Technical Appendix 8.7

Carbon Balance Assessment

This page is intentionally blank.

TA 8.7 Carbon Balance Assessment

Contents

This page is intentionally blank.

1 Introduction

1.1.1 Increasing atmospheric concentrations of greenhouse gases (GHGs), including carbon dioxide (CO_2), also referred to as carbon emissions, are resulting in climate change. A major contributor to this increase in GHG emissions is the burning of fossil fuels. With concern growing over climate change, reducing its cause is of upmost importance. The replacement of traditional fossil fuel power generation with renewable energy sources provides high potential for the reduction of GHG emissions. This is reflected in UK and Scottish Governments' climate change and renewable energy policy and commitments.

1.1.2 Whilst the Proposed Development will reduce carbon emissions by replacing the need to burn fossil fuels for power, no form of electricity generation is completely carbon free; for onshore wind farms, energy storage and solar photovoltaic (PV) installations, there will be emissions resulting from component manufacturing, transportation and installation processes associated with the Proposed Development.

1.1.3 In addition to the lifecycle emissions from the development equipment and infrastructure, where a development is located on carbon rich soils such as peat or within forestry, there are potential emissions resulting from direct action of excavating peat for construction and also the indirect changes to hydrology that can result in losses of soil carbon, as well as forestry felling. The footprint of a development's infrastructure will also decrease the area covered by carbon-fixing vegetation.

1.1.4 Conversely, restoration activities undertaken post-construction or post-decommissioning could have a beneficial effect on carbon uptake through the restoration of modified bog habitat. Carbon losses and gains during the construction and lifetime of a renewable energy generation development farm, and the long-term impacts on the peatlands on which they are sited, need to be evaluated to understand the consequences of permitting such developments.

1.1.5 Consideration of potential lifecycle emissions for onshore renewable energy development in Scotland has tended to focus on wind energy, given that wind farms are often constructed on peatlands or in forestry, resulting in associated carbon emissions from excavation of peat and forestry felling. The Scottish Government's industry-accepted 'Carbon Calculator' tool (see paragraph 1.2.1 below) relates only to onshore wind energy projects, and there is no equivalent for energy storage or solar PV installations.

1.1.6 In respect of the Proposed Development, the northern development area is located within forestry and on peat and peaty soils, therefore appropriate consideration of the carbon balance is required. The southern development area, where the solar PV panels and long-duration Battery Energy Storage System (BESS) are sited, is not within forestry and is not sited on peat soils. Although it is acknowledged that there will be carbon emissions associated with the manufacture and delivery of the BESS and solar PV infrastructure, the generation of renewable electricity is expected to outweigh those emissions to an extent that, in the absence of other construction-related emissions such as peat excavation and forestry felling, detailed carbon balance analysis is not warranted. The carbon balance assessment presented in this document therefore focuses on the wind energy element of the Proposed Development. This is in line with the approach set out at the scoping stage.

1.1.7 A technical review of energy displacement by the UK Energy Research Centre (UKERC) considered over two hundred studies and papers from all round the world for the UK Government and concluded that "*it is unambiguously the case that wind energy can displace fossil fuel-based generation, reducing both fuel use and carbon dioxide emissions*" (UKERC, 2006). Whilst the wind turbines will reduce carbon emissions by replacing the need to burn fossil fuels for power, there is the potential for carbon fixers and sinks to be lost through the clearing of vegetation and materials for construction. There must therefore be a sufficient balance between the carbon reduced and that which is produced and lost through associated processes.

1.2 Methodology

1.2.1 All applications that are over 50 MW are dealt with through the Scottish Government's Energy Consents Unit (ECU) in accordance with Section 36 of the Electricity Act 1989 and require a carbon balance assessment using the Scottish Government's online 'Carbon Calculator' tool, that can be used to calculate the greenhouse gas emissions and carbon payback times for wind farm developments on Scottish peatlands. This online tool is supported by two documents published by the Scottish Government and Scottish Renewables, and Scottish Environment Protection Agency (SEPA) to aid in calculating the potential carbon losses and savings.

1.2.2 At the time of submission, the online tool is not accessible, and therefore the assessment has been undertaken using the Carbon Assessment Tool spreadsheet (v2.14.1), issued by SEPA.

