16 Carbon Balance Assessment

16.1 Introduction

16.1.1 This chapter outlines the carbon balance for the proposed development of Talladh-a-Bheithe Wind Farm (consisting of 24 turbines), including the assumptions made for the calculations that have been undertaken (see Appendix 16.1). It has been produced to assist consultees with their review of the proposed develpoment impact on the existing peat body within the proposed site, and to assess the impact in terms of carbon dioxide (CO_2) emissions against the total potential carbon savings attributed to the proposed development.

16.1.2 Chapter 6 of the ES sets out the planning policy framework that is relevant to the EIA. Early consultation for this development was initiated with consultees to engage on the various elements of the Environmental Impact Assessment required for the proposed development and to ensure that policy requirements were being met as far as is possible. As a result of this consultation, Scottish Environment Protection Agency (SEPA), in relation to carbon balance and peat management provided the following comments:

"We note from the Scoping Report that a full carbon balance assessment will be undertaken as part of the proposed development. Scottish Planning Policy (SPP) recognises that "the disturbance of some soils, particularly peat, may lead to the release of stored carbon, contributing to carbon emissions" (Paragraph 133). In line with SPP and government guidance, we recommend that the carbon balance assessment should quantify the gains over the life of the project against the release of carbon dioxide during construction. It should include all elements of the proposed development, including borrow pits, construction of roads/tracks and other infrastructure and loss of peat bog.

Please refer to the Scottish Government guidance Calculating carbon savings from wind farms on Scottish peat lands - A New Approach, which provides a revised methodology for estimating the impacts of this type of development on carbon dynamics of peat lands. We will validate carbon balance assessments for Section 36 wind farm applications that use this revised version of the tool. In order to validate such assessments, all input data, assumptions and workings need to be provided within one dedicated section of the ES. In addition we will provide comment on drainage and waste management aspects of the peat management scheme to ensure that the carbon balance benefits of the proposed development are maximised."

16.1.3 The ECDU provided similar comments;

"*To assist Scottish Ministers in making a determination on the application, developers are invited to produce a statement of expected carbon savings over the lifetime of the wind farm. The statement should include an assessment of the carbon emissions associated with track preparation, foundations, steel, and transport; any carbon losses from tree felling (and offsetting from tree planting); and any carbon losses from loss or degradation of peaty soils. Reference can be made in this respect to the SNH guidance on 'Wind farms and Carbon Saving' (SNH 2003).*

It is also important to ensure that the carbon balance of renewable energy projects is not adversely affected by management of peat resource. There need to be measures in place to ensure that the development does not lead to significant drying or oxidation of peat through, for example, development of access tracks and other infrastructure, drainage channels, or "landscaping" of excavated peat. The basis for these measures should be set out within the ES, on which a detailed peat management scheme, required through planning condition, can *subsequently be designed to ensure that the carbon balance benefits of the proposed development are maximised.*

Developers are encouraged to submit full details of the life cycle carbon footprint of the wind farm. Guidance can be sought in the publication, "Calculating carbon savings from wind farms on Scottish peat lands - A New Approach" by Dali Rani Nayak, David Miller, Andrew Nolan, Pete Smith & Jo Smith. This can be accessed through the following link to the Scottish Government website http://www.scotland.gov.uk/Publications/2008/06/25114657/0"

16.1.4 Where relevant, and as requested in the above scoping responses, use of the carbon calculator and the associated guidance including 'Calculating Carbon Savings from Wind Farms on Scottish Peatlands – A New Approach' (Nayak et al., revised December 2010) has been adhered to. In addition, advice from the authors of the carbon calculator tool has been sought and the completion of the carbon balance assessment for the proposed development required input from hydrology, ecology and site investigation specialists to feed information into the carbon calculator.

16.1.5 Version 2.9.0 of the carbon calculator is currently the latest version of the tool available (as of June 2014) and, as it is a protected Excel spreadsheet (recommended for use in planning applications), the carbon balance assessment was undertaken subject to the specifications that the tool dictates. As such, the tool/spreadsheet does not currently allow users to comment on, or reference, the sources of the input data that are inserted to conduct the analysis. Therefore, the table below presents this source information and the numbers in the table below correspond with the numbers placed within the Core Input Data sheet of the tool/spreadsheet in the 'Record source of data' column (see Appendix 16.3):

Number	Input	Source/Comment
1	No. of turbines	Eventus BV
2	Turbine capacity	Eventus BV – Client has no plans to use a turbine capacity of greater than 3 MW
3	Capacity factor	DECC Scottish Average 2008-2012 with minimum and maximum values across this period. DECC statistics for Scotland; – Energy Trends publication and https://restats.decc.gov.uk/cms/regional-renewable-statistics/
4	Type of peatland	Senior Ecologist, Natural Power Consultants Ltd.
5	Average air temp. at site	Met Office Data from Dalwhinnie (period 1981-2010) (http://www.metoffice.gov.uk/public/weather/climate/dalwhinnie-highland#?tab=climateTables), approx. 20km from site. The minimum value is the average annual minimum temperature (tmin) and maximum value is the average annual maximum temperature (tmax) The expected value is the average annual temperature (tmax+tmin)/2
6	Average Depth of Peat on Site	Informed by peat probe data. The average of all the peat probe data collected across the site during both the 100 m grid sampling and detailed sampling surveys.
7	C content of dry peat	Scientific Laboratory Analysis Ltd. – see Appendix 16.2
8	Extent of drainage	Hydrologist, Natural Power Consultants Ltd.
9	Average water table depth	Hydrologist, Natural Power Consultants Ltd.
10	Dry soil bulk density	MAT Test Ltd. – see Appendix 16.2
11	Time for regeneration of bog plants	Senior Ecologist, Natural Power Consultants Ltd.

