North Lowther Energy Initiative:
Appendix 14.1
Carbon Report

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Contents

Illustrations

Tables

1 Introduction

The UK and Scottish Governments, in common with the majority of governments across the world, recognise the impacts of rising atmospheric levels of CO_2 and other greenhouse gases on global warming. In order to reduce the volume of CO_2 emitted, they have introduced or supported a number of measures. Under the *Climate Change (Scotland) Act 2009* (Scottish Government, 2009), the Scottish Government has set a target of reducing CO_2 emissions (based on a 1990 baseline) by 80% by 2050, with an interim target of 42% reduction by 2020. *The Scottish Government 2011 Renewables Policy* (Scottish Government, 2011) has set a target of the equivalent of 100% of annual electricity demand generated from renewable sources by 2020, with an interim target of 50% by 2015 (Scottish Government, 2016).

The North Lowther Energy Initiative (NLEI) ("the Development") will generate renewable energy that will contribute to national targets for reduction of carbon emissions into the atmosphere and for the amount of electricity supplied from renewable energy. However, it is recognised that the construction and, to a lesser extent, the operation and decommissioning of the windfarm will encompass activities that either directly or indirectly result in CO_2 emissions. Additionally, as the development is proposed in an area where peat deposits exist, there are potential losses of CO_2 from carbon stored in the peat and there is a potential loss of habitat that can capture and store carbon.

In recognising that development of renewable sources of energy could contribute to carbon emissions in the short term, the Scottish Government funded research to revise and update Scottish Natural Heritage (SNH) technical guidance note "*Windfarms and Carbon Savings*" (SNH, 2003). The output of this research, started in 2007, was a spreadsheet tool to facilitate calculation of greenhouse gas emissions and carbon payback times for windfarm developments. This spreadsheet tool, described in the report "*Calculating Carbon Savings From Wind Farms On Scottish Peat Lands - A New Approach*" (Nayak *et al.*, 2008) has been updated several times in the intervening period, with the final corrected report dated 29th June 2010. A full report on Version 2 of the calculator, titled "*Carbon Implications of Windfarms Located on Peatlands – Update of the Scottish Government Carbon Calculator Tool*" (Smith *et al.*, 2011) was published in 2011. From June 2016 an online version of the tool was made available, superseding all previous versions. The calculator is supported by two documents: *"Carbon calculator technical guidance - Version 2.10.0"* (Scottish Government, 2016) and "*Guidance on the Assessment of Peat Volumes, Reuse of Excavated Peat and the Minimisation of Waste"* (Scottish Renewables & SEPA, 2012).

There is a requirement to use this tool as part of the planning or consenting process for developments of 50 MW or greater generating capacity. This report will provide an estimate of the CO_2 emissions related to the proposed construction, operation and decommissioning of the Development and will compare these with the estimated CO_2 emissions related to the production of electricity from wind rather than from fossil fuels, to provide an overall estimate of the payback time for the development.

2 Development Description

The Development is located between Sanqhuar, Corsebank and Wanlockhead, Dumfries and Galloway. The Development is located upon a number of fells, including Willowgrain Hill, and Brown Hill to the south, Cobrig Hill to the west, Stood Hill and Glengaber Hill to the east, and Wedder Dod, Slough Hill and Clackleith Hill to the north. The fells of Well Hill and Tongue Hill are located within the centre of the Development Area.

The Development Area is predominantly rough grassland with areas of coniferous plantations in the north western areas. Peatland habitats are evident across much of the Development Area. A number of stands of conifer plantation across the Development are required to be felled to facilitate construction.

Within the Development Area there are numerous watercourse channels and a number of small artificial channels which are associated with conifer plantation and pastoral land drainage.

3 Methodology

The methodology used for calculating the impact of the windfarm development on the carbon balance was that outlined in the stated literature (Nayak *et al.,* 2008; Smith *et al.,* 2011; Scottish Government, 2016) to facilitate the completion of the online Carbon Calculator Version 1.0.1 (Project Online Calculator Reference: SI7D-S6AP-EDDC).

In a number of cases, the methods suggested in the guidance require measurement around the constructed feature. Clearly, this is not possible for a project still at the planning stage, such as the Development. Therefore, where practical, actual data has been used in the assessment; however, where real data was not obtainable, either standard (default) data or, in some cases, an estimate has been used. In each case, an explanation of the values used and their source is provided. The following section provides a more detailed explanation of the data used and respective source(s).

4 Input Parameters for Carbon Calculator

In order to calculate the carbon balance for the Development, a range of data was collated regarding the windfarm characteristics and infrastructure, construction data, the local ecology, potential restoration and the benefits of replacing fossil fuel generated electricity with renewables. Of particular note is the potential for loss of stored carbon from peatlands.

4.1 Windfarm Characteristics

4.1.1 Number of Turbines and Project Timescale

A detailed description of the Development is within ES *Chapter 4: Scheme Description*. This identifies that planning consent will be sought for 35 wind turbines with a likely operational life of 25 years. These figures have therefore been included in the carbon calculator.

4.1.2 Performance

The capacity factor for a windfarm is obtained by dividing the annual generated output with the installed capacity, multiplied by the number of operational hours per year. The annual output is a function of a wind turbine's power curve and the prevailing wind resource at the Development.

The turbine specifications defined in ES *Chapter 4: Scheme Description* indicates an individual capacity of up to 4.2 megawatts (MW). This results in at total installed capacity of 147MW. For the purposes of the calculator, a minimum power rating of 90% of the capacity, 3.8MW, is provided.

The most recent average annual capacity factors reported by the Department for Business, Energy & Industrial Strategy in the *Digest of UK Energy Statistics 2016, (DUKES) Table 6.5: Load factors for renewable electricity generation* (DBEIS, 2016a) are shown below in Table 1. However, the average capacity factor for Scotland (1998 – 2004) is quoted in Nayak *et al.* (2008) as 30%. Nayak *et al.* (2008) also recommends that the likely range of results is calculated using the best (34%) and worst (27%) case capacity factors for Scotland.