1.2.3 As noted above, given the southern development area is not located on peat, the assessment considers the northern development area only.

1.2.4 The Carbon Calculator compares an estimate of the carbon emissions from the construction, operation, and decommissioning of the Proposed Development to those emissions estimated from other electricity generation sources. Input parameters are based on the proposed site design, infrastructure dimensions, results from peat depth surveys and laboratory testing of peat, and other information gained from site survey work, desk study and, where applicable, assumptions relating to groundwater, drainage, and habitat regeneration. As no infrastructure is yet to be constructed for the Proposed Development, the assumptions relating to infrastructure have been based on information for the Proposed Development or from standard, default representative information.

2 Input Parameters

2.1.1 The carbon calculator submitted allows a range of data to be input to utilise expected, minimum and maximum values, where relevant and applicable. If several parameters are varied together, however, 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 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 site.

2.1.2 Information relating to the Proposed Development (including consideration of design, operation, and construction) has been collated, and includes details of the proposed infrastructure, local ecology, and restoration proposals associated with the Proposed Development. This collated information has been entered into the online carbon calculator and is outlined below.

Wind Farm Characteristics

2.1.3 The Proposed Development will comprise 18 turbines with an expected power rating of 7.2 MW. The operational life of the Proposed Development is expected to be 40 years.

Capacity Factor

2.1.4 The anticipated capacity factor is 37.1 %, with a minimum of 32.5 %, based on site-specific Lidar measurements and yield assessment.

Back Up

2.1.5 The Carbon Calculator indicates that if over 20 % of national electricity is generated by wind energy, the extra capacity required for backup is 5 % of the rated capacity of the wind plant. The values for 'fraction of output to backup' are therefore input as expected 5 % and maximum 5 % to represent full requirement for backup, and a minimum of 0 % to represent no backup required (Nayak et al., 2008). SEPA indicates that for this parameter, the electricity generation capacity of Scotland, rather than the UK, should be considered. In 2022, Scotland generated about 66 % of gross electricity consumption via onshore wind (Scottish Renewables Statistics, 2023). Where the balancing capacity is obtained from fossil fuel generating stations, emissions will increase by 10 % due to reduced thermal efficiency of the reserve generation stations (Dale *et al.,* 2004). This value is fixed in the Carbon Calculator.

CO_2 Emissions from Turbine Life (tCO_2/MW)

2.1.6 CO_2 emissions during the life of a wind turbine include emissions that occur during the manufacturing, transportation, erection, operation, dismantling and removal of the structures. As there is no direct Life Cycle Assessment for the Proposed Development available at this point in time, the inbuilt Carbon Calculator option which allows for emissions to be calculated according to wind turbine capacity has been selected.

Type of Peatland

2.1.7 The most appropriate habitat description available on the Carbon Calculator is Acid Bog, refer to **Chapter 7: Ecology**.

Average Annual Air Temperature at Site

2.1.8 The average annual air temperature of 8.04 °C is based on average annual temperature data from the Met Office UK climate averages (Met Office, 2025). The nearest climate station which provides this information is located at Saughall, approximately 7 km west of the Proposed Development site.

Average Depth of Peat at Site

2.1.9 The average peat depth of 0.75 m was calculated based on peat probe data from within the site boundary of the Proposed Development.

2.1.10 The assessment is based on a series of average soil depths taken from peat surveys undertaken at the site. Probe locations sited on mineral/organic soils (<0.5 m) are conservatively included within the averages.

Carbon Content of Dry Peat

2.1.11 Site specific values are not available, so the standard values from the 'Windfarm Carbon Calculator Web Tool, User Guidance' have been used. The carbon content ranges from 49 % to 62 % with an expected value of 55 % used. This reflects a range of values typical of the carbon content anticipated from Scottish Peatlands (Birnie *et al* 1991 and Lindsay 2010).

Average Extent of Drainage around Drainage Features at Site

2.1.12 Site specific values are not available, so the standard values from the 'Windfarm Carbon Calculator Web Tool, User Guidance' have been used. The expected value is 10 m, with a minimum of 5 m and maximum of 50 m.