Number	Input	Source/Comment
12	Area of forestry to be felled	Senior Ecologist and Design Manager, Natural Power Consultants Ltd. The conifer plantation on site will be partly felled to construct the wind farm and it is proposed to fell the remaining area and restore the whole plantation area to peatland habitat. Expected, minimum and maximum values entered are for the area of the whole plantation.
13	Coal-fired emission factor	DECC Digest of UK Energy Statistics 2013 (Table 5C: 2012 figure). Although the 2012 annual figure is still only provisional, this figure is used on advice from SEPA. We have been advised by SEPA not to use an average figure of recent years (2010-2012) as it does not represent a worst case scenario if it is higher than the most recent annual emissions factor figure.
14	Grid mix emission factor	Renewable UK/ASA approved figure.
15	Fossil fuel mix emission factor	DECC Digest of UK Energy Statistics 2013 (Table 5C: average 2010 to 2012). An average figure of recent years is used rather than the latest annual figure as there is variation between years and the 2012 figures that are published within DUKES 2013 are still provisional. This average figure is also lower in value than the 2012 annual figure (0.700) and therefore represents a worst case scenario.
16	Average depth of peat removed from pits/turbine foundations/hard standing	Informed by peat probe data. The average of all peat probe depths collected for these pieces of infrastructure.
17	Length of floating roads	Although 2000 m floating roads are likely to be used on site, it is not possible at this time to accurately predict their exact length. Therefore, all tracks are assumed to be excavated as a worst case scenario.
18	Excavated road length	This value includes the 3,600 m of existing track that is upgraded - this is accommodated by providing a weighted average for road width in the input fields below. See assumption 19. As the drainage from the existing track will already have had some impact on the surrounding peat, this approach presents a worst-case scenario as the calculations include this length of track (3,600 m) in the calculations for extent of drainage as occurs for full excavated road.
19	Excavated road width	Running width 5 m; drainage trench 1 m either side; cable trench 1 m; working areas either side 1.5 m = total 11 m for expected value. On advice of the author, the average values inserted are also weighted to accommodate for upgrades to existing tracks. Calculations are shown in text in Paragraphs 16.6.4. and 16.6.5.
20	Average depth of peat	Informed by peat probe data. The average of all peat probe depths for this infrastructure.
21	Length of rock filled roads	Although rock filled roads may be used on site, it is not possible to estimate the length required. Therefore, all tracks are assumed to be excavated as a worst case scenario.
22	Cable trenches	Assumed all cables will follow tracks. Subject to pre-construction design. See assumption 19 above.
23	Additional peat excavated	Calculations are shown in text in Paragraph 16.6.6.

Number	Input	Source/Comment
24	Area of degraded bog to be improved	Outline Habitat Management Plan measures. Values calculated from GIS interrogation of drainage ditch areas in terrain units shown on geomorphology map. Expected value is the area of land where artificial ditches have been found on site. The minimum value is 75% of the expected value to allow for a 25% reduction in improvement due to potential unsuccessful drain blocking. The maximum value is double the expected value to include the additional drain blocking that will be undertaken across the whole estate.
25	Time required for hydrology and habitat of borrow pits to return to its previous state on improvement	Senior Ecologist, Natural Power Consultants Ltd.
26	Area of felled plantation to be improved.	Outline Habitat Management Plan (HMP) measures. Expected minimum and maximum values based on whole area of conifer plantation minus the approximate infrastructure footprint.
27	Water table depth in borrow pits after restoration	Assumed that water depth in borrow pit will be restored and improved upon via HMP measures prior to commencement of groundwork.
28	Will the hydrology of the site be restored on decommissioning	Restoration measures are outlined in the Habitat Management Plan.
29	Will the habitat of the site be restored on decommissioning	Restoration measures are outlined in the Habitat Management Plan

The following report has been produced giving consideration to the following documents:

- D.R.Nayak et al. Calculating Carbon Budgets of Wind Farms in Scottish Peatlands (May 2010).
- J.T.Mitchell et al. CO2 Payback Time for a Wind Farm on Afforested Peatland in the UK (May 2010).
- CCW Guidance Note: Assessing the impact of windfarm developments on peatlands in Wales (Jan 2010).
- Natural England Commissioned Report: Investigating the impacts of windfarm development on peatlands in England (Jan 2010).
- Guidance on the Assessment of Peat Volumes, Reuse of Excavated Peat and the Minimisation of Waste. Scottish Renewables (2012).
- Lindsay, R. (2010) Peatlands and Carbon: a critical synthesis to inform policy development in peatland conservation and restoration in the context of climate change.
- 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.
- Scottish Natural Heritage (2003) Windfarms and Carbon Savings
- IPCC Guidelines for National Greenhouse Gas Inventories (2006).

16.2 Wind Farm CO_2 Emission Savings

16.2.1 The amount of CO_2 emissions produced during energy production varies with the type of fuel used; therefore, the potential CO_2 savings from the proposed development depends on the type of fuel it replaces.

