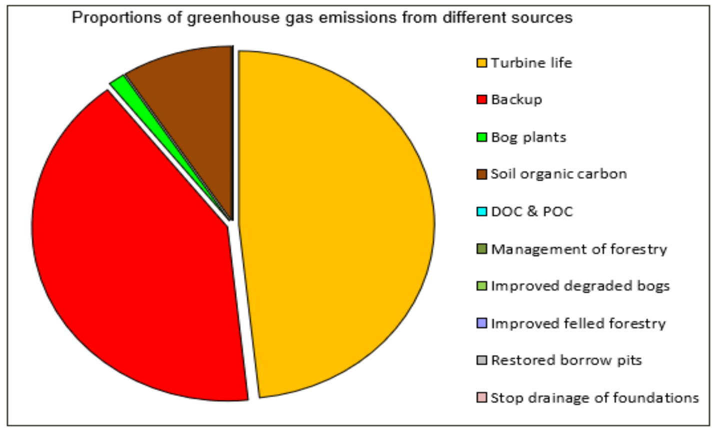
- Between 0.2 and 1.5 years, if compared against a fossil fuel mix generation, with an expected value of 1.1 years; and
- Between 0.5 and 3.0 years based on a grid mix generation, with an expected value of 2.2 years.

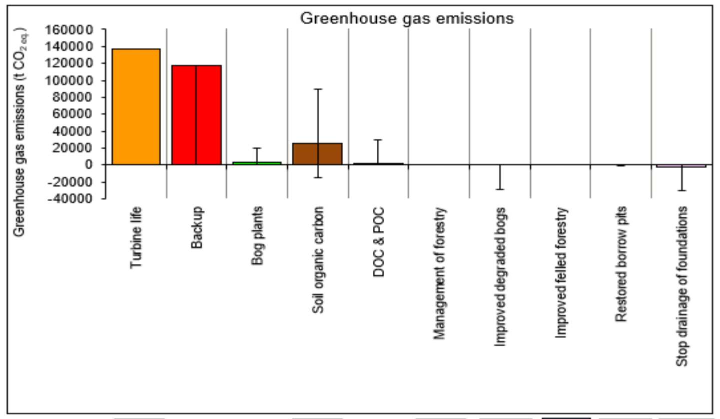
2.4.4.2 In conclusion, the Proposed Development would deliver a significant net beneficial impact in terms of the total CO_2 emissions offset given the expected operational life of 40 years.

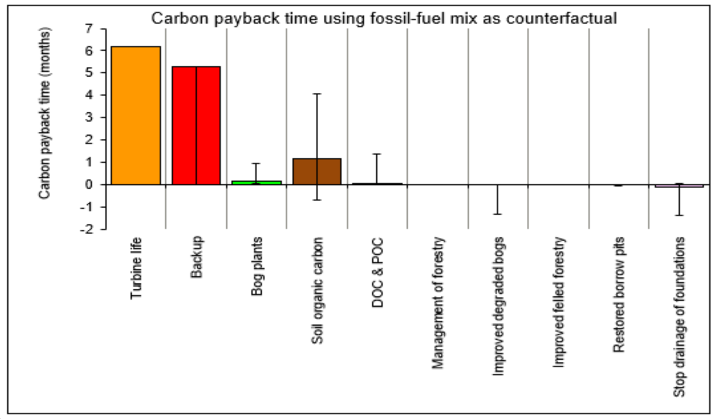
Annex 1: Carbon Calculator Assessment Results and Charts

	Exp.	Min.	Max.
1. Windfarm CO_2 emission saving over...			
...coal-fired electricity generation (tCO_2 yr^{-1})	594540	594540	594540
...grid-mix of electricity generation (tCO_2 yr^{-1})	130233	130233	130233
...fossil fuel - mix of electricity generation (tCO_2 yr^{-1})	266757	266757	266757
Energy output from windfarm over lifetime (MWh)	25165728	25165728	25165728
Total CO_2 losses due to wind farm (t CO_2 eq.)			
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	137342	137342	137342
3. Losses due to backup	116999	0	116999
4. Losses due to reduced carbon fixing potential	3937	1186	20680
5. Losses from soil organic matter	25949	-15231	90353
6. Losses due to DOC & POC leaching	18	23	30186
7. Losses due to felling forestry	0	0	0
Total losses of carbon dioxide	284244	123320	395560
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	-29237
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	-1004
8d. Change in emissions due to removal of drainage from foundations & hardstanding	-2239	1017	-30439
Total change in emissions due to improvements	-2239	1017	-60679

RESULTS	Exp.	Min.	Max.
Net emissions of carbon dioxide (t $CO_{2\ eq.}$)	**282005**	**62641**	**396577**
Carbon Payback Time			
...coal-fired electricity generation (years)	0.5	0.1	0.7
...grid-mix of electricity generation (years)	2.2	0.5	3.0
...fossil fuel - mix of electricity generation (years)	**1.1**	**0.2**	**1.5**
Ratio of soil carbon loss to gain by restoration (TARGET ratio (Natural Resources Wales) < 1.0)	No gains!	0.3	No gains!
Ratio of CO_2 eq. emissions to power generation (g / kWh) (TARGET ratio by 2030 (electricity generation) < 50 g /kWh)	**11**	**2**	**16**







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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

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

Greenhouse gas emissions

	Exp.	Min	Max
Turbine life	137342	0	0
Backup	116999	116999	0
Bog plants	3937	2750	16743
Soil organic carbon	25949	41181	64404
DOC & POC	18	0	30169
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				Carbon payback time (months)		
	Exp.	Min.	Max.	Exp.	Min.	Max.
Turbine life	137342	0	0	6	0	0
Backup	116999	116999	0	5	5	0
Bog plants	3937	2750	16743	0	0	1
Soil organic carbon	25949	41181	64404	1	2	3
DOC & POC	18	-6	30169	0	0	1
Management of forestry	0	0	0	0	0	0
Improved degraded bogs	0	0	-29237	0	0	-1
Improved felled forestry	0	0	0	0	0	0
Restored borrow pits	0	0	-1004	0	0	0
Stop drainage of foundations	-2239	-3256	-28200	0	0	-1
	282005			13		