

MYNYDD FFORCH DWM WIND FARM

Carbon Calculator
Prepared for: **Naturalis Energy**

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1.0 Introduction

In the absence of specific guidance in Wales, the Scottish Government's tool 'carbon calculator' has been used to support the process of developing wind farm developments. The purpose of the tool is to assess, in a comprehensive and consistent way, the carbon impact of wind farm developments. This is done by comparing the carbon costs of wind farm developments with the carbon savings attributable to the wind farm.

This assessment has been produced to provide an update in the carbon emission calculation generated in the construction, operation and decommissioning of the proposed development. This spreadsheet calculates payback time for windfarm sited on peatlands using 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 & 2100, and Wind Farm and Carbon Savings – Technical Note v.2 2.10.0. Input Parameters).

The calculation spreadsheet (online version v4 reference number VIOO-5B4C-7FT3 v5) allows a range of data to be input in order to utilise expected, minimum and maximum values, where relevant and applicable. 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.

A development of six turbines with an individual output of 5.5MW are proposed with an estimated total capacity of 33MW. For this reason, the factors which have been used include the following:

- The recommended capacity factor within the calculation spreadsheet has been amended from 30% to 28% (based on the average capacity factor between 1998 and 2009 for Scotland, DTI, Energy Trends, 2009). The calculation spreadsheet has used 37.3% in order to calculate the expected payback.
- No site specific measurements for carbon content of peat have been undertaken for the proposed development. The anticipated content of 55% has therefore been used as the expected value. To ensure variations are accounted for with regard to peat, variable parameters have been used ranging from 49% (minimum) to 62% (maximum). This reflects a range of values typical of the carbon content anticipated from Scottish Peatlands (Birnie et al 1991). The value of 55% is consistent with an average value for Scottish peat lands and is representative of typical peat from the area. This value is also consistent with peat values researched by Lindsey (2010).
- Generic hydrological parameters have been used for average groundwater. A value of 0.3m has been used as the expected value. A 'maximum' value of 0.4m has been used to represent areas of intact peat (the higher the water table the longer the payback period), and a 'minimum' value of 0.2m has been used to represent areas of eroded peat.
- The extent of drawdown on drainage features due to excavations on Site is based on the analysis in the EIAR. Assuming an average peat thickness of 0.3m then the extent of drawdown around infrastructure, such as turbine bases, roads and crane pads using the Site derived permeability values for the peat is an average of approximately 10m.
- The most recent values for the three required counterfactual factors provided in the Nayak et al (2014) calculation spreadsheet have been included. These are derived from the latest DUKES publication (July 2022) and are: Grid mix: 0.19338t CO₂ MWh⁻¹, fuel mix: 0.432t CO₂ MWh⁻¹ and coal: 1.002t CO₂ MWh⁻¹.
- Detail regarding the estimated excavation size for turbine foundations and hard standings is provided.

- An estimate of the total volume of concrete has been included, based on an anticipated 900m³ concrete being required for each foundation with additional provision for building foundations associated with the control building and substation.
- The choice of methodology for calculating the emission factors uses the 'Site Specific methodology' defined within the calculation spreadsheet.

2.0 Results

A summary of the anticipated carbon emissions and carbon payback of the proposed development are provided as follows:

Results	Exp.	Min.	Max.
Net emissions of carbon dioxide (t CO₂ eq)	53,207	47,185	64,077
Carbon Payback Time			
...coal-fired electricity generation (years)	0.5	0.4	0.6
...grid-mix of electricity generation (years)	2.6	2.2	3.1
...fossil fuel – mix of electricity generation (years)	1.1	1.0	1.4
Ratio of soil carbon loss to gain by restoration	No gains	No gains	No gains
Ratio of CO₂ eq. emissions to power generation (g/kWh) (Target ratio by 2030 (electricity generation) <50 g/kWh)	19.74	17.09	24.36

3.0 Conclusions

The calculations of total carbon dioxide emission savings and payback time for the proposed development indicates the overall payback period of a wind farm with six turbines with an installed capacity of 5.5MW would be around (1.0 to 1.4 years), when compared to the fossil fuel mix of electricity generation.