16.2.2 The wind farm CO_2 emission savings over other types of generation (i.e. coal-fired, grid-mix, fossil fuel-mix) is calculated by multiplying the energy output of the wind farm development by the emissions factor of the other type of generation. Both the coal-fired and fossil-fuel mix emission figures are based on values provided in the DECC publication 'Digest of UK Energy Statistics (2013)' and either the latest annual figure or average of recent years figure is used depending upon which is of lowest value (as advised by SEPA) in order to present a worst case scenario. The emission figure with the highest confidence within the industry is the grid mix which includes electricity generated from renewable sources, nuclear power and fossil fuels. This also has an element of future generation factored in, as advised by DECC, and is also approved for use by the Advertising Standards Agency (ASA).

16.2.3 The net emissions of CO_2 by the proposed development is calculated by deducting the total CO_2 gains produced by improvement of the site from the total CO_2 emissions from the construction, manufacture and decommissioning of the individual elements of the proposed development (described in the following paragraphs). The net CO_2 emissions figure is then divided by the wind farm CO_2 emissions savings over the other fuel types calculated, to reveal the payback time. It is considered that coal-fired and grid-mix emissions represent the best and worst-case scenarios respectively, and are reported at the end of the each subsection, where applicable.

16.2.4 The expected potential annual energy output of the proposed development is 167,141 MW yr-1(based on a 3 MW turbine model), with minimum and maximum potential outputs at 104,931 MW yr-1 (2.3 MW model) and 186,693 MW yr-1 (3 MW model). Although both the expected and maximum scenarios use a 3 MW turbine in the calculations for energy output, the potential maximum energy output of the proposed development results in a greater output because this uses the maximum capacity factor in the calculation.

16.2.5 Based on the expected annual energy output of the proposed development (167,141 MW yr-1), the potential expected emissions saved per year over coal-fired electricity generation is 149,591 tonnes of CO_2 (tCO_2); over grid-mix generation is 71,871 tCO_2 and over fossil-fuel mix generation is 106,302 tCO_2.

16.3 Emissions due to Turbine Life

16.3.1 Energy is consumed and associated carbon dioxide (CO_2) emissions are released during manufacture of the turbine components, construction of the site (including site tracks and turbine foundations etc), and during the decommissioning of the development.

16.3.2 The carbon calculator includes a module for assessing the carbon emissions due to turbine life. Nayak *et al.* (2010) explain that the turbine life calculation within the carbon calculator is based on generic data as it does not accommodate a site-specific full life-cycle analysis. Therefore, the turbine life emissions for the proposed development are estimated utilising an equation for ≥1 MW turbines[1] that has been derived from data from numerous European sites, and which shows a significant relationship across the European sites examined. The

[1] D.R.Nayak *et al*. Calculating Carbon Budgets of Wind Farms in Scottish Peatlands .Available online from: http://mires-and-peat.net/pages/volumes/map04/map0409.php (last accessed 08/05/2014).

carbon calculator reveals an expected emissions figure of 56,052 tonnes of CO_2 (tCO_2) equivalent (equiv.) emitted due to the manufacture, construction and decommissioning of the turbines. Based on the calculated emissions savings for coal-fired and grid-mix generation, the payback time for turbine life is expected to take between approximately 4 and 9 months respectively.

16.4 Capacity Required due to Back Up

16.4.1 In order to maintain security of energy supply, a second-by-second balance between generation and demand must be maintained by the grid operators. It has been noted that the inherent variable nature of wind energy may affect this balance and therefore, a certain proportion of power is required to stabilise the supply to the customer. The electricity system however, is designed and operated in such a way as to cope with large and small fluctuations in supply and demand. No power station is totally reliable, and demand, although predictable to a degree, is also uncertain. Therefore, the system operator establishes reserves that provide a capability to achieve balance, given the statistics of variations expected over different time scales. The variability of wind generation is but one component of the generation and demand variations that are considered when setting reserve levels.

16.4.2 It should also be noted that an individual wind turbine will generally generate electricity for 70-85% of the time, and its electricity output can vary between zero and full output in accordance with the wind speed. However, the combined output of the UK's entire wind power portfolio shows less variability, given the differences in wind speeds over the country as a whole. Whilst the amount of UK wind generation varies, it rarely, if ever, goes completely to zero, nor to full output at the same time throughout the UK.

16.4.3 The extra capacity needed for back-up power generation is currently estimated to be 5% of the rated capacity of the wind plant if UK wind power contributes more than 20% to the National Grid. Therefore, if wind generated electricity contributes less than 20% to the National Grid, the extra capacity needed for back-up is assumed to be zero. However, if wind generated electricity contributes greater than 20% to the National Grid, the extra capacity required for back-up is 5% of the rated capacity of the wind farm.

