TA2.7 Carbon Balance Assessment

Glenshero Wind Farm
Carbon Balance Assessment

Technical Appendix 2.7

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CONTENTS

1. INTRODUCTION

MacArthur Green has been commissioned by RES Ltd on behalf of Simec Wind One Ltd to produce a Carbon Balance Assessment Report for the proposed Glenshero Wind Farm (hereafter referred to as the 'proposed development') and has undertaken an assessment of the carbon balance of the proposed development; the results of this assessment are presented within this report.

This assessment has been carried out by MacArthur Green in accordance with Scottish Government and SEPA guidelines. All staff contributing to this technical appendix have undergraduate and/or postgraduate degrees in relevant subjects, have deep professional experience, and hold professional membership of either the Chartered Institute of Ecology and Environmental Management (CIEEM) or Institution of Civil Engineers (ICE). The report has been reviewed and approved by David MacArthur of MacArthur Green and a copy of his CV is included in EIAR Volume 4: Technical Appendix 1.2.

Whilst the proposed development will generate renewable energy that will contribute to carbon emissions reduction targets, it is recognised that the construction of the proposed infrastructure, and subsequent operation and decommissioning of the proposed development will include activities that either directly or indirectly result in CO_2 emissions. In particular, the construction of the infrastructure for the proposed development could result in the potential loss of CO_2 from carbon stored within the peat deposits within the proposed development site ("the site").

The Scottish Government has published an online calculation tool (the "carbon calculator") that should be used to calculate the greenhouse gas emissions and carbon payback times for windfarm developments in Scottish peatlands. This online tool[1], originally published in 2011, is supported by two further documents published by the Scottish Government[2], and Scottish Renewables/SEPA[3] respectively.

The carbon calculator must be adopted for developments with a 50 MW or greater generating capacity, and will compare an estimate of the CO_2 emissions from the construction, operation and decommissioning of the proposed development to those emissions estimated from other wind based electricity generation sources.

2. PROPOSED DEVELOPMENT DESCRIPTION

The proposed development is located on the Glenshero Estate in an area of treeless upland and montane habitat in the southern Monadhliath mountains of the Scottish Highlands. A detailed description of the proposed development is provided in EIAR Volume 2: Chapter 2: Development Description.

The proposed development site is predominantly blanket bog and wet heath communities interspersed with mosaics and transitional zones containing mire, wet heath and flushed communities. Dry heath communities are present over the steep slopes, summits, knolls and rocky plateaus. Various watercourses exist within the proposed development site, however, no notable artificial drainage channels are present.

[1] "Carbon Implications of Windfarms Located on Peatlands – Update of the Scottish Government Carbon Calculator Tool", Version 2 (Smith et al., 2011)
[2] "Calculating Potential Carbon Losses & Savings form Wind Farms on Scottish Peatlands, Technical Guidance, Version 2.10.0" (Scottish Government, 2016)
[3] "Guidance on the Assessment of Peat Volumes, Reuse of Excavated Peat and the Minimisation of Waste" (Scottish Renewables & SEPA, 2012)

3. CARBON ASSESSMENT METHODOLOGY

The methodology adopted to calculate the impact on the carbon balance of a site as a result of the windfarm development, and to enable the online carbon calculator version 1.4.0 to be completed (Project Online Calculator Reference: FEYA-HDMU-Q31R v5), has been outlined in various literature (Nayak et al., 2008; Smith et al., 2011; Scottish Government, 2016).

This report should be read in conjunction with the online carbon calculator inputs and outputs, the project description contained in EIAR Volume 2: Chapter 2: Development Description and Chapter 6: Ecology. Whilst various guidance indicates that actual measurements of the site infrastructure are utilised in the calculations, for projects in the planning stage no infrastructure has been constructed. Therefore, the assumptions for the infrastructure are either based on information provided for the proposed development (where practical) or standard, default information that is representative for the proposed development. In each case, an explanation of the assumptions adopted and their respective source is provided in the following section.

4. CARBON BALANCE ASSESSMENT INPUT PARAMETERS

To enable the carbon balance assessment of the proposed development to be completed, information relating the design, construction and operation of the proposed development was collated, including details of the proposed infrastructure, local ecology and potential for loss of stored carbon, potential restoration proposals and the benefits of replacing fossil fuel generated electricity with electricity generated from renewable energy sources.

4.1 Windfarm Characteristics

4.1.1 Dimensions

The detailed description of the proposed development provided in EIAR Volume 2: Chapter 2: Development Description identifies that planning consent will be sought for 39 turbines with an operational life of 30 years. The carbon balance assessment presented below is based on these considerations.

4.1.2 Performance

The capacity factor for the proposed development is determined by dividing the annual generation output (MWh) by the installed capacity (MW) multiplied by the number of operational hours per annum. Generation output is a function of a wind turbine's power curve and the prevailing wind resource at the site.

EIAR Volume 2: Chapter 2: Development Description indicates that the wind turbines would have an individual capacity of up to 4.3 megawatts (MW), resulting in a total installed capacity of 167.7 MW. For the purposes of the carbon assessment, a minimum power rating of 90% of the capacity, 150.93 MW, is assumed.

The most recent average annual capacity factors reported by the Department for Business, Energy & Industrial Strategy in the Digest of UK Energy Statistics 2018, (DUKES) Table 6.5: Load factors for renewable electricity generation (DBEIS, 2018) are shown below in Table 2.7.1. 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 2.7.1: Annual UK Onshore Wind Capacity Factor

Year	2013	2014	2015	2016	2017
Capacity Factor (%)	28.4	26.2	29.3	23.6	28.0

The capacity factor for the proposed development is estimated to be greater than 32%. The worst (27%) and best (34%) capacity factors from Nayak et al. (2008) case scenarios are used as minimum and maximum values in the carbon assessment. For the purposes of the carbon assessment, conservatively the expected value of 32% has been adopted in the carbon assessment, which is aligned with the best case scenario according to Nayak et al. (2008), and the minimum and maximum values adopted are 30% and 34% respectively.