This means that the proposed development is anticipated to take around 13 months (1.1 years) to repay the carbon exchange to the atmosphere (the CO₂ debt) through construction of a wind farm; the Site would in effect be in a net gain situation following this time period and can then claim to contribute to national objectives.

4.0 References

Calculating Carbon Savings from Wind Farms on Scottish Peatlands - A New Approach, Nayak et al; 2008 and 2010 and Smith et al; 2011. (<http://www.gov.scot/Publications/2008/06/25114657/0>)

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.

<http://www.gov.scot/Topics/Business-Industry/Energy/Energy-sources/19185/17852-1/CSavings/PSG2011>

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

ANNEX A

Payback Time

Payback Time
Payback Time - ChartsInput Data
1. Windfarm CO2 emission saving over... 2. CO2 loss due to turbine life 3. CO2 loss due to backup 4. Loss of CO2 fixing potential 5. Loss of soil CO2 (a-b) 5. Loss of soil CO2 (c-d e) 6. CO2 loss by DOC & POC loss 7. Forestry CO2 loss 8. CO2 gain - site improvement

1. Windfarm CO2 emission saving over...	Exp.	Min.	Max.
...coal-fired electricity generation (t CO2 / yr)	108,042	105,436	110,649
...grid-mix of electricity generation (t CO2 / yr)	20,852	20,348	21,355
...fossil fuel-mix of electricity generation (t CO2 / yr)	46,581	45,457	47,705
Energy output from windfarm over lifetime (MWh)	2,695,671	2,630,628	2,760,714

Total CO2 losses due to wind farm (tCO2 eq.)	Exp.	Min.	Max.
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	32,541	32,452	32,610
3. Losses due to backup	15,610	15,610	15,610
4. Lossess due to reduced carbon fixing potential	907	391	1,441
5. Losses from soil organic matter	4,149	-1,268	14,415
6. Losses due to DOC & POC leaching	0	0	0
7. Losses due to felling forestry	0	0	0
Total losses of carbon dioxide	53,207	47,185	64,077

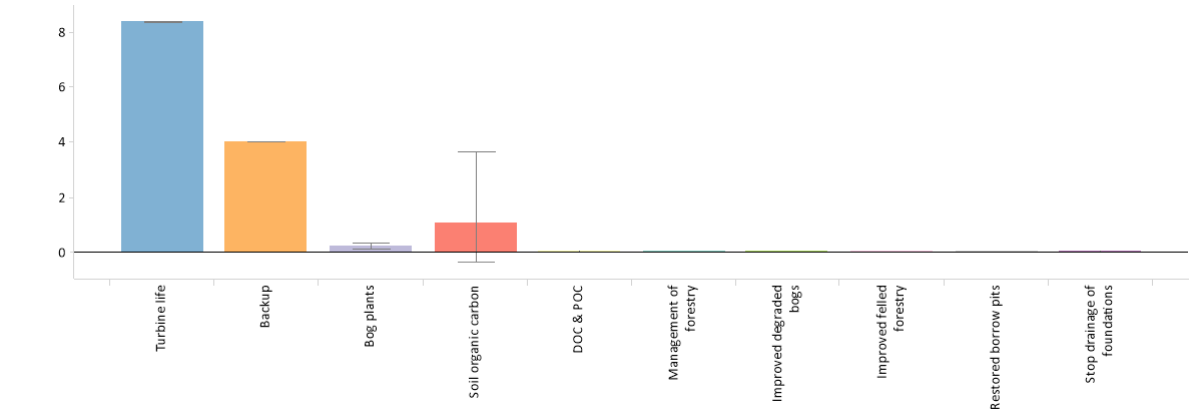
8. Total CO2 gains due to improvement of site (t CO2 eq.)	Exp.	Min.	Max.
8a. Change in emissions due to improvement of degraded bogs	0	0	0
8b. Change in emissions due to improvement of felled forestry	0	0	0
8c. Change in emissions due to restoration of peat from borrow pits	0	0	0
8d. Change in emissions due to removal of drainage from foundations & hardstanding	0	0	0
Total change in emissions due to improvements	0	0	0