Table 1: Annual UK Onshore Wind Capacity Factor

Year	2011	2012	2013	2014	2015
Capacity Factor (%)	27.6	26.4	28.8	26.4	29.5

The capacity factor is estimated to be around 36%. The worst (27%) and best (34%) from Nayak *et al.* (2008) case scenarios are used as minimum and maximum values in the calculator. For the Development, a conservative expected value of 34% will be used in the calculator, which will also be in line with the best case scenario from Nayak *et al.* (2008).

4.1.3 Balancing capacity

Due to the inherent variability of wind generated electricity, it is recognised that conventional generation facilities are required to stabilise supply. Nayak *et al.* (2008) refers to 'backup power generation' and identifies that the balancing capacity (as referred to henceforth) required is estimated as 5% of the rated capacity of the windfarm. It is also stated that balancing capacity is only necessary where wind power contributes more than 20% to the national grid.

It is assumed that the balancing capacity is from fossil fuels and also that where such power is required there will be additional emissions of 10% due to reduced thermal efficiency of the reserve generation.

DUKES Table 6.4: Capacity of, and electricity generated from, renewable sources (DBEIS, 2016b) indicates that the installed onshore wind capacity in the UK in 2015 was 9,188MW, and installed offshore wind capacity 5,103MW, giving a total of 14,291MW. The RenewableUK website (RenewableUK, 2017), accessed on 15th March 2017, identifies installed UK wind capacity as 14,609.93 MW, amounting to approximately 20.3% of total generation capacity (71,879 MW in 2015 (DBEIS, 2016c)). It is assumed that, when electricity generated from wind energy forms 20% of national electricity generation, it will be necessary to implement balancing capacity, suggested to be 5% of the actual output of the windfarm (Scottish Government, 2016).

Comparing the electricity generated in the UK during 2015 of 336,359 gigawatt hours (GWh) (DBEIS (2016d)) with that generated from wind of 34,662GWh), wind energy accounts for 10.3% of total generation. Therefore, at current levels, balancing capacity is not required as it can be assumed to be obtained from within the spare generating capacity of other power sectors.

Nayak *et al.* (2008) identifies, based on 2006 figures, that the contribution of wind power to the national grid will not reach 20% until 2038. On the basis of a 25 year operational life for the Development, from 2023 to 2048, for example, this would result in balancing capacity being required for the final 5 years of the planned operational period of the Development.

The timescale of 2038 for achieving 20% of production from wind is subject to a number of assumptions. Therefore, to provide a comparison, the "expected value" of the carbon calculator has been populated based on two options, depending on whether or not it has been assumed that balancing capacity will be required through the operational period.

The minimum value used for balancing capacity is 0% (with 0% additional emissions due to thermal inefficiency) and the maximum value 5% (with 10% additional emissions due to thermal inefficiency (Scottish Government, 2016)).

4.1.4 Carbon Dioxide Emissions from Turbine Life

Carbon dioxide emissions during the life of a wind turbine include those that occur during production, transportation, erection, operation, dismantling and removal of turbines and foundations. Where possible, the best option for this factor is to have an actual calculation determining the total emissions for the windfarm based on generating capacity. In the absence of this information, emissions are estimated based on turbine capacity and previously identified emission values. This calculation is embedded in the calculator spreadsheet. In this case, the latter approach has been taken as detailed data on emissions from turbine life are not available.

4.1.5 Characteristics of Peatland before Windfarm Development

As described in Section 2, the Development Area is typically upon rough grassland, with mainly shallow peat-containing soils and limited blanket peat evident (Mouchel, 2017a). There is evidence of frequent and widespread artificial channels, peat bodies on the Development are generally in good condition, but erosion features often present on steeper slopes.

4.1.6 Type of Peatland

The calculator offers two options for this item: Fen or Acid Bog. The peat deposits on this Development are consistent with the Acid Bog option.

4.1.7 Average Air Temperature at the Development

The closest Met Office station to the Development is Camps Reservoir, approximately 15km north-east of the Development Area, with an annual average maximum and minimum temperature of 10.5ºC and 3.4ºC, respectively (Met Office, 2017), giving a mean temperature of 6.95ºC. From the western Scotland regional temperature mapping (Met Office, 2017), the Development lies close to the intersection of areas with mean annual temperature of 9.0 – 10.0ºC and 10.0 – 11.0ºC. Based on this information and given that the Development is within close proximity, a mean annual temperature of 10.0ºC is proposed, with maximum and minimum values of 11.0°C and 9.0°C, respectively, reflecting the extremes of the stated mean Met office temperature ranges.

4.1.8 Average Depth of Peat at the Development

Extensive peat probing has been carried out, initially at representative locations across the Development and latterly in the vicinity of proposed infrastructure. In total, across the Development Area 2,607 peat probes were recorded. Results of peat depth probing are summarised in Table 7.8 of ES *Chapter 7: Hydrology, Hydrogeology, Geology and Soils*, where an average peat depth was 0.44m.

The assessment has been conducted on the basis that probes less than 0.5m are included. This would include organic soils as peat for the purposes of the calculator and therefore represents an overestimation of development on peat.

Specifically and more representative for the Development, 955 probes are within 25m of the new planned track centreline, excluding floating track sections, these have an average peat depth of 0.46m.

The large number of probing points taken provides a robust base for the average figure of 0.46m. However, for the purposes of the calculator, maximum and minimum average peat depths varying by ± 10% from the average have been used, to reflect the variability of peat across the Development.

4.1.9 Carbon Content of Dry Peat

Actual figures were not available for this parameter. In the absence of site specific data, values for carbon content in the peat component of the principal soil units on the Development (soil units 226, 228 and 229, covering the majority of the Development were obtained from The James Hutton Institute (JHI) Soil Indicators for Scottish Soils (SIFSS) website (JHI, 2017). This provided a median value for carbon content of 45%. The website also yielded ± one standard deviation values for carbon content of blanket peat of 55% and 35% respectively. These figures have been adopted as the maximum and minimum input values for the carbon calculator, with 45% used as the expected value.