4.1.3 Backup

It is recognised that, due to the inherent variability of wind generated electricity, conventional generation facilities will be required to provide stability in the overall supply of electricity. Nayak et al. (2008) refers to 'backup power generation' and identifies that the balancing capacity required is estimated as 5% of the rated capacity of the windfarm. However, this balancing capacity is only necessary where wind power contributes more than 20% of the national supply. Where the balancing capacity is obtained from fossil fuel generating stations, emissions will increase by 10% due to reduced thermal efficiency of the reserve generation stations.

The installed onshore and offshore wind capacities in the UK in 2017 were 12,847 MW and 6,988 MW respectively, totalling 19,835 MW (DUKES Table 6.4: Capacity of, and electricity generated from, renewable sources (DBEIS, 2018)).

In 2017 27.9% of the electricity generated came from renewable sources, and in particular wind energy accounted for 50% of this subtotal (13.9% of the total electricity generated in the UK during 2017) (DUKES Table 6.7: Renewable sources data used to indicate progress under the 2009 EU Renewable Energy Directive (measured using net calorific values) (DBEIS, 2018)). Therefore, based on current installed wind generation capacity (less than 20% overall capacity), it can be assumed that balancing capacity is not immediately required.

Nayak et al. (2008) identifies, based on 2006 figures, that wind energy will not contribute greater than 20% supply until 2038. On the basis of a 30 year operational life for the proposed development, from 2022 to 2052, for example, balancing capacity would be required for the final 14 years (or 46.7%) of the planned operational period of the proposed development. Conservatively, whilst achieving 20% of electricity production from wind energy by 2038 requires the assumptions made in this prediction to be realised, the expected value adopted for the balancing capacity is 5%. 5% contribution from the balancing capacity equates to 10% additional emissions due to thermal inefficiency of the balancing generation units (Scottish Government, 2016).

So that a comparison of what may or may not be achieved can be undertaken, the carbon assessment assumes the minimum and maximum values of 0% and 5% respectively, (representing no and full contribution from the balancing capacity).

4.1.4 CO_2 Emissions from Turbine Life (tCO_2/MW)

Carbon dioxide emissions during the life of a turbine include those emissions that occur during the manufacturing, transportation, erection, operation, dismantling and removal of those turbines. On the basis that the candidate turbine has not been selected for the proposed development at this stage, this information is not available. Therefore, the emissions assumed in the carbon assessment are estimates based on the turbine capacity and previously determined emission values for such turbines. The expected value has been calculated based on the default values embedded within the carbon calculator.

4.2 Characteristics of Peatland before Proposed Development

4.2.1 Type of Peatland

As detailed in Section 2 above, the on-site habitats are typically blanket bog and wet heath communities, with wet heath and flushed, and dry heath communities also present. For the purpose of the carbon assessment, the type of peatland has been designated as "acid bog".

4.2.2 Average Annual Air Temperature at Site (^oC)

The closest representative Met Office stations to the proposed development are located at Tulloch Bridge (elevation: 237 m) and Aonach Mor Summit (elevation: 1130 m), approximately 25.98 km and 40.78 km south-west of the proposed development[4] respectively. The annual average minimum temperatures at these stations are 3.9^{o}C and -0.6^{o}C, and the annual average maximum temperatures at these stations are 11.0^{o}C and 3.9^{o}C, respectively (Met Office, 2017). Based on this information and given that the proposed development is located at an elevation of circa 700 m, the expected value for the mean annual temperature is 4.66^{o}C, and for the purposes of the carbon assessment, the minimum and maximum values of 1.7^{o}C and 7.6^{o}C respectively have been adopted.

4.1.8 Average Depth of Peat at Site (m)

Extensive peat probing has been carried out, initially on a 100 m^2 grid across the site and latterly focused on the location of the proposed infrastructure. In total, across the site 4,173 peat probes were recorded, which is considered to provide a robust assessment of the peat depth across the site. Results of peat depth probing are summarised in EIAR Volume 4: Figure 2.9.2, Technical Appendix 2.9: Phase 2 Peat Depth and Coring Survey, where an average peat depth was 0.7 m. For the purposes of the carbon assessment, the minimum and maximum values are 0 m and 3.51 m respectively.

The assessment of soil depth assumes peat exists to full depth, and therefore could classify organic soils or underlying clay as peat for the purposes of the carbon calculator, and therefore represents an overestimation of volume of peat present.

Specifically, and more representative for the proposed development, and excluding floating sections of the access tracks, 1,161 probes are located within 25 m of the new planned track centreline. The average peat depth at these probe locations is 0.55 m. For the purposes of the carbon calculator, the maximum and minimum average peat depths are assumed to vary by ±10% from the average peat depth, which is considered an appropriate reflection of the variability of peat across the site.

[4] Distances calculated in GIS using coordinates for the centre of the proposed development as defined in Annex B of this Technical Appendix and the coordinates for the Met Office stations as listed on the Met Office website.

4.1.9 Carbon Content of Dry Peat (% by weight)

From the laboratory test results (EIAR Volume 4: Technical Appendix 2.9: Phase 2 Peat Report, p16) the expected value for the carbon content of dry peat is 50.57%. For the purposes of the carbon assessment, the minimum and maximum values are 42.96% and 55.68% respectively.