RESULTS	Exp.	Min.	Max.
Net emissions of carbon dioxide (t CO2 eq.)	53,207	47,185	64,077
Carbon Payback Time			
...coal-fired electricity generation (years)	0.5	0.4	0.6
...grid-mix of electricity generation (years)	2.6	2.2	3.1
...fossil fuel-mix of electricity generation (years)	1.1	1.0	1.4
Ratio of soil carbon loss to gain by restoration (not used in Scottish applications)	No gains!	No gains!	No gains!
Ratio of CO2 eq. emissions to power generation (g/kWh) (for info. only)	19.74	17.09	24.36

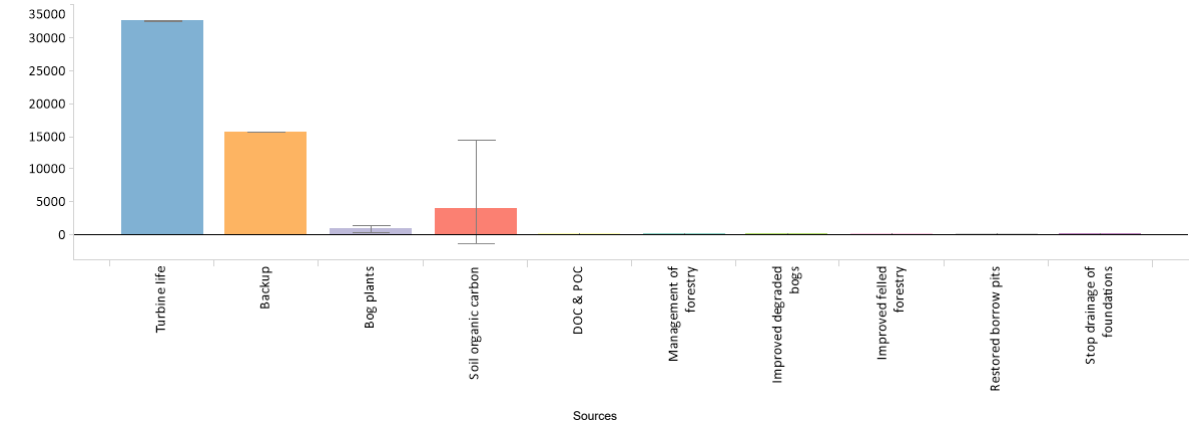
Payback Time - Charts

Payback Time
Payback Time - ChartsInput Data
1. Windfarm CO2 emission saving 2. CO2 loss due to turbine life 3. CO2 loss due to backup 4. Loss of CO2 fixing potential 5. Loss of soil CO2 (a.b) 5. Loss of soil CO2 (c.d.e) 6. CO2 loss by DOC & POC loss 7. Forestry CO2 loss 8. CO2 gain - site improvement