16.4.4 Comparing operational wind farm capacity figures from the State of the Industry Report 2013[2] (9,710 MW operational capacity generating approximately 23.544 TWh [using the Renewable UK calculation: electricity produced = capacity x 0.2768 x 8760][3]) and UK electricity consumption figures from 2012[4] (317.575 TWh), it is possible to give an estimate of the contribution of onshore and offshore wind farms to the total current UK energy demand, which at the date of writing stands at 7.4%. Using published capacity figures from the State of the Industry Report 2013 for wind energy projects that are operational, have been consented, are under construction,

[2] Wind Energy in the UK – State of the Industry Report 2013 (October 2013). Available online from: http://www.renewableuk.com/en/publications/index.cfm/state-of-the-industry-report-2012-13 (last accessed 21/03/2014)

[3] Available online from: http://www.renewableuk.com/en/renewable-energy/wind-energy/uk-wind-energy-database/figures-explained.cfm (last accessed 08/05/2014)

[4] Table 5.2 Electricity supply and consumption 2012. Digest of the United Kingdom Energy Statistics (DUKES 2013). Available online from: http://www.decc.gov.uk/en/content/cms/statistics/publications/dukes/dukes.aspx (last accessed 21/03/2014).

and 82% of those in the UK planning system[5], the total electricity generated from 32,134 MW capacity, which includes the capacity from Talladh-a-Bheithe turbines, is approximately 77.92 TWh. Therefore, assuming that the UK electricity consumption remains constant, the contribution of wind energy (onshore and offshore) to the UK electricity demand will be 24.5%. For the purposes of the carbon calculator run for Talladh-a-Bheithe, as this calculated wind generated electricity contribution to the National Grid is greater than 20%, the extra capacity required for back-up has been stated as 5%, and the additional payback is taken into account when reporting the results from the carbon balance calculations.

16.4.5 Accordingly, the carbon calculator assumes that backup is provided by a fossil fuel mix of energy generation and reveals an expected emissions figure of 50,142 tCO_2 equiv. due to the back-up. Based on the calculated emissions savings for other electricity generation methods (i.e., coal-fired and grid mix), the payback time for back-up is expected to take 6 months for both.

16.5 Loss of Carbon Fixing Potential

16.5.1 Construction of the development will involve the installation of infrastructure such as turbine foundations, access tracks and hardstandings etc. Where vegetation and/or peat is removed or covered, the vegetation will no longer be able to photosynthesise and therefore, its ability to fix carbon will be lost. In addition, changes to drainage can have an effect on the vegetation of peatlands. Accordingly, the carbon calculator assumes that the carbon-fixing potential is lost from both the area occupied by infrastructure as well as areas affected by drainage.

16.5.2 The Talladh a Bheithe Estate covers 4,270 hectares (ha) of upland moorland and montane habitat lying between the southern end of Loch Ericht and the western end of Loch Rannoch. Peatland habitats dominate with extensive areas of blanket bog grading into wet heath, dry heath and montane heath, with Calluna dominating in the northern half of the estate and a gradual increase in Molinia dominance as grazing pressure (historical and current) increases to the south. Artificial drainage is in evidence in many areas, installed presumably in attempts to improve grazing for sheep and deer but also to increase drainage flow and catchment area for the Rannoch hydro-electric scheme constructed at the south end of the estate on the shores of Loch Rannoch in the 1930s. The River Ericht flows along the western boundary south of Loch Ericht and most of the estate drains south or west into this, with some smaller burns draining south-east into the Killichonan Burn (or the power station aqueduct) to the south-east of the estate. The estate is managed as a sporting estate for deer stalking and, until recently, sheep grazing.

16.5.3 Talladh-a-Bheithe site is comprised of a mosaic of habitats. The Phase 1 mapping (See Chapter 8) of the site shows that blanket bog communities are prevalent with occasional heath habitat. Mire habitats are extensive and whilst human activities have led to a degree of modification over much of the bog habitat here, the majority of it still presents the appearance of semi-natural blanket bog and only those areas most overtly changed by the combination of drainage and grazing have been mapped as wet modified bog.

16.5.4 On hilltops and upper slopes heath communities are found where the underlying rocks protrude through the blanket of peat, but there are also occasional small heath patches on hummocks of moraine scattered through the mire vegetation on the lower slopes of the study area. In Phase 1 Habitat survey terms the various National Vegetation Classification (NVC) heath communities found here fit the D1 dry dwarf shrub heath found in montane

[5] A figure of 82% of the total capacity in planning has been used as it has been reported that rate of consent at the Ministerial level in Scotland has fallen from 89% in 2011/12 to 82% in 2013. (State of the Industry Report: Wind Energy in the UK. Renewable UK, October 2013).

areas, with coverage of dwarf ericoid shrubs such as: heather (*Calluna vulgaris*) bell heather (*Erica cinerea*), blaeberry (*Vaccinium myrtillus*), crowberry (*Empetrum nigrum*) and cowberry, (*Vaccinium vitis-idaea*). The heathland is further distinguished from the mire types by being defined as occurring on peat of less than 0.5 m depth.

16.5.5 The results of the NVC survey are reported in Chapter 8 of the ES and identified that he majority of the site is a mix of blanket bog/wet heath communities. As well as blanket bog and wet heath habitats, small scattered areas of dry heath are present on hummocks of moraine in the central area of the site.

16.5.6 Additionally, the vegetation communities associated with southern shore of Loch Ericht and those adjacent to the adjoining track were assessed. The access track leading to the southern shore of the loch is bounded by thin strips of grassland comprising a mix of acid and neutral grassland communities. Beyond this, a mix of wet heath and mire vegetation was dominant with occasional areas of dry heath/acid grassland mosaic vegetation present on bunds of moraine.

16.5.7 The areas that underwent Phase 1 Habitat and NVC surveys revealed that blanket bog/wet heath altogether comprise approximately 90% of the total area of the site for the proposed development (approximately 666 ha). Therefore, 100% cover of the site by carbon fixing mire habitat does not exist. However, in order to present a worst-case scenario the carbon calculator does assume 100% coverage of bog plants in areas where the vegetation is removed through construction or is compromised through drainage. In order to demonstrate a worst-case scenario of the development's impact on drainage of the carbon fixing potential, the extent of drainage around infrastructure is given as 10 m expected and 5 m and 15 m as minimum and maximum values respectively.