4.1.10 Average Extent of Drainage around Drainage Features at Site (m)

The extent of drainage incorporated into the proposed development influences the total volume of peat impacted by the construction of the proposed development. Therefore, the extent of drainage has an impact on the carbon payback time calculated for the proposed development.

A review of the available literature (Nayak et al., 2008) found that the extent of drainage effects are reported as being anything from 2 m to 50 m 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 2 m. It is thought that in extreme cases, this may extend between 15 m and 30 m, though 15 m is considered to be an appropriate distance.

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

As noted in Section 2 above, whilst the proposed development contains a number of watercourses, no notable artificial drainage channels are present at the site.

Due to the lack of artificial drainage channels and the limited watercourses that exist on the site, the expected value for extent of drainage has conservatively been assumed as 10 m, at the upper end of the measured values quoted above by Smith et al. (2011). Furthermore, for the purposes of the carbon assessment, the minimum and maximum values have been conservatively assumed as 5 m and 30 m respectively.

When determining the carbon loss from peat removed as part of the construction of the drainage works, the area where peat is removed is not included in the extent of drainage calculations because has already been accounted for in the direct losses.

4.1.11 Average Water Table Depth at Site (m)

Guidance provided in "Calculating Potential Carbon Losses & Savings from Wind Farms on Scottish Peatlands" (Scottish Government, 2016) indicates that on intact peat sites the depth to water table may be less than 0.1 m, but up to 0.3 m on eroded peat sites. The peat at the proposed development is considered to be generally eroded, due to the extensive hagging recorded during the Phase 1 peat depth and mire assessment (EIAR Volume 4: Technical Appendix 2.9). For the purposes of the carbon assessment the expected depth to water table adopted is 0.3 m, with minimum and maximum values of 0.1 m and 0.4 m respectively.

4.1.12 Dry Soil Bulk Density (g/cm^3)

From the laboratory test results (EIAR Volume 4: Technical Appendix 2.9: Phase 2 Peat Report, p15) the expected value for the mean dry soil bulk is 0.126 g/cm^3. For the purposes of the carbon assessment, the minimum and maximum values are 0.102 $g/cm^3$and 0.181 g/cm^3respectively.

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; (b) minimum value of 0.072g/cm^3; and (c) maximum values of 0.293g/cm^3. Therefore, the values determined from the laboratory testing are considered to be representative.

4.2 Characteristics of Bog Plants

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

Based on MacArthur Green's experience of peat management, restoration and regeneration work on other wind farm developments in similar environments, and the adoption of good industry practice during the restoration works, conservatively the expected value for the time duration adopted is 10 years. For the purposes of the carbon assessment, the minimum and maximum durations assumed in the carbon assessment are 5 and 10 years respectively.

4.2.2 Carbon Accumulation due to Carbon Fixation by Bog Plants in Undrained Peat (tC/ha/yr)

There are a number of factors controlling the carbon cycle in peatlands, including plant community, temperature range, extent and type of drainage, depth to water table and peat chemistry. The estimated global average for apparent carbon accumulation rate in peatland ranges from 0.12 tC/ha/yr to 0.31t C/ha/yr (Botch et al., 1995; Turunen et al., 2001).

The SNH Guidance (SNH, 2003) proposes an average value of 0.25 tC/ha/yr, which falls within the range quoted above. For the purposes of the carbon assessment, the SNH accumulation rate has been used as the expected value, with the accumulation rates of 0. 21 tC/ha/yr and 0.31 tC/ha/yr adopted as the minimum and maximum values respectively.

4.3 Counterfactual Emission Factors

The counterfactual emission factors for different energy generation sources is fixed in the carbon assessment. The data provided from the "DUKES Data" is shown in Table 2.7.2 below.

Table 2.7.2: Carbon Dioxide emissions from electricity generation (tCO_2/MWh)

Fuel Source	2016
Coal-fired plant	0.925
Grid-mix	0.34885
Fossil fuel-mix	0.477

4.4 Proposed Development Infrastructure

4.4.1 Temporary Mineral Workings

Seven potential temporary mineral workings locations have been identified for the proposed development. The location and estimated dimensions of these temporary mineral workings are provided in EIAR Volume 2: Chapter 2: Development Description and summarised below in Table 2.7.3.

Table 2.7.3: Potential Temporary Mineral Workings Details)

Temporary Mineral Workings Ref.	Average Depth of Overburden (m)	Maximum Footprint (m^2)
TMW1	0.33	28,413
TMW2	0.67	23,562
TMW3	0.35	13,391
TMW4	0.52	8,176
TMW5	0.42	16,105
TMW6	0.40	16,058
TMW7	0.42	12,717

The nominal footprint of each potential temporary mineral workings provided in Table 2.7.3, which are irregularly shaped, has been calculated from the proposed development's GIS data. The carbon assessment requires the average length and width for the combined temporary mineral workings to be entered. The footprint of each temporary mineral workings has been combined to determine the dimensions of a rectangular polygon. For the purposes of the carbon assessment, the expected values for the dimensions of the combined temporary mineral workings are length 337 m and width 193 m. An error of ± 5% in surface area of each temporary mineral workings has been assumed, and has been reflected in the minimum and maximum values selected, namely length 320 m by 183 m and 354 m by 203 m respectively.

The final dimensions of each temporary mineral workings would vary depending on a number of factors: the quality of rock; local geology and topography conditions, and the final wind farm design.

For the purposes of the carbon assessment, the expected value for the average depth of peat to be removed from the combined temporary mineral workings is 0.44 m, with an assumed minimum and maximum depth of peat of 0.418 m and 0.462 m respectively.