Average Water Table Depth at Site

2.1.13 Site specific values are not available, so the values for 'intact peat' from 'Windfarm Carbon Calculator Web Tool, User Guidance' have been used as a worst-case scenario. The expected value is 0.3 m, with a minimum 0.1 m, and a maximum 0.5 m.

Dry Soil Bulk Density

2.1.14 Given the difficulty of collecting sufficient samples to derive a representative site-specific value for this parameter, Scottish generic values for peat from 'Windfarm Carbon Calculator Web Tool, User Guidance' have been used. The expected value is 0.132 g/cm^3, with a minimum of 0.072 g/cm^3 and a maximum of 0.293 g/cm^3.

Characteristics of Bog Plants

Regeneration of Bog Plants

2.1.15 This can vary widely depending on the location of the site and the target bog plants for restoration, and whether the ground was previously afforested or open moorland. The speed of regeneration will also depend on species present and their colonising ability and traits, as well as the methods of restoration and maintenance of hydrology. Typical bog plants may take longer to establish where suitable conditions exist. The values stated take this into account considering available literature and anectodical observations of wind farms in Scotland.

2.1.16 As such, five years has been stated as a reasonable precautionary estimate for the regeneration time needed for most bog species, with a minimum of two years and a longer establishment time of 15 years.

Carbon Accumulation

2.1.17 The Carbon Calculator Guidance (Technical Note, Version 2.10.0, Scottish Government) suggests a mid-range value of 0.25 tC ha-1 yr-1 and a range of 0.12 to 0.31 t C ha-1yr-1.

Forestry Plantation Characteristics

Area of Forestry Plantation to be Felled

2.1.18 There is no net loss of forestry plantation from felling. Any crops that are cleared will be replanted back on the site or on a compensatory planting site so that the overall area of forestry is maintained.

Average Rate of Carbon Sequestration in Timber

2.1.19 The average rate of carbon sequestration in timber to be felled on site has been calculated as 1.71 tC ha $^{-1}$ yr $^{-1}$, based on information provided by the project forestry consultant.

Counterfactual Emission Factors

2.1.20 The counterfactual emission factors for three methods of energy generation are fixed in the carbon calculator. Values for both coal-fired and fossil fuel-mix emission factors are updated from Diget of UK Energy Statistics (DUKES) data for the UK which is published annually. The source for the grid-mix emission factor is the list of emission factors used to report on greenhouse gas emissions by UK organisations published by the Department for Business, Energy & Industrial Strategy (BEIS).

Borrow Pits

2.1.21 Borrow pit search areas have been included for the Proposed Development (refer to **Chapter 3: Proposed Development**). Although not all proposed borrow pit search areas are sited on peatland or likely to be used for extraction, conservatively, each location has been included in the assessment. The final dimensions of each borrow pit have yet to be defined however initial calculations, based on a series of assumptions (including suitable aggregate being located close to surface), indicate that an average dimension of 107 m x 82 m would provide sufficient yield. These dimensions have been included for each borrow pit.

2.1.22 The average peat depth in the borrow pit search areas is 0.37 m, conservatively, organic soils (<0.5 m) have also been included in the calculation of averages.

Foundations and Hardstand Areas

2.1.23 The wind turbine foundations for the Proposed Development are expected to be 30 m in diameter, with hardstands expected to be 78 m x 31 m.

2.1.24 The average peat depth in the turbine foundation areas is 0.71 m, and the average peat depth in the hardstand areas is 0.67 m. Conservatively, organic soils (<0.5 m) have also been used in the calculation of averages.

Access Tracks

2.1.25 There is 1,369 m of existing tracks within the Proposed Development site. The total length of new access tracks proposed is approximately 17.4 km. Small changes to the access track layout may occur post consent (e.g., as a result of micrositing) leading to minor variations to the overall track length. Of the 17.4 km of new track, 2.7 km are proposed to be floated.

2.1.26 The average peat depth on the route of the proposed cut access track is 0.67 m. Conservatively, organic soils (<0.5 m) have also been used in the calculation of averages.

Cable Trenches

2.1.27 The wind farm array cables on site will be laid in trenches, laid on a sand bed and backfilled using suitably graded material, and will mainly be located adjacent to the access tracks within the Proposed Development. See also **Chapter 3: Proposed Development**.