16.5.8 In accordance with the calculator's methodology, the total emissions attributable to the loss of carbon accumulation by bog plants is equivalent to 2,074 tCO_2 equiv. over the operational period of the wind farm. This emissions figure is based on a development footprint plus the area affected by drainage (71 hectares) based on the 10 m expected extent of drainage and assumes 100% mire habitat cover. However, again, it is important to recognise that 100% mire habitat cover is not an accurate description of the site's characteristics and this value is therefore a worst-case estimate. Based on the calculated emissions savings for coal-fired and grid-mix generation the payback time for loss of carbon fixing potential is expected to be less than a month against coal-fired generation and grid-mix generation.

16.6 Loss of Carbon Dioxide from Removed Peat (Direct Loss)

16.6.1 Over 2,600 peat depth measurements were taken across the proposed development to inform average peat depths within the immediate vicinity of the proposed infrastructure. All of these peat depth measurements were used to calculate an average depth of peat across the site.

16.6.2 The peat depth data is taken from the detailed peat depth study undertaken for the site, and in accordance with the following scope:

- Peat probing at all turbine bases and hardstanding areas within a 50 x 50 m area at 10 m spacing; and
- Peat probing at 50 m intervals along all proposed access tracks (at each 50 m interval; three probe locations aligned perpendicular to the track alignment, one at the centre of the track with a further two probes spaced 10 m from the centre at both sides of the track).
- Peat probing at 20 m intervals for proposed borrow pits and substation/construction compound.

16.6.3 Using GIS to define the peat probe results within the micrositing buffer of each piece of infrastructure, the average expected peat depths were calculated for turbines and reported within the Peat Slide Risk Assessment for the site (Appendix 11.1). In addition, all the infrastructure peat probe raw data were placed into a spreadsheet and the arithmetic mean was then calculated from the detailed raw data for each infrastructure type i.e. turbine foundations, borrow pits etc. and these values placed into the 'expected' inputs for average peat depths in the carbon calculator. In addition, the minimum and maximum values are reported for peat depths for each infrastructure element. As advised by the authors of the tool, the minimum and maximum values provided represent the lower and upper bound values of the 95% confidence intervals of the sample data collected for each infrastructure element.

16.6.4 In addition, the excavated peat volumes calculated within this assessment accommodate realistic working areas with the assumption built into the model that all peat in working areas is excavated and lost whereas the Peat Management Plan presented in Appendix 11.2 of this ES uses different parameters which allow for the fact that not all peat areas stated are excavated (but may only be disturbed) and that a proportion of the excavated peat will be re-used. Within this assessment, in order to represent a worst case scenario the following working areas and assumptions have been incorporated into the analysis:

- new roads include the running width (5 m) and additional width to account for drainage (2 m), cable trench (1 m) and a working area/batters of 1.5 m either side providing an expected width of 11 m. In some areas, batters would not need to be so wide and drainage may only be needed on one side so minimum and maximum values of 10 m and 12 m provided respectively;
- 2000 m of floating roads have been proposed however, it is assumed that all 12,800 m of track will be excavated in this assessment in order to present a worst case scenario;
- working areas have been included around turbine foundations with an expected working area and batters of 13.5 m, and minimum and maximum working area values of 9 m and 18 m respectively;
- 2-5 m working areas have been included around hardstandings however, only on one side of the hardstanding as the other side is bounded by the road; and
- borrow pit dimensions are based on the Borrow Pit Search Report (see Appendix 4.1) and are excavated to their maximum extent. Minimum length and width values presented are the indicative work area estimates from the Search Report, and the expected and maximum values allow for any potential wastage/poor rock conditions as realistic and worst-case scenarios respectively.

16.6.5 Version 2.9.0 of the carbon calculator does not accommodate inputs for upgrading tracks. However, under advice from the authors of the tool, the widening/upgrading of the existing tracks has been accounted for in this assessment by calculating the **weighted** average width of tracks along the total length of new (excavated) and upgraded (existing) tracks and entering these weighted averages into the input page for the tool.

The calculations for 'expected' width were as follows:

12,800 (length of new track) x 11 m (expected width of track – see paragraph 16.7.4)

+ 3,600 (length of existing track) x 6 m (expected width of upgrade)

= 162,400/16,400 (total length of tracks) = 9.9 m

Calculations were also undertaken for minimum and maximum scenarios using the values below:

	Minimum (m)	Maximum (m)
New excavated track width	10	12
Upgrade to existing track width	5	7

16.6.6 The publication of Version 2.9.0 of the carbon calculator contains a useful addition to the tool that accounts for other infrastructure not explicitly accounted for above, namely the substation and construction compound. The following table contains the expected dimensions of the construction compound and substation and peat depths used to calculate the total area and total volume of excavation. External transformers have not been included in the calculation as it is assumed that they are located within the turbine foundation working area or hardstanding areas and therefore it would be double counting if these were to be included.