4.4.2 Foundations and Hardstanding Area associated with each Turbine

The turbine foundations for the proposed development are assumed to be circular with vertical walls and 20 m in diameter. Excess excavated peat would be used for reinstatement of the foundation excavation post-construction; therefore, the foundation footprint represents the volume of peat lost. Assuming that the actual dimensions may vary by up to ± 5%, for the purposes of the carbon assessment the minimum and maximum dimensions of the foundation are 19 m and 21 m respectively.

Based on the peat probing undertaken, the average peat depth at the turbine centres is estimated to be 0.61 m. For the purposes of the carbon calculator, a maximum and minimum depth of ± 10% of the average depth is assumed, therefore the maximum and minimum peat depths are 0.55 m and 0.67 m respectively.

The crane hardstandings for the proposed development are assumed to be 45 m by 26.66 m, with the same excavation footprint. Assuming that the actual dimensions may vary by up to +5%, the minimum and maximum dimensions are 25.33 m by 42.75 m and 27.99 m by 47.25 m respectively.

Based on the peat probing undertaken, the average peat depth at the crane hardstandings is 0.65 m. For the purposes of the carbon calculator, a maximum and minimum depth of ± 10% of the average depth has been is assumed, therefore the maximum and minimum peat depths are 0.59 m and 0.72 m respectively.

4.5 Access Tracks

A combination of new and widened existing access tracks would be incorporated into the proposed development. Access tracks would be constructed to all turbine locations, meteorological masts and temporary mineral workings. During the design and construction phases of the proposed development small changes to the access track layout could be introduced (e.g. as a result of micrositing of the turbines), leading to minor variations in the overall track length. For the purposes of the carbon assessment it is assumed the total track length would not change by more than ± 5%, therefore the minimum and maximum access track lengths will be calculated accordingly.

4.5.1 Existing Access Tracks

The existing access track within the Stronelairg Wind Farm could be improved for the proposed development, however, no widening works are proposed.

For the purposes of the carbon assessment any widening of the existing access track from the Stronelairg Wind Farm substation to the array access tracks has been taken into account in the calculations for the excavated access tracks in section 4.5.3 below.

4.5.2 Floating Access Tracks (Roads)

Floating access track construction would be adopted for sections of access track where the peat depth is greater than 1 m over an appreciable distance. Floating construction would be selected to minimise: (a) excavation within deeper peat deposits; (b) the impact on groundwater dependent terrestrial ecosystems (GWDTEs); the impact on peat stability considerations; and (d) minimise the changes to the hydrological conditions at the site.

There is 4,631 m of floating access track to be constructed. The proposed width of the floating access track is 5.5 m (running width: 4.5 m), with the maximum unlikely to exceed 6 m. For the purposes of the carbon assessment it is assumed the minimum and maximum width of floating access track are 5 m and 6 m respectively. The construction of any floating access track would not require the excavation of peat or soil, and therefore, for the purposes of the carbon assessment the depth values are 0 m.

For the purposes of the carbon assessment the expected value for the length of floating access track is 4,631 m, with the minimum and maximum access track lengths of 4,515 m and 4,747 m respectively.

No drainage ditches are proposed for the floating access track construction. If required, cross drains would be incorporated to redistribute any intercepted flow across the access track to minimise the impacts on local hydrology. Such drainage would be determined at the detailed design phase, and in conjunction with the consideration of any GWDTE features.

4.5.3 Excavated Access Tracks (Roads)

Where the peat depth is less than 1 m, the proposed access track would be constructed by excavating the peat, with the aim of minimising the haulage of excavated material. The estimated length of excavated access track to be constructed is 23,132 m, including widening existing access tracks where necessary. The proposed width of the excavated access track is 5.5 m (running width: 4.5 m), with the maximum unlikely to exceed 6 m. Whilst the sections of access tracks servicing the temporary mineral workings could have a narrower width, conservatively these access tracks would be assumed to have the same, common width as the main access tracks. This approach may slightly overestimate the excavation volume.

For the purposes of the carbon assessment the expected value for the length of excavated access track is 23,132 m, with the minimum and maximum access track lengths of 22,554 m and 23,710 m respectively.

The total excavation width would vary with peat depth and local topography, but it is considered unlikely that total track width will vary on average by more than ± 0.5 m, giving a minimum and maximum width of 5 m and 6 m respectively.

The average peat depth for excavated sections of access track, based on peat probing results, is 0.55 m. On the basis that 1,161 peat probe measurements are included in this calculation, this depth is considered to be robust. Furthermore, as it assumes all probed material is peat, which will not be the case in practice, the average depth calculated may be overestimated. Minor changes in access track routing, during the detailed design phase of the proposed development could result in a change in the average depth of peat excavated. For the purposes of the carbon assessment the expected value for the depth of peat is assumed as 0.55 m, with the minimum and maximum average peat depths assumed as 0.523 m and 0.578 m respectively.

4.5.4 Rock Filled Access Tracks (Roads)

There are no sections of rock filled access track in the proposed development, therefore the expected value used in the carbon assessment is zero, and no further parameters are required.

4.5.5 Cable Trenches

Where possible, all cable trenches would follow the alignment of the access tracks, and cables would be laid within trenches excavated in the existing material and backfilled with that same material. For the purposes of the carbon assessment it is assumed that there would be zero impact from this construction methodology, and therefore the expected value used is zero.

4.5.6 Additional Peat Excavated

The proposed development would include the following permanent infrastructure: (a) a substation compound, measuring 66.5 m by 65 m; and (b) a control building, measuring 15 m by 15 m. The combined area of these facilities is 4,548 m^2. That actual dimensions of these facilities may vary by up to ±5%. For the purposes of the carbon balance assessment the expected value of this infrastructure footprint is 4,548 m^2, with minimum and maximum footprints of 4,321 m^2 and 4,775 m^2 respectively.