4.1.10 Average Extent of Drainage around Development Features at Development

The extent of drainage around construction strongly influences the total volume of peat impacted by the construction of the windfarm. Thus, the extent of drainage has a significant impact on the calculated carbon payback time for the development.

A review of the available literature (Nayak *et al.*, 2008) found that the extent of drainage effects are reported as being anything from 2m to 50m horizontally around the site of disturbance. Research into the effects of moor gripping and water table data from other sites yielded a horizontal draw down distance typically of about 2m. It is thought that in extreme cases, this may extend as far as 15m – 30m, though this would be exceptional - and is why most grips are about 15m apart.

Smith *et al.* (2011), identified the average extent of drainage impact at three sites (Cross Lochs, Farr Windfarm and Exe Head) as ranging from 3m to 9m. The actual extent of drainage at any given location will be dependent on local conditions, including topography.

As noted in Section 2, the Development contains a number of drainage channels. Visual examinations indicated that many of these are historic in nature and that revegetation with bog plants is advanced. The photographs below (and Illustration 2) show typical examples of historic drainage ditches at the Development Area and show little evidence of changes in vegetation within and surrounding the drainage channels.

Illustration 1: Photograph showing drainage ditch with minimal vegetation change nearby

Illustration 2: Revegetated drainage ditch with second ditch visible in distance

Based on the above, the expected value for extent of drainage is 10m, at the upper end of the measured values quoted above by Smith *et al.* (2011). However, based upon site photographic evidence, it can be argued that the minimum value is less than 5m. As such, maximum and minimum values of 15m and 5m respectively are used in the carbon calculator.

It should be noted that the area where peat is removed is not included when estimating the extent of drainage because carbon loss from removed peat has already been counted in direct losses.

4.1.11 Average Water Table Depth at Development

Drainage channels in the centre of the Development are generally revegetated, with water levels close to surface. The "*Calculating Potential Carbon Losses & Savings from Wind Farms on Scottish Peatlands*" (Scottish Government, 2016) guidance indicates that on intact sites, the depth to water table may be <100mm (0.10m), with up to 300mm (0.3m) to water table on eroded sites. The Development is considered to be intact, given that many of the drainage ditches are historic and are revegetating and also given the extent of wet areas. Accordingly, the expected depth to water table used is 0.1m, with maximum and minimum values of 0.3m and 0.5m, respectively, included in the carbon calculator.

4.1.12 Dry Soil Bulk Density

Guidance on conducting site surveys on peatland (Scottish Government, 2014) suggests the following generic values for dry bulk density for basin and blanket peat; a mean value of 0.132g/cm^3 and maximum and minimum values of 0.293g/cm^3 and 0.072g/cm^3, respectively. These values were used in the calculator.

4.2 Characteristics of Bog Plants

4.2.1 Time Required for Regeneration of Bog Plants after Restoration (years)

The expected value used here is 5 years. This is a judgement made by Mouchel based on their experience of other windfarms and evidence of repopulation / regrowth within drainage channels on the Development. This figure assumes the use of best practice during restoration.

Values of 3 years and 10 years are used as the minimum and maximum in the calculator.

4.2.2 Carbon Accumulation due to Carbon Fixation by Bog Plants

There are a number of factors controlling the carbon cycle in peatlands, including plant community, temperature, drainage, depth of water table and peat chemistry. The estimated global average for apparent carbon accumulation rate in peatland ranges from 0.12 tCha^{-1}yr^{-1} to 0.31 tCha^{-1}yr^{-1} (Botch *et al*., 1995; Turunen *et al*., 2001). However, the accumulation of carbon in peat is highly site specific and it should be noted that the expected range for homogeneous peatlands will be considerably more than a heterogeneous site such as this.

The SNH Guidance (SNH, 2003) proposes an average value of 0.25 tCha^{-1}yr^{-1}, which is within the range quoted above. This value has conservatively been used as the expected value for the Development. The accumulation rates 0.12 tCha^{-1}yr^{-1} and 0.31 tCha^{-1}yr^{-1} are proposed as the minimum and maximum values, respectively.

4.3 Forestry Plantation Characteristics

The presence of extensive areas of forestry on and in the vicinity of the Development can significantly reduce the yield of wind energy, so it has often been the practice to clear existing forestry prior to windfarm development. It is expected that there will be felling of areas equating to 36.61ha of forestry plantation to facilitate the Development.

For the purposes of the calculator, maximum and minimum areas of felling varying by ±5% from the expected have been used, providing maximum and minimum values of 38.44ha and 34.78ha, respectively.

The average rate of carbon sequestration in timber (tCha^{-1}yr^{-1}) is dependent on the yield class (YC) of the forestry (m^{3}ha^{-1}yr^{-1}). Results from a preliminary yield class assessment carried out by forest managers, as part of the ES Forestry Appendix (LUC, 2017), indicate that the dominant tree species present are Sitka Spruce, mixed conifers and native broadleaves, together making up the site's forested area; approximately 82% as Sitka Spruce, 6% as mixed conifers and 12% as native broadleaves. The Sitka Spruce has been assessed as between YC 10 and YC 18.

Carbon sequestration rates for various Sitka YC values have been published by Cannell (1999) and a range from YC 8 to YC 24 has been equated to a carbon storage of 2.4 $tCha^{-1} yr^{-1}$ and 4.4 $tCha^{-1}yr^{-1}$, respectively.