Additional Peat Excavated

2.1.28 The volume of additional peat predicted to be excavated is 405 m^3. Further information can be found in **Technical Appendix 8.4 Outline Peat Management Plan**.

Peat Landslide Hazard

2.1.29 The peat landslide hazard is a fixed value automatically defined by the Carbon Calculator, and is shown to be ‘negligible’.

Improvement of Carbon Sequestration at the Site

Improvement of Felled Plantation Land

2.1.30 The outline Habitat Management and Enhancement Plan (OHMEP) (**Technical Appendix 7.5**) outlines the objective to deliver forest to bog peatland restoration within the site boundary. The area of forestry to be improved is approximately 56 ha.

Restoration of Peat Removed from Borrow Pits

2.1.31 **Technical Appendix 8.4** outlines that all borrow pits will be restored following the completion of construction. This is a total area of 2.3 ha.

Restoration of Site after Decommissioning

Hydrology & Habitats

2.1.32 The OHMEP outlines the proposed habitat and conservation management measures in relation to the Proposed Development. The management recommendations include the aim of drain blocking to promote restoration of the hydrological conditions within the site and managing areas to favour the reintroduction of species.

Methodology for Calculating Emission Factors

2.1.33 Site-specific values have been used as required for a planning or Section 36 application.

3 Carbon Calculator Output

3.1.1 The output from the Carbon Calculator indicates the expected total carbon dioxide loss for the Proposed Development (from manufacture of turbines, construction, decommissioning, and carbon sink losses, also taking account of gains due to restoration of borrow bits) is 257,763, tonnes of carbon dioxide (tCO_2 eq). Input and output parameters are detailed in **Annex 1**.

3.1.2 Scottish Government guidance on wind farm carbon savings (Scottish Government, 2018), states: “*carbon emission savings from wind farms should be calculated using the fossil fuel sourced grid mix* *as the counterfactual, rather than the grid mix*." Taking account of the expected total CO_2 loss from the Carbon Calculator result, the Proposed Development would be expected to result in a saving of approximately **181,956 tonnes** of carbon dioxide (tCO_2) per annum, meaning a total of **over 7 million tonnes** over the 40-year operational lifetime of the Proposed Development, through displacement of carbon-emitting generation.

3.1.3 The carbon payback time of the wind element of the Proposed Development is between 0.5 and 2.2 years, with an expected payback period of **1.2 years** (approximately 14 months). This is the period of time for which a wind farm needs to be in operation before it has, by displacing generation from fossil-fuelled power stations, avoided as much carbon dioxide as was released in its lifecycle.

3.1.4 As recommended in current guidance estimated savings are for replacement of fossil fuel electricity generation but, while this could be the case in the short term, it is not the most probable scenario in the longer-term. The grid-mix of electricity generation represents the overall carbon emissions from the grid per unit of electricity and includes nuclear and renewables as well as fossil fuels. Based on the grid-mix results, the Proposed Development is expected to result in a saving of approximately 81,451 tCO_2 per annum with an expected carbon payback time of 2.6 years.

3.2 References

Dale, L, Millborrow, D, Slark, R and Strbac, G (2004) Total Cost Estimates for Large-Scale Wind Scenarios in UK, Energy Policy, 32, 1949-56

Birnie R.V., Clayton P., Griffiths P., Hulme P.D., Robertson, R.A., Sloane B.D., and S.A. Ward. (1991). Scottish peat resources and their energy potential. Department of Energy

Forestry Commission (1993). The Carbon Content of Trees, Technical Paper 4.

Forestry Commission (2011). Research Report, Wood Properties and uses of Sitka spruce in Britain

Levy, P.E., Hale, S.E., Nicoll, B.C. (2004). Biomass expansion factors and root: shoot ratios for coniferous tree species in Great Britain. Forestry

Lindsay, R. (2010). Peatbogs and Carbon: a critical synthesis. RSPB

Meteorological Office (2025). UK Climate Averages. Available at: https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages. Accessed 17/03/2025

Nayak D.R., Miller D., Nolan A., Smith P., Smith J.U. (2008). Calculating Carbon Savings from Windfarms on Scottish Peatlands - Revision of Guidelines. October 2007 to January 2008. Final Report

Nayak D.R., Miller D., Nolan A., Smith P., Smith J.U. (2010) Mires and Peat., Article 09 4, 1-23 http://www.mires-and-peat.net/, ISSN 1819-754X.