Substation			
	Expected	Minimum	Maximum
Substation Area (m²)	750	400	1,500
Depth of Peat (m)	0.34	0.16	0.52
Substation Volume of Peat (m³)	255	64	780
Construction Compound			
Construction Compound Area (m²)	5,000	5,000	5,000
Depth of Peat (m)	0.34	0.16	0.52
Construction Compound Volume of Peat (m³)	1,700	800	2,600

16.6.7 Full depth peat sampling was undertaken using a Russian peat corer at all proposed turbine centres and along access tracks and additional infrastructure. Core samples were examined by hand, and samples retained for laboratory and geochemical analysis.

16.6.8 Carbon content of dry peat (% by weight) and dry soil bulk density (g cm-3) were calculated in the laboratory and the expected, minimum and maximum values have been inserted in the carbon calculator. Again, as advised by the authors of the tool, the minimum and maximum values provided represent the lower and upper bound values of the 95% confidence intervals of the sample data collected. The laboratory results are shown in Appendix 16.2 of this document.

16.6.9 The figures shown in Sheet 5a of the carbon calculator spreadsheet calculate the total volume of peat removed over the footprint of the wind farm; expected to be 182,069m³ (which includes working areas and cable trenches and drainage ditches). The CO_2 release associated with the volume of peat excavated assumes a worst-case scenario that 100% of the peat is lost. However, it is anticipated that all excavated peat will be re-used or reinstated on site according to best practice guidance and as outlined within the Peat Management Plan (Appendix 11.2), where possible. The total expected amount of direct CO_2 loss, attributable to peat removal only, is calculated to be 38,482 tCO_2 equiv.

16.7 Loss of Carbon Dioxide from Drained Areas left in Situ (Indirect Loss)

16.7.1 Carbon is also lost from peat habitats through drainage that occurs in the peat around the proposed development's infrastructure. The carbon calculator tool and associated guidance refers to this CO_2 loss as an "indirect loss". The equations and guidance refer to the impact resulting from drainage as extending from between 1.5 m to 50 m. The extent of the site affected by drainage is calculated assuming an expected, minimum and maximum extent of drainage around each drainage feature e.g. turbine foundation, tracks etc.

Although the extent of drainage is heavily dependent on topography, the analysis itself assumes relatively level terrain.

16.7.2 Hydrological and site investigation specialists visually noted and recorded extents of drainage during the surveys which informed the site design evolution, concluding that much of the original mire has been substantially modified by previous land usage and grazing. Following this survey, a recommended average extent around the drainage feature of 10 m was suggested as an appropriate expected average for the calculation.

16.7.3 The carbon calculator tool calculates the area surrounding the wind farm infrastructure that is within the extent of drainage and multiplies this by an emissions rate for before (undrained), and after (drained) construction scenarios. Site specific emission rates have been used, which are derived from soil characteristics including:

- Average annual air temperature (6.6oC)
- Average water table depth on site (0.2 m)
- Average water table depth on drained land (0.34 m) (as calculated directly from the carbon calculator)

NB: Figures shown in brackets have been used to quantify the expected emission rate.

16.7.4 Accordingly, the expected CO_2 emissions loss from drained peat is 11,969 tCO_2 equiv. across approximately 43 hectares of land over the operational lifetime of the wind farm.

16.7.5 The total expected CO_2 loss from removed peat and drained peat is 50,451 tCO_2 equiv. Based on the calculated emission savings for coal-fired and grid-mix generation, this carbon cost repayment is expected to take between approximately 4 and 8 months respectively.

16.8 Loss of Carbon Dioxide from DOC and POC loss

16.8.1 Additional CO_2 emissions from organic matter can occur as carbon dioxide and methane, which can leach out of peat that is restored to conditions where the water table depth is higher after restoration than before restoration and is a further consideration of the carbon calculator. Dissolved Organic Carbon (DOC) is defined as the organic matter that is able to pass through a filter (range in size generally between 0.7 and 0.22 μm). Conversely, Particulate Organic Carbon (POC) is the fraction of soil carbon that is larger in particle size. The assessment tool assumes that 100% of the losses due to leaching DOC and POC from restored drained and improved land are eventually lost as gaseous CO_2.

16.8.2 Only restored drained and improved land has been included in the calculations within the carbon calculator for DOC and POC, because if the land is not restored or improved, then the carbon loss has already been accounted for in the calculations for excavated and drained peat.

16.8.3 The carbon calculator calculates that there will be an expected 4,611 tCO_2 equiv. lost due to DOC and POC leaching over the operational life of the wind farm.

16.9 Total Loss of Carbon Dioxide from Impact on Peat

16.9.1 The following calculations on total loss of CO_2 from the impact on peat have been based on a number of key assumptions (some of which are built into the tool itself), specifically in relation to peat in order to demonstrate a worst-case scenario using on-site data with input from ecology and hydrology specialists. In summary, these assumptions are:

- 100% of the area potentially affected by the wind farm is covered in peat forming mire habitat;
- The terrain is relatively flat with no existing drainage;
- Infrastructure dimensions for foundations, tracks and hardstandings include working areas;
- 100% of the carbon stored in the excavated peat will be lost as carbon dioxide and not reinstated on site;
- 10 m metre expected average extent of drainage to demonstrate a conservative expected scenario;
- The average extent of drainage assumes that the depth of peat affected by drainage is equal to the depth of peat removed.
- The depth data used to inform the volumes of peat removed assume that all recorded depths are in peat;
- The model assumes no micrositing to further reduce impacts on peat; and
- The borrow pits will all be used to their maximum extent.