SNH technical guidance suggests a YC value of 16 $m^3ha^{-1}yr^{-1}$ for Sitka which equates to 3.6 $tCha^{-1}yr^{-1}$ (Cannell, 1999). This value has been adopted for the expected value in the calculator as it fits within the observed range whilst still sitting in the conservative upper end of the range. The values of 2.4 $tCha^{-1}yr^{-1}$ and 4.4 $tCha^{-1}yr^{-1}$ have been used as minimum and maximum values, respectively, in order to encompass the range of YC values observed on site. The lowest value of the range is associated with Sitka YC and that the equivalent sequestration values for mixed conifers and native broadleaves has not been used as the minimum value, as data for this has not been found. The values for both expected and maximum have been applied conservatively, and it is these values that the conclusions of this assessment are based upon, rather than minimum values.

4.4 Counterfactual Emission Factors

These figures represent the estimated average emission of CO_2 resulting from generation of energy from different sources. Table 2 displays data from the *Greenhouse gas reporting - Conversion factors 2016* (DBEIS, 2016e). These emissions values have been used in the carbon calculator.

Table 2: Carbon Dioxide emissions from electricity generation (tCO_2MWh^{-1})

Fuel source	2016
Coal	0.903
Grid-Mix	0.410
Fossil Fuel-Mix	0.642

4.5 Development Infrastructure

4.5.1 Borrow Pits

Five potential borrow pit locations have been identified for the Development. Small sections of four of these have been previously excavated and are suspected to have been used to gain material for current forestry access tracks within the Development Area. The location and estimated dimensions of these are provided in **Appendix 4.1: Borrow Pit Report** of the ES (Mouchel, 2017b).

Table 3: Development Borrow Pit Dimensions

Borrow Pit ID	Maximum Depth of Overburden (m)	Footprint Area (m^2)
BP01	0.17	10,140
BP02	0.26	16,290
BP03	0.20	10,083
BP04	0.17	4,745
BP05	0.25	5,603

Dimensions of the borrow pits are provided in Table 3. The nominal footprint dimensions represent an approximate width and length of the proposed borrow pits, which are irregularly shaped. The calculator requires entry of an average length and width for the borrow pits. The average surface area of the borrow pits is 9,372m^2, which equates to a square of side of 96.81m. This is used as the expected value for both the average length and width of the borrow pits. The actual dimensions of the borrow pits will vary depending on the quality of rock, local geology and topography and windfarm design. An error of ± 10% in surface area is proposed to reflect the maximum and minimum values. This equates to a square of side of 106.49m and of 87.13m for the maximum and minimum, respectively.

Appendix 4.1: Borrow Pit Report of the ES (Mouchel, 2017b) indicates that surface soils are limited in the vicinity of the borrow pits and are generally not peat. Therefore, an expected value for peat depth at the borrow pits of 0.21m is proposed, with a maximum of 0.3m and minimum of 0.1m.

4.5.2 Wind Turbine Foundations

The turbine foundations at the Development are expected to be rectangular with vertical walls. The dimensions of the wind turbine foundations are estimated to be 25m x 25m with the excavations for these estimated at 30m x 30m. Excess excavated peat will be used for reinstatement of the foundation excavation post construction, therefore, the foundation area represents the volume of peat lost. Assuming that actual dimensions may vary by up to +5%, the maximum dimensions are 26.25m x 26.25m, respectively.

Based on the peat probing undertaken, the average peat depth at the turbine centres is estimated to be 0.5m. For the purposes of the calculator, a maximum and minimum depth of ± 10% is assumed, giving peat depths of 0.55m and 0.45m, respectively.

4.5.3 Hardstanding Area Associated with each Turbine

The average dimensions of the excavations for crane hardstandings will be 25m x 62.5m; assuming that actual dimensions may vary by up to + 5%, the maximum dimensions are 26.25m x 65.63m.

Based on the peat probing undertaken, the average peat depth at the hardstanding area associated with each turbine is 0.52m. For the purposes of the calculator, a maximum and minimum depth of ± 10% is assumed, giving peat depths of 0.57m and 0.47m, respectively.

4.6 Access Tracks

4.6.1 Access Track Lengths

The total length of access track to be constructed is estimated to be approximately 36.49km. Of this 3.08km is existing tracks, to be widened, with 0.94km of floating track. This includes; site access, all spurs to turbines and borrow pits and the main Development access tracks. As the design and construction process progresses, there may be small changes in track length as a result of micrositing etc. It is considered unlikely that the total track length will change by more than ± 5%, giving a maximum length of 38.32km and minimum of 34.66km.

As existing tracks are to be widened involving the excavation of land, for the purposes of the calculator, no existing track length is provided thereby assuming a worst case for this value.

4.6.2 Length of Access Track - Floating Track

There are a number of discrete sections of floating track planned at the Development.

There are a number of reasons for choosing floating construction methods for specific sections of the Development access tracks. Principal among these are four factors: peat stability; minimisation of the need to excavate peat on deeper deposits; because of the presence of groundwater dependant terrestrial ecosystems (GWDTEs); and local hydrological conditions, such as waterlogging.

In total, these aggregate to a total value of 0.94km, and by applying ±10%provides a maximum length of 0.99km and minimum of 0.89km.

The running width of floating track will be 7m. On average it is considered unlikely that the width of floating road will vary by more than +1m, giving a maximum of 8m and minimum of 7m.

Floating construction will not involve excavation of peat or soil. For the purposes of the calculator, the depth values are 0m.

Floating construction may include a shallow drainage ditch on one side of the track. Where this is the case, regular cross drains will be incorporated to redistribute any intercepted flow across the track to minimise the impacts on local hydrology. The drainage ditch is proposed to be 0.5m in depth. For calculation purposes, the maximum and minimum depth values are 0.3m and 0.7m respectively.

4.6.3 Length of Access Track - Excavated Track

Cut and fill construction will be used along the route of the proposed access track where peat depth is less than 1m and there are no other factors favouring floating construction. The estimated length of access track using cut and fill construction is 35.55km. Of this, 3.08km will be widening existing tracks with a running width of 4m, with 32.47km of standard construction, with a running width of 8m. Sections of tracks accessing borrow pits will have a narrower running width. For convenience in populating the calculator, all cut and fill construction track is considered to be single track. Although this may slightly underestimate the excavation volume, this is offset by the assumption that all excavated material will be peat, which is not the case.