Rochefort, Quinty, Campeau, Johnson & Malterer (2003). North American approach to the restoration of Sphagnum dominated peatlands. Wetlands Ecology and Management 11: 3–20

Smith J.U., Graves P., Nayak D.R., Smith P., Perks M., Gardiner B., Miller D., Nolan A., Morrice J., Xenakis S., Waldron S., Drew S. (2011) Carbon implications of windfarms located on peatlands – update of the Scottish Government Carbon Calculator tool. Final Report, RERAD Report CR/2010/05.

Scottish Government (2016). Calculating Potential carbon losses and savings from wind farms on Scottish peatlands. Technical Note – Version 2.10.0. Available at: https://www.gov.scot/publications/carbon-calculator-for-wind-farms-on-scottish-peatlandsfactsheet/

Scottish Government (2018). Carbon Calculator: Technical Guidance. Available at: https://www.gov.scot/publications/carboncalculator-technical-guidance/

SEPA. Windfarm Carbon Calculator Web Tool, User Guidance.

UKERC – United Kingdom Energy Research Council (2006). The Costs and Impacts of Intermittency: An assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network. Available at: http://www.ukerc.ac.uk/support/Intermittency

Annex 1: Carbon Calculator Assessment Tool Output

Results

PAYBACK TIME AND CO_2 EMISSIONS

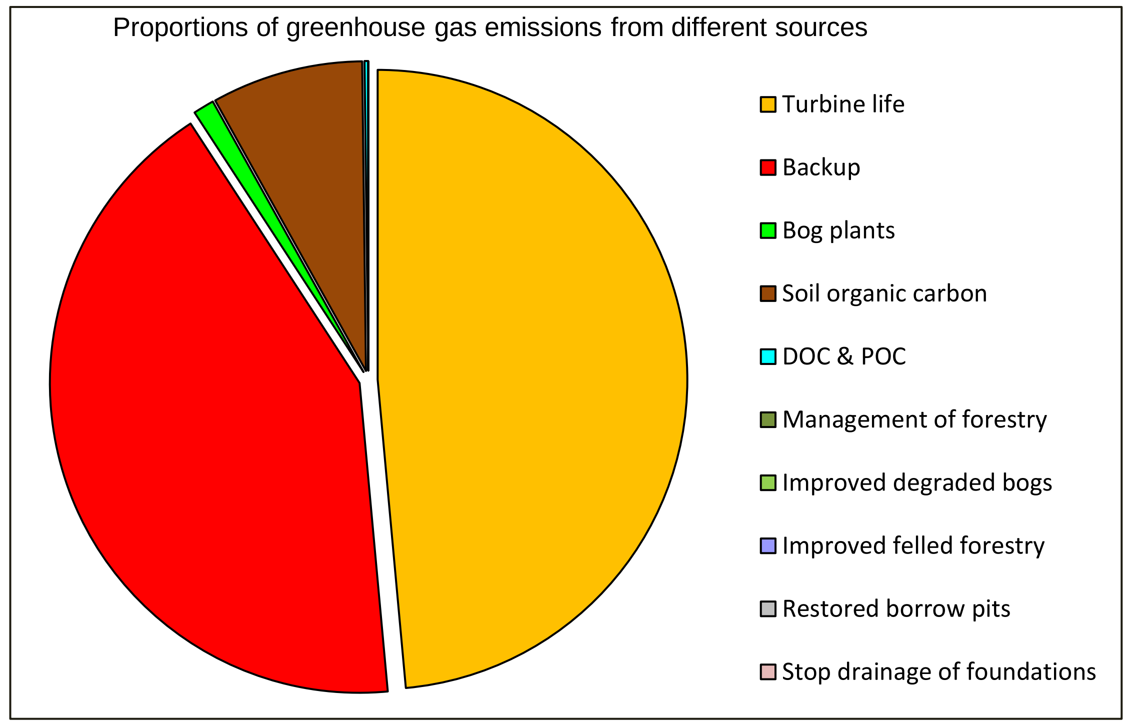
Note: The carbon payback time of the windfarm is calculated by comparing the loss of C from the site due to windfarm development with the carbon-savings achieved by the windfarm while displacing electricity generated from coal-fired capacity or grid-mix.