The average measured depth of peat for all locations referred to above is 0.71 m. Using this average depth value along with the overall footprint areas, for the purposes of the carbon calculator the expected value of this peat volume is 3,229 m^3, with minimum and maximum values for the peat volumes of 3,068 m^3 and 3,390 m^3 respectively.

The proposed development would include the following temporary infrastructure: (a) three main construction compounds, measuring 80m by 50m each; and (b) two secondary construction compounds, measuring 45 m by 20 m each. As these facilities are temporary, and the peat excavated to form the compounds would be reinstated within the excavation on completion of the construction works, these areas are excluded from the carbon assessment.

4.6 Peat Landslide Hazard

A peat landslide ("peatslide") risk and hazard risk assessment has been undertaken for the proposed development, details of which are provided in EIAR Volume 4: Technical Appendix 2.6: Peat Landslide and Hazard Risk Assessment. The overall conclusion regarding peat stability is that there is a negligible to low risk of peat instability over most of the proposed development site although limited areas of medium risk have been identified. For these medium risk areas, a hazard impact assessment was completed which concluded that, subject to the employment of appropriate mitigation measures, all these areas can be considered as an insignificant risk.

The areas of thick peat are generally located towards the north of the site and coincide with the flatter gradients (<4^0). The steeper slopes have significantly less peat and in general comprise mainly peaty soils (<0.5m)

On the basis that peat instability would be appropriately mitigated throughout the construction and operation of the proposed development to reduce the likelihood and scale of any peatslide related incident, for the purposes of the carbon assessment the expected, minimum and maximum values are all negligible.

4.7 Improvement of Carbon Sequestration at the Site

Any local improvements to carbon sequestration, such as areas of peatland habitat restoration, would result in a reduction in the net carbon emissions from the proposed development.

4.7.1 Improvement of Degraded Bog

The peatland within the site, has minimal drainage channels, and appears to be generally degraded as indicated by extensive peat hagging throughout the site.

The outline habitat management plan for the proposed development (EIAR Volume 4: Technical Appendix 6.5) includes restoration and enhancement of the around 400 ha of blanket bog, which will retain, and potentially sequester, carbon. This proposal has been taken into account in the carbon assessment.

4.7.2 Improvement of Plantation Land

No felling of plantation would be undertaken as part of the proposed development, and therefore there would be no opportunity for improvement of felled plantation land. For the purposes of the carbon assessment the expected value has been entered as zero.

4.7.3 Restoration of Peat Removed from Temporary Mineral Workings

Within the seven proposed temporary mineral workings search areas the average depth of peat is 0.44 m, with a maximum recorded depth of peat of 1.97 m. Peat and any other superficial materials would be excavated and stockpiled adjacent to the temporary mineral workings. When the construction works are complete this stockpiled material would be utilised to restore each temporary mineral workings excavation. Due to the generally shallow nature of surface deposits at the temporary mineral workings locations, it is proposed to utilise additional peat excavated on site for the temporary mineral workings restoration works. The proposed nominal depth of peat utilised for restoration will be 1.25 m (as detailed in EIAR Volume 4: Technical Appendix 2.5: Draft Peat Management Plan). The total surface area of the temporary mineral workings, presented in Table 3 above, is estimated to be 65,000 m^2 (6.5 ha).

The footprint of the temporary mineral workings may vary by ±10%, therefore for the purposes of the carbon calculator the expected value for borrow pit restoration is 6.5 ha, with minimum and maximum values of 6.338 ha and 6.663 ha respectively, all to a depth of 1.25 m.

The temporary mineral workings are designed to be self-draining. The restoration profile would be designed as far as is practicable to facilitate maintenance of a high water table within the peat post-restoration. For calculation purposes, it has been assumed that restoration of the temporary mineral workings would be carried out using good practice and that the post-restoration water table in the temporary mineral workings will be similar to the water table across the proposed development. In Section 4.1.11 above, this water table was estimated to be 0.25 m, with minimum and maximum values of 0.09 m and 0.4 m respectively.

Peat plant communities typically found within peat bogs are typically slow growing and may take a number of years to become established. In the absence of any measured data or detailed study, for the purposes of the carbon calculator it has conservatively assumed that recovery will take 10 years, with a minimum and maximum time to recovery of 5 years and 15 years respectively.

4.7.4 Early Removal of Drainage from Foundations and Hardstandings

Temporary drainage would be constructed around the turbine foundations and crane hardstandings (as part of the proposed development). This drainage would be removed on completion of the construction works, and therefore, the area surrounding the foundations and hardstandings can be assumed to be drained only up to the time of completion of backfilling, and removal of any temporary surface water drains. Subsequently, the hydrological regime adjacent to the foundation and hardstanding is assumed to return to its pre-construction condition. The findings of Isselin-Nondedeu et al. (2007) *"Long-term vegetation monitoring to assess the restoration success of a vacuum-mined peatland (Québec, Canada)"*, indicates that 90% of the vegetation cover is achieved within 6 years. Whilst six years would be a conservative assumption, the maximum permitted value within the carbon assessment is 5 years. Therefore, for the purposes of the carbon calculator the expected value is 2 years, and the maximum and minimum times to recovery are assumed to be 1 year and 5 years respectively.

4.8 Restoration of Site after Decommissioning

The restoration work undertaken as part of the decommissioning of the proposed development would be likely to result in a reduction in total carbon lost. By restoring the hydrological conditions and returning the remaining stored carbon to anaerobic conditions, further oxidative loss would be prevented. The restoration of existing habitats represents an opportunity to enhance carbon sequestration. For the purposes of the carbon assessment no benefit has been assumed for the post-decommissioning restoration works, and therefore 100% loss of carbon from the drained volume of soil has been accounted for. During the construction of the proposed development, good industry practice would be employed to minimise any disruption to peatland hydrology. It has been assumed that the access tracks (constructed as part of the proposed development) would remain in-situ following decommissioning of the proposed development.