It is considered unlikely that the total length of cut and fill track will vary by more than ± 5%, giving a maximum length of 37.33km and minimum of 33.77km.

The width of cut and fill track is therefore estimated at 8m including running width (5m), track shoulder (2 x 1.0m) and drainage (2 x 0.5m) with an average excavated depth of 0.46m, based on measured peat depths within 25m of the new proposed cut access track routes, excluding depths adjacent to three floating tracks sections.

The total excavation width will vary with peat depth and local topography, but it is considered unlikely that total track width will vary on average by more than ± 0.5m, giving a maximum width of 8.5m and minimum of 7.5m.

The average peat depth for cut and fill sections of track, based on peat probing results, is considered to be robust, being based on 955 measured peat depths. Indeed, this is a conservative approach as it assumes all probed material is peat, which will not be the case in practice. It is recognised that minor changes in access track routing will result in a change in the average depth of peat excavated. Given that micrositing will be in part to minimise peat depth, a maximum average peat depth of 0.56m and minimum of 0.36m is proposed for the calculator, based on an expected depth of 0.46m.

4.6.4 Length of Access Track – Rock Filled Road

There are no sections of track that are planned to be rock filled. The value used in calculator is therefore zero.

4.6.5 Cable Trenches

It is intended that all cable trenches will follow the route of access tracks and that there will be zero impact for the purpose of the calculator, and the value used is zero.

4.6.6 Additional Peat Excavated

There is a requirement for two main compounds, each measuring 120m x 60m, three smaller satellite compounds, each measuring 40m x 50m and a substation measuring 100m x 60m, combined this results in an area of 21,000m^2 which is entered in the calculator as the expected value; assuming that actual dimensions may vary by up to ±5%, the minimum and maximum dimensions have been entered as 19,950m^2 and 22,050m^2, respectively.

Plans have been provided for three option areas for this development and therefore soil/peat depth values have been aggregated for these areas combined. The average measured depth for all locations is 0.47m. Using this depth value along with the overall footprint areas above an expected peat volume of 9,870m^3 has been derived and a minimum and maximum volumes, using minimum and maximum dimensions, of 9,376.5m^3 and 10,363.5m^3, respectively.

4.7 Peat Landslide Hazard

A peat landslide ("peatslide") risk assessment has been carried out and this is detailed in **Appendix 7.2: Peat Stability Assessment** of the ES (Mouchel, 2017c). The majority of the Development was considered to have a low risk of peatslide, however 11 moderate and four high risk locations were identified based on peat depths and slope angles applying the factor of safety stability analysis, these locations were generally on edge of steep slopes. With mitigation measures planned there are considered to be no high risk locations, but a number of moderate risk locations are evaluated.

All entries for this section of the calculator are zero, with the expectation that peat instability will be appropriately mitigated to reduce likelihood and scale of any incident that did occur.

4.8 Improvement of Carbon Sequestration at the Development

Any local improvements to carbon sequestration, for example by blocking of drains or habitat restoration, will result in a reduction in the net carbon emissions from the development.

4.8.1 Improvement of Degraded Bog

Peatlands on the Development, although in places crossed by historic drainage ditches, appear generally to be in good condition. It has therefore been assumed that there will be no improvement of degraded bog. This section has therefore been entered as zero.

Based on the Habitat Management Plan (HMP) for the Development, restoration and enhancement of blanket and wet modified bog is planned. It is likely that this will retain, and potentially sequester, carbon, however, this is not accounted for within the carbon calculator.

4.8.2 Improvement of Felled Plantation Land

As it has been assumed that felling will be restricted to that necessary for construction, there will be no opportunity for improvement of felled plantation land. A value of zero has therefore been entered for this section in the calculator.

4.8.3 Restoration of Peat Removed from Borrow Pit

Peat coverage at the five proposed borrow pit locations is minimal, with the maximum recorded depth of overburden 0.3m (Mouchel, 2017a). Peat and any other superficial soils will be removed and stockpiled adjacent to the borrow pit. When construction is complete this material will be utilised to landscape the sides and floor of the excavation. Due to the shallow nature of surface deposits at the borrow pit locations, it is proposed to utilise peat excavated elsewhere on site for restoration, to a nominal depth of 1.0m (see **Appendix 4.4: Soil and Peat Management Plan** of the ES (Mouchel, 2017d)). The surface area of the borrow pits, given in Table 3, is estimated to be 46,861m^2 (4.6861ha) in total.

Restoration is planned to be undertaken for 42,789m^2 (4.2789ha) of the borrow pit surface area, ±10%, giving a maximum of 4.70679ha and minimum of 3.85101ha, to a depth of 1m.

The borrow pits are designed to be self-draining. The restoration profile will be designed as far as is practicable to facilitate maintenance of a high water table in the peat post restoration. For calculation purposes, It has been assumed that restoration of the borrow pits will be carried out using good practice and that the post restoration water table in the borrow pits will be similar to the water table across the Development. In Section 4.1.11, this was estimated to be 0.1m, with maximum and minimum values of 0.3m and 0.05m respectively.

Peat deposits can take many years to develop. The plant communities found on peat bogs are typically slow growing and may take a number of years to become established. In the absence of measured data or detailed study, it has conservatively been estimated that recovery will take 10 years, with a maximum time to recovery of 20 years and minimum of 5 years.

4.8.4 Removal of Drainage from Foundations and Hardstandings

It has been assumed that drainage around foundations and hardstandings will be temporary, only necessary during construction. Therefore, the area can be assumed to be drained only up to the time of completion of backfilling, removal of any temporary surface drains, and full restoration of the hydrology. Subsequently, the water table level is assumed to return to pre-construction levels. A conservative timescale of six years has been assumed, based on the findings of Isselin-Nondedeu *et al*. (2007) "*Long-term vegetation monitoring to assess the restoration success of a vacuum-mined peatland (Québec, Canada)*", who report 90% vegetation cover after 6 years. However the maximum permitted value within the online calculator is 5 years. The minimum and maximum time to recovery is estimated to be 2 years and 5 years respectively.