Click here to return to Input data — Click here

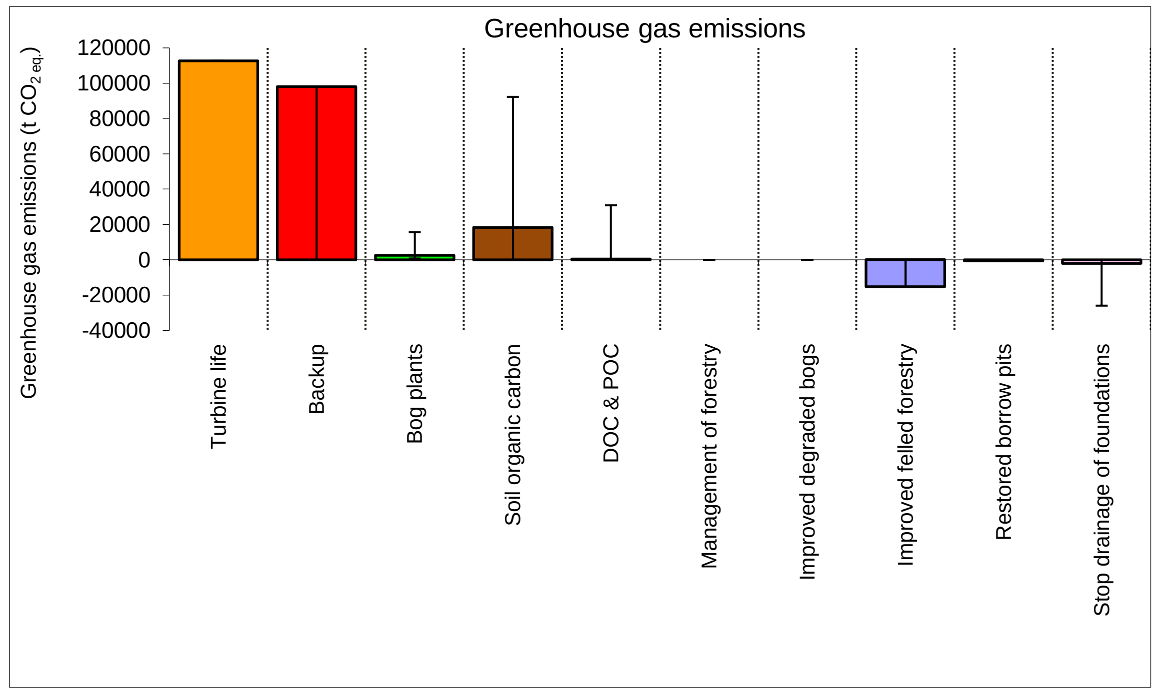
Click here to return to Instructions — Click here