16.9.2 The combined expected impact of the development on peat over the operational lifetime of the development is therefore calculated as:

Total Loss tCO_2=	CO_2 from plants	+	CO_2 loss from removed peat	+	CO_2 loss from drained peat	+	CO_2 DOC & POC loss
Total Loss tCO_2 equiv.=	2,074 tCO_2	+	38,482 tCO_2	+	11,969 tCO_2	+	4,611 tCO_2
Total Loss tCO_2 equiv. =	57,136tCO_2						

16.10 Loss of Carbon Fixing Potential due to Forest Felling

16.10.1 The carbon calculator assessment conducts a simple analysis for the CO_2 emissions from felled forestry. Only a small part of the conifer forestry will be felled for wind farm infrastructure and the Outline HMP proposes that the rest of the forestry is to be felled to restore this area back to peatland habitats. The calculation uses the figure from the carbon calculator and Cannell (1999)[6] for carbon sequestration of forestry plantation of 3.6 tCO_2/ha/yr. However, this value is based on dense planting of spruce trees but the planation on site is quite sparse in areas and dense in others, and is actually a mix of spruce, pine and larch with occasional birch and bog habitats. In addition, the values inserted into the carbon calculator are for the whole of the conifer plantation area (45 ha) as shown on the Phase 1 habitat map in Chapter 8. However, as already mentioned, the forestry does not cover this whole area but has a more patchy distribution within this area and therefore, the values entered represent a worst case scenario.

16.10.2 Assuming that 45 ha of forestry is lost, the emissions from felling and lost sequestration results in 14,851 tCO_2 equiv. lost through emissions. The additional payback time is calculated between 1 and 2 months over coal-fired and grid mix generation respectively.

16.11 Carbon Gain Due to Site Improvement and Restoration

16.11.1 Restoration of areas within the site can reverse emissions and act as carbon storage, reducing the total CO_2 emissions as a result of the development. The carbon calculator takes into account reductions for emissions

[6] Cannell M.G.R. (1999) Growing trees to sequester carbon in the UK: answers to some common questions. *Forestry* 72: 238-247.

resulting from the improvement of degraded bog, felled forestry as well as the restoration of borrow pits and turbine foundations.

16.11.2 For the site at Talladh-a-Bheithe, an overarching Outline Habitat Management Plan (HMP: see Appendix 9.2) has been produced to pull together the proposed plans for land improvements within the proposed development area as well as the existing land management plans for the Talladh-a-Bheithe Estate.

16.11.3 The estate covers 4,270 hectares (ha) of upland moorland and montane habitat lying between the southern end of Loch Ericht and the western end of Loch Rannoch. Peatland habitats dominate with extensive areas of blanket bog grading into wet heath, dry heath and montane heath, with Calluna dominating in the northern half of the estate and a gradual increase in Molinia dominance as grazing pressure (historical and current) increases to the south. Artificial drainage is in evidence in many areas installed presumably in attempts to improve grazing for sheep and deer but also to increase drainage flow and catchment area for the Rannoch hydro-electric scheme constructed at the south end of the estate on the shores of Loch Rannoch in the 1930s.

16.11.4 Section 4.1 of the Outline HMP describes the measures to be taken to restore the areas of blanket bog where the natural hydrology of the habitats have been degraded through artificial ditches. The use of excavated peat from wind farm construction activities as well as plastic piled dams is proposed to rewet these areas (in addition to the deer management and muir burning management plans which are not accounted for in the carbon calculator).

16.11.5 According to the authors of the tool;

"*Degraded bog is that which has had its water table lowered so that the peat has started to decompose. The important point is that it is possible to raise the water table depth and so stop the degradation that would have occurred if you had not done this. It doesn't matter how far the degradation has gone before you do this; it's the change in the water table depth that is important*."

16.11.6 Based on the geomorphology map presented within the Outline HMP, the expected (224 ha) and minimum (168 ha) and maximum (449 ha) areas of bog to be improved were calculated using GIS interrogation of the areas where existing bog is considered to have degraded due to the presence of numerous artificial drains/ditches on site which will be blocked. The minimum value represents a reduced area to the expected value to represent a scenario whereby attempts at drain blocking are not completely successful, whereas the maximum value accounts for areas dedicated for improvements within the wind farm development site as well as the proposed areas where improvement measures will be implemented across the entire estate.

16.11.7 Section 4.2 of the Outline HMP describes the measures to be taken to fell the conifer plantation on site and restore the whole area to peatland habitat. This will be combined with blocking of any forestry drainage with peat dams (or plastic piling if too steep for peat dams) and forestry furrows with peat and mulch, and follow up management to control undesirable regeneration of conifers may be required, although deer grazing levels may be high enough to keep this in check. The values entered into the carbon calculator are the area of forestry to be felled minus the development footprint of wind farm infrastructure in this area.

16.11.8 Borrow pits will be restored in line with best practice[7] and every effort will be made to restore the borrow pits back to the original habitat present before construction. Full details of restoration of infrastructure are outlined in

[7] Good Practice During Wind farm Construction. SNH (2010)

the Peat Management Plan in Appendix 11.2 but will also be agreed with relevant parties should the development be consented. Further to this, during construction and operation, through the production of Construction Method Statements, habitat restoration will aim to block construction ditches and drains and this will be ongoing process to minimise impacts.