4.9 Restoration of Development after Decommissioning

Restoration following decommissioning is likely to reduce the total carbon loss. By restoring the hydrology and returning remaining stored carbon to anaerobic conditions, further oxidative loss will be arrested. Restoration of habitats presents an opportunity for additional carbon sequestration. In the absence of restoration after decommissioning, the model assumes 100% loss of carbon from the drained volume of soil. For the Development, good practice will be employed during construction to minimise disruption to peatland hydrology. It is considered likely that access tracks will not be restored, rather they will remain *in-situ* following windfarm decommissioning due to their amenity value in providing access.

4.9.1 Blocking of gullies

In the event that any gullies in peat have formed due to erosion during the windfarm operation, these will be blocked using good practice techniques such as plastic piling to promote restoration of the local hydrology. In this case, it has been assumed that the Development will be restored on decommissioning.

4.9.2 Blocking of artificial drainage ditches

Given that it has been assumed that access tracks will remain *in-situ* post-decommissioning, drainage associated with the access tracks will not be blocked. As good practice will be followed during construction, it is expected that with appropriate maintenance, disruption of local hydrology due to artificial drainage will be minimised.

4.9.3 Restoration of habitat

Much of the Development is currently used for low density sheep grazing. There is little evidence of habitat degradation at current grazing densities. It has been assumed that during the operational phase and post decommissioning of the windfarm, sheep grazing, at a controlled density, will continue. Grazing will be prevented where there are areas of visible degradation.

4.9.4 Management to favour species reintroduction

Where there is evidence of degradation of peat bodies, positive action will be taken to restore these. This will include as necessary, programmed planting or seeding of selected plant communities to facilitate restoration of degraded areas.

4.10 Choice of Methodology for Calculating Emission Factors

There are two choices for methodology. The IPCC method is an internationally accepted standard. However, the values used are rough estimates and an improved estimate can be obtained (IPCC 1997) using site specific values and the site specific estimates generated by the Ecosse project (Smith *et al.*, 2007). Accordingly, the site specific option is chosen as being most appropriate.

4.11 Summary of Input Data

The values entered into the carbon calculator are summarised in Appendix 1 of this report (Project Online Calculator Reference: SI7D-S6AP-EDDC).

5 Output from Carbon Calculator

Based on the figures input to the carbon calculator (Reference: SI7D-S6AP-EDDC) as described in Section 4 and provided in Appendix 1, the total carbon losses associated with the Development are summarised in Table 4 and fully detailed in Appendix 2.

Table 4: Total Carbon Losses Due to Windfarm

Source of Losses	Carbon Losses (tCO_2)		
	Expected Value*	Minimum Value	Maximum Value
Turbine life cycle	120,985	107,904	120,985
Balancing capacity	103,340	0	103,340
Reduction in carbon fixing potential	3,599	998	7,455
Soil organic matter	34,343	-171	143,109
DOC & POC leaching	32	0	220
Felling of forestry	12,081	7,652	15,504
Total	**274,380**	**116,383**	**390,613**

With the exception of the balancing capacity (assumed to be from conventional fossil fuel sources), the carbon losses are independent of the generation mix used to calculate the overall carbon balance. Assuming a requirement for balancing capacity, the calculator model indicates that based on expected values, approximately 44.1% of the carbon losses are from turbine life cycle, 37.7% of the potential carbon losses are due to the requirement for balancing capacity and 12.5% due to losses of soil organic matter, as demonstrated in Table 4.

Based on the figures input to the carbon calculator, the predicted payback time for the windfarm from the carbon calculator tool is summarised in Table 5 and fully detailed in Appendix 2. The counterfactual emission factor values for each generation source shown in Table 5 were provided in Table 2.

Table 5: Carbon Payback Period

Generation Source	Counterfactual emission factors ($t\ CO_2\ MWh^{-1}$)	Carbon Payback Period (years)		
		Expected Value	Minimum Value 0% Balancing Capacity	Maximum Value 5% Balancing Capacity
Coal Fired	0.903	0.7	0.3	1.4
Grid Mix	0.410	1.5	0.6	3
Fossil Fuel Mix	0.642	1	0.4	1.9

Given that the 'Grid Mix' will involve renewable energy developments that are operational, the 'Fossil Fuel Mix' represents the most likely scenario in terms of the existing capacity to be replaced by electricity generated from the Development.

Therefore, with the figures used (see Section 4) the expected payback time, with little or no requirement for balancing capacity, based on predictions for the growth in the contribution of wind energy to the national grid, is calculated to be approximately 1.0 years (12 months), if replacing the 'Fossil Fuel Mix'. Based on the worst case scenario, represented by the maximum values entered in the calculator across all generation source types and also taking account of a requirement for balancing capacity, the payback time is calculated to be 3.0 years (36 months).

6 Conclusions

Use of the carbon calculator with best estimate values, based on available information, indicates that the Development will pay back the carbon emissions associated with its construction, operation and decommissioning in 1.0 year. Assuming a 25 year windfarm life, this equates to an overall carbon saving of 25 times the carbon emitted.

Outputs from the carbon calculator demonstrate some key points, summarised below:

- There are two principal sources of carbon emissions that are independent of losses due to the requirement for balancing capacity, covering the life of the windfarm: emissions due to turbine life cycle and losses of soil organic matter. Between them when applying expected values, these sources account for 90.8% of emissions in the scenario where balancing capacity is not required (reducing to 56.6% in the scenario where balancing capacity is required, with balancing making up the remainder of the emissions in this scenario).
- In compiling carbon data, a conservative approach has been taken; therefore, little allowance has been made for CO_2 gains due to on-site improvements.