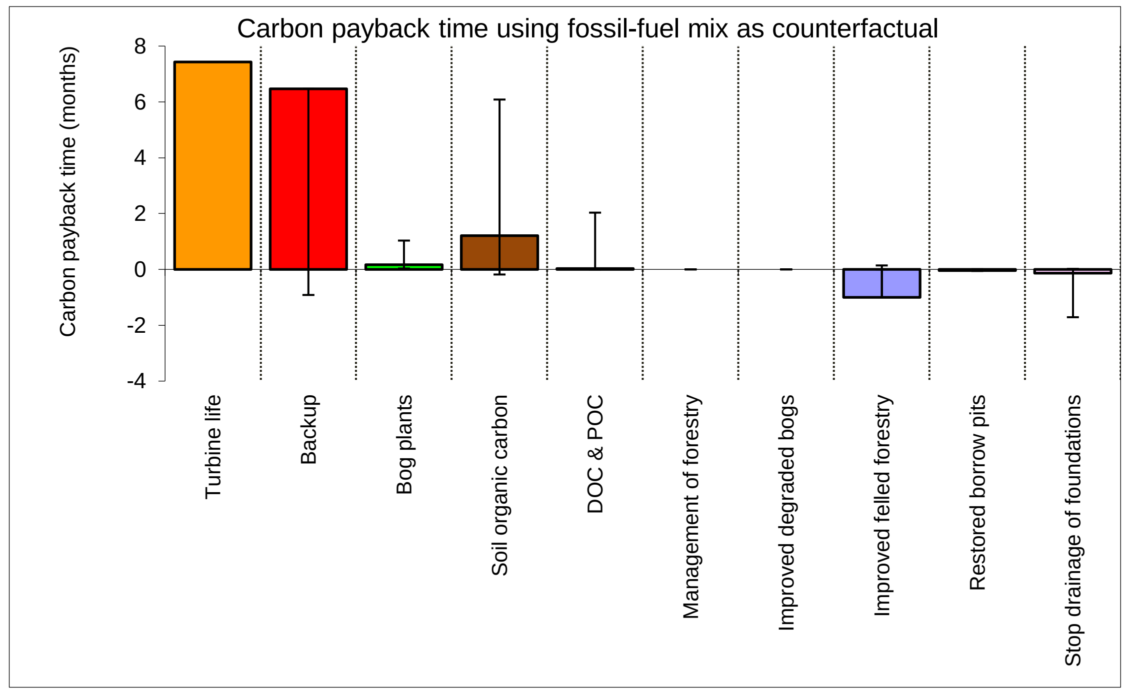
	Exp.	Min.	Max.
1. Windfarm CO_2 emission saving over…			
…coal-fired electricity generation ($tCO_2\ yr^{-1}$)	422037	369709	422037
…grid-mix of electricity generation ($tCO_2\ yr^{-1}$)	81451	71352	81451
…fossil fuel - mix of electricity generation ($tCO_2\ yr^{-1}$)	181956	159396	181956
Energy output from windfarm over lifetime (MWh)	16847793	14758848	16847793
Total CO_2 losses due to wind farm (t CO_2 eq.)			
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	112676	112676	112676
3. Losses due to backup	98090	0	98090
4. Losses due to reduced carbon fixing potential	2541	738	15668
5. Losses from soil organic matter	18329	-148	92272
6. Losses due to DOC & POC leaching	455	0	30839
7. Losses due to felling forestry	0	0	0
Total losses of carbon dioxide	232091	113266	349545

RESULTS	Exp.	Min.	Max.
Net emissions of carbon dioxide (t $CO_{2\ eq.}$)	**214174**	**86463**	**349545**
Carbon Payback Time			
…coal-fired electricity generation (years)	0.5	0.2	0.9
…grid-mix of electricity generation (years)	2.6	1.1	4.9
…fossil fuel - mix of electricity generation (years)	**1.2**	**0.5**	**2.2**
Ratio of soil carbon loss to gain by restoration (TARGET ratio (Natural Resources Wales) < 1.0)	No gains!	No gains!	No gains!
Ratio of CO_2 eq. emissions to power generation (g / kWh) (TARGET ratio by 2030 (electricity generation) < 50 g /kWh)	**13**	**5**	**24**



Turbine life	112676	0	0
Backup	98090	98090	0
Bog plants	2541	1803	13127
Soil organic carbon	18329	18478	73943
DOC & POC	455	455	30384
Management of forestry	0	0	0
Improved degraded bogs	0	0	0
Improved felled forestry	0	0	15253
Restored borrow pits	0	0	0
Stop drainage of foundations	0	0	0





Check Check Check Check Check Check Check Check Check Check

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	112676	0	0	7	0	0
Backup	98090	98090	0	6	7	0
Bog plants	2541	1803	13127	0	0	1
Soil organic carbon	18329	18478	73943	1	1	5
DOC & POC	455	455	30384	0	0	2
Management of forestry	0	0	0	0	0	0
Improved degraded bogs	0	0	0	0	0	0
Improved felled forestry	-15253	-15253	15253	-1	-1	1
Restored borrow pits	-626	-626	-212	0	0	0
Stop drainage of foundations	-2039	-2039	-23926	0	0	-2
	214174			14		

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