4.8.1 Blocking of Gullies

In the event that any gullies in peat have formed due to erosion during the proposed development's operation, these would be blocked using good industry practice techniques to promote restoration of the local hydrological conditions. This approach has been assumed in the carbon assessment.

4.8.2 Blocking of Artificial Drainage Channels

Any drainage channels constructed with the access tracks would remain in-situ post-decommissioning, and therefore would not be blocked up. Disruption of the hydrological conditions that exist in the vicinity of the drainage channels would be minimised by the adoption of maintenance techniques that follow good industry practice.

4.8.3 Restoration of Site Habitat

The majority of the proposed development is currently used for deer management, with varying degrees of degradation of the existing habitat. It has been assumed that during the operational phase, and post-decommissioning of the proposed development, deer management, at an appropriate density to control degradation of the peatland, would continue.

4.8.4 Management of Favoured Species Reintroduction

The reintroduction of favoured species has not been taken into account in the carbon assessment.

4.10 Methodology for Calculating Emission Factors

Whilst two methodologies exist, namely the IPCC method (IPCC 1997) and Ecosse project method (Smith et al., 2007), the latter method is required to be adopted for a planning application. The Ecosse method, which is based on site specific values, is considered to provide appropriate site-specific results, whereas the values determined from the IPCC method are considered to be rough estimates.

4.11 Summary of Input Data

The expected values entered into the carbon calculator (Project Online Calculator Reference: FEYA-HDMU-Q31R) are summarised in Annex A of this report.

5. CARBON ASSESSMENT OUTPUTS

Based on the figures input to the carbon calculator (Reference: FEYA-HDMU-Q31R) as described in Section 4 and provided in Annex A, the total carbon losses associated with the proposed development are summarised in Table 2.7.4 and fully detailed in Annex B.

Table 2.7.4: Total Carbon Losses Due to Windfarm

Source of Losses	Carbon Losses (tCO_2)		
	Expected Value	Minimum Value	Maximum Value
Turbine life	144,233	127,881	144,915
Back Up	105,111	0	105,111
Reduced carbon fixing potential	3,193	830	10,032
Soil organic matter	28,335	11,570	107,422
DOC & POC leaching	16	0	677
Felling of forestry	0	0	0
Total	280,887	140,281	368,157

The carbon losses calculated are independent of the generation mix used to calculate the overall carbon balance with the exception of the back-up generation capacity (which is assumed to be from conventional fossil fuel sources). Assuming the back-up generation capacity is required, the approximate potential carbon losses, based on the expected values for all factors considered, are summarised as: (a) turbine life, 51.3%; (b) back up generation capacity, 37.4%; and (c) soil organic matter, 10.1% (as detailed in Table 2.7.4 above).

The predicted payback time for the proposed development, as determined from the carbon calculator tool, is summarised in Table 2.7.5 below and fully detailed in Annex B. The counterfactual emission factor values for each generation source shown in Table 2.7.5 are derived from Table 2.7.2 above.

Table 2.7.5: Carbon Payback Period

Generation Source	Counterfactual emission factors (t CO2 MWh-1)	Carbon Payback Period (years)		
		Expected Value	Minimum Value 0% Balancing Capacity	Maximum Value 5% Balancing Capacity
Coal Fired	0.925	0.6	0.1	1.0
Grid Mix	0.34885	1.7	0.3	2.7
Fossil Fuel Mix	0.477	1.2	0.2	1.9

The ‘Grid Mix’ generation source includes renewable energy sources that are operational, therefore the ‘Fossil Fuel Mix’ represents the most likely scenario when considering replacing existing generation capacity with electricity generated from the proposed development.

Based on the assumptions detailed in Section 4 above, the expected payback time, assuming a requirement for back up generation capacity, and therefore the predictions for the growth in the contribution of wind energy generation to be met, is calculated to be approximately 1.2 years (14.4 months), if replacing generation capacity from the ‘Fossil Fuel Mix’. Using the worst case scenario, represented by adopting the maximum values entered in the carbon assessment and taking account of a requirement for back up generation capacity, the payback time is calculated to be 2.7 years (32.4 months).

The outputs from the carbon calculator (Project Online Calculator Reference: FEYA-HDMU-Q31R) are summarised in Annex B of this report.

6. CONCLUSIONS

The output from the carbon balance assessment indicates, based on the best estimate values determined from the information currently available, that the proposed development would pay back the carbon emissions associated with its construction, operation and subsequent decommissioning in a 1.2 year period. Assuming a 30 year operational period for the proposed development, this equates to an overall carbon saving of 25 times the total carbon emitted.

Outputs from the carbon assessment demonstrate the following key points:

- The data used to undertake the carbon assessment has adopted conservative values;
- The two key sources of carbon emissions, which are independent of losses from any back up generation capacity are: (a) carbon emissions due to the turbine life cycle; and (b) carbon losses from soil organic matter. These two key sources account for 99.4% of the carbon emissions when back up generation capacity is not required, and 61.4% when back up generation capacity is required;
- No allowance has been accounted for in the carbon assessment for any site improvements that are incorporated into the final design of the proposed development that reduce further any carbon losses.

Changes to the factors incorporated into the carbon assessment could impact on the overall carbon payback period calculated, however, the sensitivity analysis embedded within the carbon calculator tool takes such variations into account by considering a range of values for each factor considered. Furthermore, by adopting conservative values for various factors contributing to the overall carbon payback, the carbon savings from the proposed development could be significantly greater than the carbon emissions attributable to the its construction, operation and subsequent decommissioning.