16.11.9 Even though not all of the methods of restoration and improvement are taken into account within the carbon calculator (such as muir burning management and deer control), the results report 12,972 tCO_2 equiv. in carbon gains from improvements in the expected scenario and 70,117 tCO_2 equiv. in carbon gains from improvement in the maximum (best case) scenario. No carbon gains result in the minimum (worst case) scenario, as the time required for hydrology and habitat to return to its previous state of improvement is entered as 25 years (considered worst case scenario) therefore, no improvements are achieved in this scenario.

16.12 Carbon Balance Summary and Conclusions

16.12.1 Table 17.1 and Figure 17.1 below outline the overall carbon payback time for the Talladh-a-Bheithe Wind Farm turbines and associated infrastructure. The wind farm CO_2 emissions savings over other types of generation (i.e. coal-fired, grid-mix, fossil fuel-mix) is calculated by multiplying the energy output of the development by the emissions factor of the other type of generation.

16.12.2 The net emissions of CO_2 of the proposed development is calculated by deducting the total CO_2 gains produced by improvement and restoration of the site from the total CO_2 emissions from manufacture of, construction of, and impacts on peat from, the individual elements of the proposed development (described in the preceding paragraphs). The carbon payback time for the wind farm is calculated by comparing the loss of CO_2 from the site due to wind farm development with the carbon savings achieved by the wind farm while displacing electricity generated from coal-fired generation, grid-mix generation or fossil-fuel mix electricity generation. The minimum and maximum columns presented in Table 16.1 below present the best case and worst case scenarios respectively.

Table 16.1: Summary of the carbon payback time associated with the Talladh-a-Bheithe Wind Farm

	EMISSIONS PAYBACK TIME (YEARS)		
Carbon Payback Time	Expected	Minimum	Maximum
…coal-fired electricity generation	1.1	0	2.7
…grid-mix electricity generation	2.3	0.1	5.6
…fossil fuel-mix electricity generation	**1.6**	**0.1**	**3.8**

16.12.3 The full assessment also evaluates the carbon payback time of many different parameters associated with the wind farm development as illustrated in Figure 16.1.

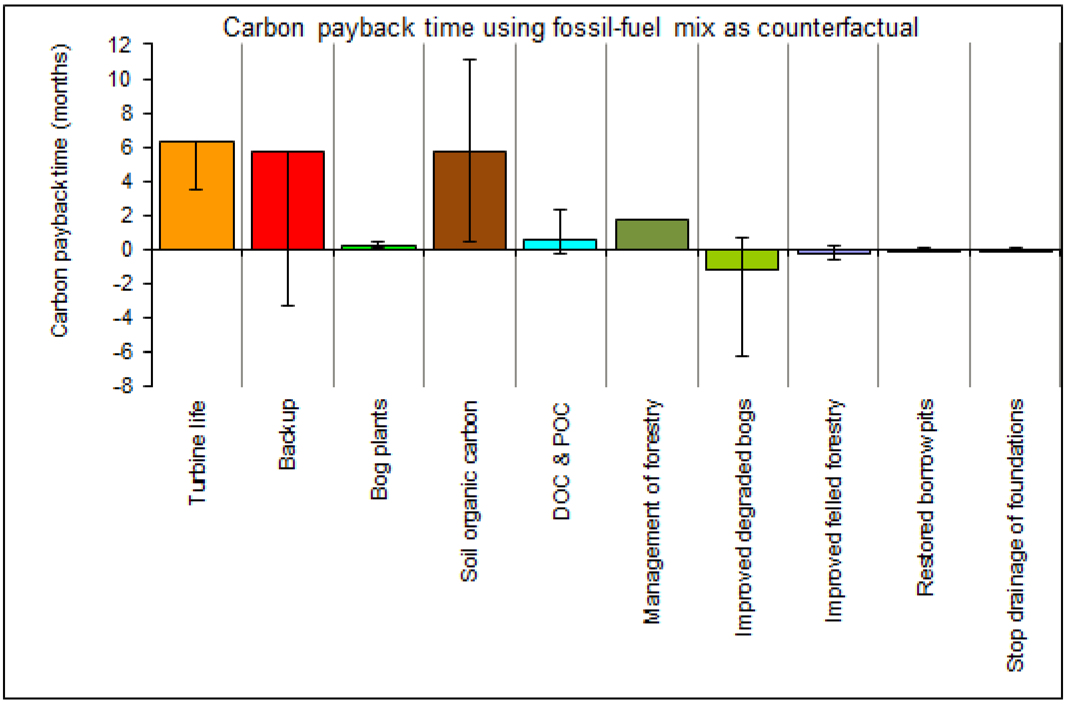

Figure 16.1: Carbon payback time using fossil fuel mix as the counterfactual

16.12.4 The conclusion of the carbon calculator tool reveals that the proposed wind farm will effectively pay back its expected carbon debt from manufacture, construction, impact on habitat and decommissioning within 1.6 years, if it replaces the fossil fuel electricity generation method. Based on the minimum and maximum scenarios, the analysis shows that the payback time for fossil fuel-mix generation ranges between 0.1 and 3.8 years and illustrates that over the 25-year lifespan of the proposed development, it is likely to generate 21 years' worth of clean energy based on the maximum worst-case scenario. Therefore, over the expected 21 years that the wind farm is likely to be generating carbon-free electricity, this could result in expected CO_2 emission savings of 2..23 million tonnes of CO_2 ($MtCO_2$) when replacing fossil fuel electricity generation.