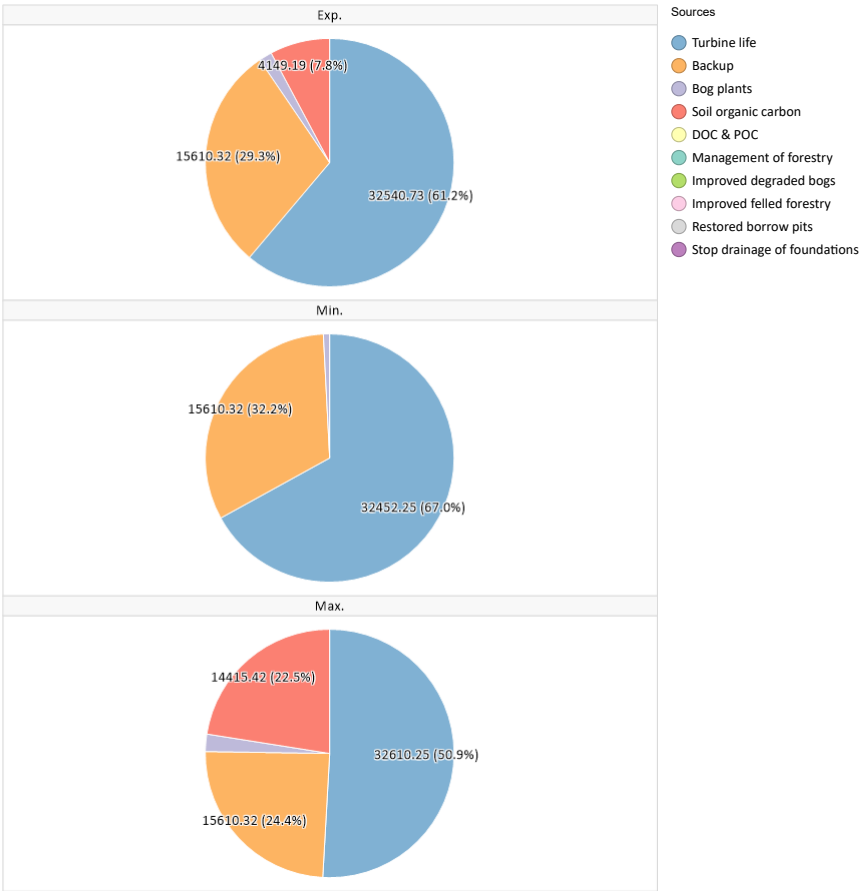
Carbon payback time (months) using fossil-fuel mix as counterfactual



Greenhouse gas emissions (t CO2 eq.)



Proportions of greenhouse gas emissions from different sources



Carbon Calculator v1.7.0
Mynydd Fforch Dwm Wind Farm Location: 51.666433 -3.70501
REG Power Management

Core input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Windfarm characteristics				
<u>Dimensions</u>				
No. of turbines	6	6	6	Number of turbines included in Proposed Development. Lifetime is 25 years – assumed
Duration of consent (years)	25	25	25	
<u>Performance</u>				
Power rating of 1 turbine (MW)	5.5	5.5	5.5	Assumed
Capacity factor	37.3	36.4	38.2	Average capacity factor measured at the site is 37.3%. Minimum and maximum figures are based on 2.5% movement down or up
<u>Backup</u>				
Fraction of output to backup (%)	5	5	5	Following the guidance provided by Nayak et al, UK Energy in brief 2013, confirms that wind energy accounts for less than 20% of total national electricity generation therefore 0% could be used however 5% has been used to reflect a worst case scenario 0% is entered as a minimum value
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	.
Average annual air temperature at site (°C)	11	7	15	Average annual temperature taken for Cardiff BUte Park Met Office station 1977-2022.
Average depth of peat at site (m)	0.3	0	1.8	Expected value calculated as average value of all 824 peat depth measurements taken at site. Minimum and maximum values chosen as a range.
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	8	12	No site specific measurements available, precautionary values used
Average water table depth at site (m)	0.3	0.2	0.4	No site specific values available. Values taken from a similar upland site with underlying peat.
Dry soil bulk density (g cm ⁻³)	0.25	0.2	0.3	Due to lack of site specific information, indicative figures taken from Lily 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 values provided by Nayak et al.
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	0	0	0	Not required
Average rate of carbon sequestration in timber (tC ha ⁻¹ yr ⁻¹)	3.6	3.4	3.8	Figures from Cannell, 1999. min and max entered as a range.
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	0	0	0	Not required
Average length of pits (m)	0	0	0	Not required
Average width of pits (m)	0	0	0	Not required
Average depth of peat removed from pit (m)	0	0	0	Not required
Access tracks				
Total length of access track (m)	8330	8310	8350	Peat Management Plan - Excavated Materials Calculation
Existing track length (m)	2850	2840	2860	Peat Management Plan - Excavated Materials Calculation
<u>Length of access track that is floating road (m)</u>	0	0	0	Not required
Floating road width (m)	5	5	5	Not required
Floating road depth (m)	0	0	0	Not required
Length of floating road that is drained (m)	0	0	0	Not required
Average depth of drains associated with floating roads (m)	0	0	0	Not required
<u>Length of access track that is excavated road (m)</u>	5480	5470	5490	Peat Management Plan - Excavated Materials Calculation
Excavated road width (m)	5	5	6	Peat Management Plan - Excavated Materials Calculation
Average depth of peat excavated for road (m)	0.22	0.2	0.3	Peat Management Plan - Excavated Materials Calculation
<u>Length of access track that is rock filled road (m)</u>	0	0	0	Not required
Rock filled road width (m)	5	5	5	Not required