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ANNEX A CARBON CALCULATOR INPUTS

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Carbon Calculator v1.4.0
Glenshero Location: 57.052013 -4.44668
RES Ltd

Core input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Windfarm characteristics				
Dimensions				
No. of turbines	39	39	39	EiAR, Volume 2, Chapter 2, Para 2.3.1, p.2-2.
Duration of consent (years)	30	30	30	From information from RES.
Performance				
Power rating of 1 turbine (MW)	4.3	3.87	4.3	EIAR, Volume 2, Chapter 2, Para 2.3.1, p.2-2.
Capacity factor	32	30	34	From information from RES.
Backup				
Fraction of output to backup (%)	5	0	5	Calculating Potential Carbon Losses & Savings from Wind Farms on Scottish Peatlands, Para19.
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	EIAR, Volume 2, Chapter 6.
Average annual air temperature at site (°C)	4.66	1.7	7.6	Calculated from data from Met Office monitoring stations at Tulloch Bridge & Aonach Mor.
Average depth of peat at site (m)	0.7	0	3.51	Calculated from GIS database. Mean depth taken from the Interpolation Raster within the study area.
C Content of dry peat (% by weight)	50.57	42.96	55.68	From laboratory results, Technical Appendix 2.9, Charts 2.9.16 and 2.9.17, p.16.
Average extent of drainage around drainage features at site (m)	10	5	30	Carbon Calculator default values.
Average water table depth at site (m)	0.3	0.1	0.4	Carbon Calculator default values.
Dry soil bulk density (g cm^{-3})	0.126	0.102	0.181	From laboratory results, Technical Appendix 2.9, Charts 2.9.14 and 2.9.15, p.15.
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	10	5	10	Based on MacArthur Green's experience.
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha^{-1} yr^{-1})	0.25	0.12	0.31	Calculating Potential Carbon Losses & Savings from Wind Farms on Scottish Peatlands, Version 2.10.0, para 25.
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	0	0	0	No forestry to be felled.
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	0	0	0	No forestry to be felled.
Counterfactual emission factors				
Coal-fired plant emission factor (t CO2 MWh^{-1})	0.925	0.925	0.925	
Grid-mix emission factor (t CO2 MWh^{-1})	0.34885	0.34885	0.34885	
Fossil fuel-mix emission factor (t CO2 MWh^{-1})	0.477	0.477	0.477	
Borrow pits				
Number of borrow pits	1	1	1	7 temporary mineral workings search areas combined into single values.
Average length of pits (m)	337	320	354	Based on temporary mineral workings search areas referred to in EIAR, Chapter 2, Para 2.3.2, p.2-2.
Average width of pits (m)	193	183	203	Based on temporary mineral workings search areas referred to in EIAR, Chapter 2, Para 2.3.2, p.2-3.
Average depth of peat removed from pit (m)	0.44	0.418	0.462	Based on temporary mineral workings search areas referred to in EIAR, Chapter 2, and GIS database.
Access tracks				
Total length of access track (m)	46263	45569	46957	EIAR, , Volume 2, Chapter 2, Para 2.3.2, p.2-2
Existing track length (m)	18500	18500	18500	EIAR, Volume 2, Chapter 2, Para 2.3.2, p.2-2.
Length of access track that is floating road (m)	4631	4515	4747	Based on layout in EIAR, Volume 2, Chapter 2, Figure 2.1, and GIS data for peat depth.
Floating road width (m)	5.5	5	6	EIAR, Volume 2, Chapter 2, Para 2.3.9, p.2-3.
Floating road depth (m)	0.95	0.9	1	Based on experience from previous windfarm projects.
Length of floating road that is drained (m)	0	0	0	No drainage constructed within floating access track.
Average depth of drains associated with floating roads (m)	0.5	0.45	0.55	No drainage constructed in floating access track.
Length of access track that is excavated road (m)	23132	22554	23710	Based on layout in EIAR, Volume 2, Chapter 2, Figure 2.1, and GIS database peat depth.
Excavated road width (m)	5.5	5	6	EIAR, Volume 2, Chapter 2, Para 2.3.9, p.2-5.
Average depth of peat excavated for road (m)	0.55	0.523	0.578	Based on layout in EIAR, Volume 2, Chapter 2, Figure 2.1, and interpretation of GIS database.
Length of access track that is rock filled road (m)	0	0	0	No rock filled access tracks.
Rock filled road width (m)	5.5	5	6	No rock filled access tracks.
Rock filled road depth (m)	0	0	0	No rock filled access tracks.
Length of rock filled road that is drained (m)	0	0	0	No rock filled access tracks.
Average depth of drains associated with rock filled roads (m)	0	0	0	No rock filled access tracks.
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	All cables will follow access tracks.
Average depth of peat cut for cable trenches (m)	0	0	0	Any cables will be installed within peat, and recovered by existing excavated material.
Additional peat excavated (not already accounted for above)				
Volume of additional peat excavated (m^3)	3229	3068	3390	Quantity calcuated from information in EIAR, Volume 2, Chapter 2.
Area of additional peat excavated (m^2)	4548	4321	4775	Area based on information in EIAR, Volume 2, Chapter 2.