Although it is possible that some combination of changes could have an impact greater than the sum of their individual effects on payback, the sensitivity analysis embedded within the carbon calculator demonstrates that, even using conservative values for all of the factors contributing to the overall estimation of carbon payback, the carbon savings of the Development will still be significantly greater than the carbon emissions attributable to the development.

7 References

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Appendix 1: Inputs to Online Calculator (Reference: SI7D-S6AP-EDDC)

Carbon Calculator v1.0.1
NLEI Location: 55.399664 -3.844902
NLEI Ltd

Core input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Windfarm characteristics				
Dimensions				
No. of turbines	35	35	35	NLEI, Appendix 14.1: Carbon Report, Pg.1
Duration of consent (years)	25	25	25	NLEI, Appendix 14.1: Carbon Report, Pg.1
Performance				
Power rating of 1 turbine (MW)	4.2	3.8	4.2	NLEI, Appendix 14.1: Carbon Report, Pg.1
Capacity factor	34	27	36	NLEI, Appendix 14.1: Carbon Report, Pg.1
Backup				
Fraction of output to backup (%)	5	0	5	NLEI, Appendix 14.1: Carbon Report, Pg.2
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	NLEI, Appendix 14.1: Carbon Report, Pg.
Average annual air temperature at site (°C)	10	9	11	NLEI, Appendix 14.1: Carbon Report, Pg.2
Average depth of peat at site (m)	0.46	0.41	0.51	NLEI, Appendix 14.1: Carbon Report, Pg.2
C Content of dry peat (% by weight)	45	35	55	NLEI, Appendix 14.1: Carbon Report, Pg.2
Average extent of drainage around drainage features at site (m)	10	5	15	NLEI, Appendix 14.1: Carbon Report, Pg.3
Average water table depth at site (m)	0.1	0.05	0.3	NLEI, Appendix 14.1: Carbon Report, Pg.3
Dry soil bulk density (g cm^{-3})	0.13	0.07	0.29	NLEI, Appendix 14.1: Carbon Report, Pg.3
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	5	3	10	NLEI, Appendix 14.1: Carbon Report, Pg.3
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha^{-1} yr^{-1})	0.25	0.12	0.31	NLEI, Appendix 14.1: Carbon Report, Pg.3
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	36.61	34.78	38.44	NLEI, Appendix 14.1: Carbon Report, Pg.3
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	3.6	2.4	4.4	NLEI, Appendix 14.1: Carbon Report, Pg.4
Counterfactual emission factors				
Coal-fired plant emission factor (t CO2 MWh^{-1})	0.903	0.903	0.903	
Grid-mix emission factor (t CO2 MWh^{-1})	0.40957	0.40957	0.40957	
Fossil fuel-mix emission factor (t CO2 MWh^{-1})	0.642	0.642	0.642	
Borrow pits				
Number of borrow pits	5	5	5	NLEI, Appendix 14.1: Carbon Report, Pg.4
Average length of pits (m)	96.81	87.13	106.49	NLEI, Appendix 14.1: Carbon Report, Pg.4
Average width of pits (m)	96.81	87.13	106.49	NLEI, Appendix 14.1: Carbon Report, Pg.4

Input data	Expected value	Minimum value	Maximum value	Source of data
Average depth of peat removed from pit (m)	0.21	0.1	0.3	NLEI, Appendix 14.1: Carbon Report, Pg.4
Foundations and hard-standing area associated with each turbine				
Average length of turbine foundations (m)	25	25	26.25	NLEI, Appendix 14.1: Carbon Report, Pg.4
Average width of turbine foundations (m)	25	25	26.25	NLEI, Appendix 14.1: Carbon Report, Pg.4
Average depth of peat removed from turbine foundations(m)	0.5	0.45	0.55	NLEI, Appendix 14.1: Carbon Report, Pg.4
Average length of hard-standing (m)	25	25	26.25	NLEI, Appendix 14.1: Carbon Report, Pg.4
Average width of hard-standing (m)	62.5	62.5	65.53	NLEI, Appendix 14.1: Carbon Report, Pg.4
Average depth of peat removed from hard-standing (m)	0.52	0.47	0.57	NLEI, Appendix 14.1: Carbon Report, Pg.4
Volume of concrete used in construction of the ENTIRE windfarm				
Volume of concrete (m^3)				
Access tracks				
Total length of access track (m)	36490	34660	38320	NLEI, Appendix 14.1: Carbon Report, Pg.4
Existing track length (m)	0	0	0	NLEI, Appendix 14.1: Carbon Report, Pg.4
Length of access track that is floating road (m)	940	890	990	NLEI, Appendix 14.1: Carbon Report, Pg.5
Floating road width (m)	7	7	8	NLEI, Appendix 14.1: Carbon Report, Pg.5
Floating road depth (m)	0	0	0	NLEI, Appendix 14.1: Carbon Report, Pg.5
Length of floating road that is drained (m)	940	890	990	NLEI, Appendix 14.1: Carbon Report, Pg.5
Average depth of drains associated with floating roads (m)	0.5	0.3	0.7	NLEI, Appendix 14.1: Carbon Report, Pg.5
Length of access track that is excavated road (m)	35550	33770	37330	NLEI, Appendix 14.1: Carbon Report, Pg.5
Excavated road width (m)	8	7.5	8.5	NLEI, Appendix 14.1: Carbon Report, Pg.5
Average depth of peat excavated for road (m)	0.46	0.36	0.56	NLEI, Appendix 14.1: Carbon Report, Pg.5
Length of access track that is rock filled road (m)	0	0	0	NLEI, Appendix 14.1: Carbon Report, Pg.5
Rock filled road width (m)	5	5	5	NLEI, Appendix 14.1: Carbon Report, Pg.5
Rock filled road depth (m)	0	0	0	NLEI, Appendix 14.1: Carbon Report, Pg.5
Length of rock filled road that is drained (m)	0	0	0	NLEI, Appendix 14.1: Carbon Report, Pg.5
Average depth of drains associated with rock filled roads (m)	0	0	0	NLEI, Appendix 14.1: Carbon Report, Pg.5
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	NLEI, Appendix 14.1: Carbon Report, Pg.5
Average depth of peat cut for cable trenches (m)	0	0	0	NLEI, Appendix 14.1: Carbon Report, Pg.5
Additional peat excavated (not already accounted for above)				
Volume of additional peat excavated (m^3)	9870	9376.5	10363.5	NLEI, Appendix 14.1: Carbon Report, Pg.5
Area of additional peat excavated (m^2)	21000	19950	22050	NLEI, Appendix 14.1: Carbon Report, Pg.5
Peat Landslide Hazard				