Input data	Expected value	Minimum value	Maximum value	Source of data
Rock filled road depth (m)	0	0	0	Not required
Length of rock filled road that is drained (m)	0	0	0	Not required
Average depth of drains associated with rock filled roads (m)	0	0	0	Not required
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	Included in access tracks
Average depth of peat cut for cable trenches (m)	0	0	0	
Additional peat excavated (not already accounted for above)				
Volume of additional peat excavated (m ³)	10386	10000	11000	Includes additional site infrastructure, see PMP
Area of additional peat excavated (m ²)	105720	105000	106000	Includes additional site infrastructure, see PMP
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				
<u>Improvement of degraded bog</u>				
Area of degraded bog to be improved (ha)	0	0	0	Currently unspecified
Water table depth in degraded bog before improvement (m)	0	0	0	n/a
Water table depth in degraded bog after improvement (m)	0	0	0	n/a
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	2	2	2	n/a
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	2	2	2	n/a
<u>Improvement of felled plantation land</u>				
Area of felled plantation to be improved (ha)	0	0	0	Not required
Water table depth in felled area before improvement (m)	0	0	0	n/a
Water table depth in felled area after improvement (m)	0	0	0	n/a
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	5	2	10	Estimated values, based on professional judgement.
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	10	5	15	Estimated values, based on professional judgement.
<u>Restoration of peat removed from borrow pits</u>				
Area of borrow pits to be restored (ha)	0	0	0	Not required
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	0	0	0	n/a
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0	0	0	n/a
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	1	1	1	n/a
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	2	2	2	n/a
<u>Early removal of drainage from foundations and hardstanding</u>				
Water table depth around foundations and hardstanding before restoration (m)	0	0	0	Assume no removal of drainage.
Water table depth around foundations and hardstanding after restoration (m)	0	0	0	Assume no removal of drainage.
Time to completion of backfilling, removal of any surface drains, and full restoration of the hydrology (years)	0.1	0.1	0.1	Assume no removal of drainage.
Restoration of site after decommissioning				
<u>Will the hydrology of the site be restored on decommissioning?</u>				
Will you attempt to block any gullies that have formed due to the windfarm?	No	No	No	Currently unspecified
Will you attempt to block all artificial ditches and facilitate rewetting?	No	No	No	Currently unspecified
<u>Will the habitat of the site be restored on decommissioning?</u>				
Will you control grazing on degraded areas?	No	No	No	Currently unspecified
Will you manage areas to favour reintroduction of species	Yes	Yes	Yes	Assumed

Input data	Expected value	Minimum value	Maximum value	Source of data
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
Development Area				
Number of turbines in this area	6	6	6	from Peat Management Plan (PMP)
Turbine foundations				
Depth of hole dug when constructing foundations (m)	0.29	0.16	0.49	from Peat Management Plan (PMP)
Aproximate geometric shape of whole dug when constructing foundations	Circular	Circular	Circular	Assumed
Diameter at bottom	25	25	25	
Diameter at surface	25	25	25	
Hardstanding				
Depth of hole dug when constructing hardstanding (m)	0.37	0.11	0.92	from Peat Management Plan (PMP)
Aproximate geometric shape of whole dug when constructing hardstanding	Rectangular	Rectangular	Rectangular	Assumed
Length at surface	35	35	35	
Width at surface	40	40	40	
Length at bottom	35	35	35	
Width at bottom	40	40	40	
Piling				
Is piling used?	No	No	No	Assumed
Volume of Concrete				
Volume of concrete used (m ³) in the entire area	14280	14000	14500	Calculated from area of rock foundations and depth of excavation.