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Carbon Calculator v1.4.0
Glenshero Location: 57.052013 -4.44668
RES Ltd

Core input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Peat Landslide Hazard				
Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments	negligible	negligible	negligible	Fixed
Improvement of C sequestration at site by blocking drains, restoration of habitat etc				
Improvement of degraded bog				
Area of degraded bog to be improved (ha)	400	360	440	No bog improvement allowed for.
Water table depth in degraded bog before improvement (m)	0.3	0.1	0.5	Carbon calculator default values.
Water table depth in degraded bog after improvement (m)	0.25	0.09	0.4	Default values after improvement.
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	10	5	15	Within range of carbon calculator default figures.
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	10	5	15	Within range of carbon calculator default values.
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	0	0	0	No felled plantation to be improved.
Water table depth in felled area before improvement (m)	0.3	0.1	0.5	No felled plantation to be improved.
Water table depth in felled area after improvement (m)	0.1	0.05	0.3	No plantation to be improved.
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	10	5	15	No plantation to be improved.
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	10	5	15	No plantation to be improved.
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	6.5	6.338	6.663	EIAR, Volume 2, Technical Appendix 2.3, Para 4.1.
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	0.3	0.1	0.4	Default values from Carbon Calculator.
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.1	0.05	0.3	Default values from Carbon Calculator.
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	10	5	15	Default values from Carbon Calculator.
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	10	5	15	Default values from Carbon Calculator.
Early removal of drainage from foundations and hardstanding				
Water table depth around foundations and hardstanding before restoration (m)	0.3	0.1	0.5	Default values from Carbon Calculator.
Water table depth around foundations and hardstanding after restoration (m)	0.1	0.05	0.3	Default values from Carbon Calculator.
Time to completion of backfilling, removal of any surface drains, and full restoration of the hydrology (years)	2	1	5	Based on MacArthur Green's experience from other windfarm projects.
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	Construction works and subsequent operations to follow good practice.
Will you attempt to block all artificial ditches and facilitate rewetting?	No	No	No	Minimal artificial drainage ditches exist at the site.
Will the habitat of the site be restored on decommissioning?	No	No	No	
Will you control grazing on degraded areas?	Yes	Yes	Yes	EIAR, Volume 2, Chapter 2, Technical Appendix 6.5, OHMP.
Will you manage areas to favour reintroduction of species	No	No	No	Reintroduction not considered likely based on the condition of the peat. appropriate.
Methodology				
Choice of methodology for calculating emission factors	Site specific (required for planning applications)			

Forestry input data

N/A

Construction input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Windfarm				
Number of turbines in this area	39	39	39	EIAR, Volume 2, Chapter 2, Para 2.3.1, p.2-2.
Turbine foundations				
Depth of hole dug when constructing foundations (m)	0.61	0.55	0.67	Calculated from GIS: Mean depth taken from the Interpolation Raster within the study area.
Aproximate geometric shape of whole dug when constructing foundations	Circular	Circular	Circular	EIAR, Volume 2, Chapter 2, Para 2.3.6, p.2-3.
Diameter at bottom	22	20.9	23.1	
Diameter at surface	26	24.9	27.1	
Hardstanding				
Depth of hole dug when constructing hardstanding (m)	0.65	0.59	0.72	Calculated from GIS: Mean depth taken from the Interpolation Raster within the study area.
Aproximate geometric shape of whole dug when constructing hardstanding	Rectangular	Rectangular	Rectangular	EIAR, Volume 2, Chapter 2, Para 2.3.2, p.2-2.
Length at surface	49	46.75	51.25	
Width at surface	30.66	29.33	31.99	
Length at bottom	45	42.75	47.25	
Width at bottom	26.66	25.33	27.99	
Piling				
Is piling used?	No	No	No	EIAR, Volume 2, Chapter 2, Para 2.3.2, p.2-2.
Volume of Concrete				
Volume of concrete used (m^3) in the entire area	18280	16120	20441	Based in information provided in Glenshero EIAR, Chapter 2: Development Description, Para 2.3.2, p.2-2.

ANNEX B CARBON CALCULATOR PAYBACK TIME AND CO_2 EMISSIONS OUTPUT

Payback Time and CO_2 emissions • FEYA-HDMU-Q31R v5

1. Windfarm CO2 emission saving over...	Exp.	Min.	Max.
...coal-fired electricity generation (t CO2 / yr)	434,839	366,896	462,017
...grid-mix of electricity generation (t CO2 / yr)	163,993	138,369	174,243
...fossil fuel-mix of electricity generation (t CO2 / yr)	224,236	189,199	238,251
Energy output from windfarm over lifetime (MWh)	14,102,899	11,899,321	14,984,330

Total CO2 losses due to wind farm (tCO2 eq.)	Exp.	Min.	Max.
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	144,233	127,881	144,915
3. Losses due to backup	105,111	0	105,111
4. Lossess due to reduced carbon fixing potential	3,193	830	10,032
5. Losses from soil organic matter	28,335	11,570	107,422
6. Losses due to DOC & POC leaching	16	0	677
7. Losses due to felling forestry	0	0	0
Total losses of carbon dioxide	280,887	140,281	368,157

8. Total CO2 gains due to improvement of site (t CO2 eq.)	Exp.	Min.	Max.
8a. Change in emissions due to improvement of degraded bogs	0	0	-64,736
8b. Change in emissions due to improvement of felled forestry	0	0	0
8c. Change in emissions due to restoration of peat from borrow pits	0	0	-711
8d. Change in emissions due to removal of drainage from foundations & hardstanding	-2,146	0	-16,393
Total change in emissions due to improvements	-2,146	0	-81,840

RESULTS	Exp.	Min.	Max.
Net emissions of carbon dioxide (t CO2 eq.)	278,741	58,441	368,157
Carbon Payback Time			
...coal-fired electricity generation (years)	0.6	0.1	1.0
...grid-mix of electricity generation (years)	1.7	0.3	2.7
...fossil fuel-mix of electricity generation (years)	1.2	0.2	1.9
Ratio of soil carbon loss to gain by restoration (not used in Scottish applications)	13.21	0.14	No gains!
Ratio of CO2 eq. emissions to power generation (g/kWh) (for info. only)	19.76	3.90	30.94