Input data	Expected value	Minimum value	Maximum value	Source of data
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				
Improvement of degraded bog				
Area of degraded bog to be improved (ha)	0	0	0	NLEI, Appendix 14.1: Carbon Report, Pg.5
Water table depth in degraded bog before improvement (m)	0	0	0	NLEI, Appendix 14.1: Carbon Report, Pg.5
Water table depth in degraded bog after improvement (m)	0	0	0	NLEI, Appendix 14.1: Carbon Report, Pg.5
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	10	5	20	NLEI, Appendix 14.1: Carbon Report, Pg.5
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	15	5	20	NLEI, Appendix 14.1: Carbon Report, Pg.5
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	36.61	34.78	38.44	NLEI, Appendix 14.1: Carbon Report, Pg.5
Water table depth in felled area before improvement (m)	0.1	0.05	0.3	NLEI, Appendix 14.1: Carbon Report, Pg.5
Water table depth in felled area after improvement (m)	0.09	0.04	0.29	NLEI, Appendix 14.1: Carbon Report, Pg.5
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	10	5	20	NLEI, Appendix 14.1: Carbon Report, Pg.5
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	15	5	20	NLEI, Appendix 14.1: Carbon Report, Pg.5
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	4.2789	3.85101	4.70679	NLEI, Appendix 14.1: Carbon Report, Pg.5
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	0.1	0.05	0.3	NLEI, Appendix 14.1: Carbon Report, Pg.5
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.09	0.04	0.29	NLEI, Appendix 14.1: Carbon Report, Pg.5
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	10	5	20	NLEI, Appendix 14.1: Carbon Report, Pg.5
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	15	5	20	NLEI, Appendix 14.1: Carbon Report, Pg.5
Early removal of drainage from foundations and hardstanding				
Water table depth around foundations and hardstanding before restoration (m)	0.1	0.05	0.3	NLEI, Appendix 14.1: Carbon Report, Pg.6
Water table depth around foundations and hardstanding after restoration (m)	0.09	0.04	0.29	NLEI, Appendix 14.1: Carbon Report, Pg.6
Time to completion of backfilling, removal of any surface drains, and full restoration of the hydrology (years)	5	2	5	NLEI, Appendix 14.1: Carbon Report, Pg.6
Restoration of site after decomissioning				
Will the hydrology of the site be restored on decommissioning?	No	No	No	
Will you attempt to block any gullies that have formed due to the windfarm?	Yes	Yes	Yes	NLEI, Appendix 14.1: Carbon Report, Pg.6
Will you attempt to block all artificial ditches and facilitate rewetting?	No	No	No	NLEI, Appendix 14.1: Carbon Report, Pg.6
Will the habitat of the site be restored on decommissioning?	Yes	Yes	No	
Will you control grazing on degraded areas?	Yes	Yes	No	NLEI, Appendix 14.1: Carbon Report, Pg.6
Will you manage areas to favour reintroduction of species	Yes	Yes	No	NLEI, Appendix 14.1: Carbon Report, Pg.6
Methodology				
Choice of methodology for calculating emission factors	Site specific (required for planning applications)			

Forestry input data

N/A

Construction input data

N/A

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Appendix 2: Payback Time and CO_2 Emissions from Online Calculator (Reference: SI7D-S6AP-EDDC)

Payback Time and CO_2 emissions • SI7D-S6AP-EDDC v1 MENU

1. Windfarm CO2 emission saving over...	Exp.	Min.	Max.
...coal-fired electricity generation	395,356	284,058	418,612
...grid-mix of electricity generation	179,320	128,839	189,868
...fossil fuel-mix of electricity generation	281,084	201,955	297,618
Energy output from windfarm over lifetime	10,945,620	7,864,290	11,589,480

Total CO2 losses due to wind farm (tCO2 eq.)	Exp.	Min.	Max.
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	120,985	107,904	120,985
3. Losses due to backup	103,340	0	103,340
4. Lossess due to reduced carbon fixing potential	3,599	998	7,455
5. Losses from soil organic matter	34,343	-171	143,109
6. Losses due to DOC & POC leaching	32	0	220
7. Losses due to felling forestry	12,081	7,652	15,504
Total losses of carbon dioxide	274,380	116,383	390,613

8. Total CO2 gains due to improvement of site (t CO2 eq.)	Exp.	Min.	Max.
8a. Gains due to improvement of degraded bogs	0	0	0
8b. Gains due to improvement of felled forestry	156	0	-3,735
8c. Gains due to restoration of peat from borrow pits	18	0	-457
8d. Gains due to removal of drainage from foundations & hardstanding	188	0	-2,726
Total gains	361	0	-6,918

RESULTS	Exp.	Min.	Max.
Net emissions of carbon dioxide (t CO2 eq.)	274,741	109,465	390,613
Carbon Payback Time			
...coal-fired electricity generation (years)	0.7	0.3	1.4
...grid-mix of electricity generation (years)	1.5	0.6	3.0
...fossil fuel-mix of electricity generation (years)	1.0	0.4	1.9
Ratio of soil carbon loss to gain by restoration (not used in Scottish applications)	No gains!	No gains!	20.72
Ratio of CO2 eq. emissions to power generation (g/kWh) (for info. only)	25.10	9.45	49.67