Technical Appendix 13.4

Carbon Balance Assessment

SCOTTISHPOWER RENEWABLES

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1 Introduction

1. 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) set a target of the equivalent of 100% of annual electricity demand generated from renewable sources by 2020, having met the interim target of 50% by 2015 (Scottish Government, 2015). Having met the targets to date, these have been amended in the Climate Change (emissions Reduction Targets) (Scotland) Act 2019 (Scottish Government, 2019), which sets targets to reduce Scotland's emissions of all greenhouse gases to net-zero by 2045 at the latest, with interim targets for reductions of at least 56% by 2020, 75% by 2030, 90% by 2040.

2. The Harestanes South Windfarm Extension project ('the Proposed 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 Proposed Development is 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.

3. 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), now NatureScot, 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 Wind Farms 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).

4. There is a requirement to use this tool as part of the planning or consenting process for developments of 50MW 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 Proposed 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 Proposed Development.

2 Development Description

5. The Proposed Development is located on Forestry and Land Scotland land in Dumfries and Galloway, to the south of the operational Harestanes Windfarm within a plantation forestry site, approximately 13km to the north of Dumfries. The Site is situated upon a number of hills, including Pumro Fell, Kirkland Hill, Muir Hill, Whitefaul Hill, and Brownmoor Hill. The main site access track extends south to the A701 road, crossing areas of forestry, and agricultural land as the track approaches the public road. The turbines and their associated access tracks are located within the plantation forestry site and make use of the operational Harestanes Windfarm access tracks and operational forestry tracks. Within the site there are numerous forestry drainage channels.

3 Methodology

6. 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 1.6.1 (Project Online Calculator Reference: 84MD-S80H-KGJK).

7. 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 Proposed 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 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

8. In order to calculate the carbon balance for the Proposed 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

9. A detailed description of the Proposed Development is within **Chapter 4: Development Description of the EIA Report**. This identifies that planning consent will be sought for eight wind turbines with no proposal to limit the lifetime of the Proposed Development. The assessment of all technical areas considers the effects of the operational phase of the Proposed Development without time limitations; however, for the purpose of undertaking a carbon balance assessment utilising the Carbon Calculator, an assumption has been made for the operational lifespan as a minimum of 40 years. This presents a conservative approach to the assessment.

4.1.2 Performance

10. 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 Site.

11. The turbine specifications defined in **Chapter 4: Development Description of the EIA Report** indicates the typical individual capacity of around 5.6 megawatts (MW), which has been applied as the expected value within the calculator. This results in a total installed capacity of 44.8 MW. It is also indicated that the exact model of wind turbine to be installed would be selected through a competitive procurement process. It has been assumed that the overall rating may change as a result of this. Therefore, for the purposes of the calculator, minimum and maximum power ratings of 5.5 MW and 5.7 MW, respectively, have been applied.

12. The most recent average annual capacity factors reported by the Department for Business, Energy & Industrial Strategy in the Digest of UK Energy Statistics 2020, (DUKES) Table 6.5: Load factors for renewable electricity generation (DBEIS, 2020a) are shown 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-case (27%) capacity factors for Scotland.

Year	2015	2016	2017	2018	2019
Capacity Factor (%)	29.3	23.6	28.0	26.4	26.6

Table 1: Annual UK Onshore Wind Capacity Factor (%)

13. A capacity factor of 30.9 for the Site has been provided by ScottishPower Renewables based on their own wind yield assessments. This estimate supports the quoted capacity factor reported by Nayak et al. (2008) and therefore the recommended best- and worst-case values have been adopted also as minimum and maximum values, respectively.

4.1.3 Balancing Capacity

14. 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.

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

16. DUKES Table 6.4: Capacity of, and electricity generated from, renewable sources (DBEIS, 2020b) indicates that the installed onshore wind capacity in the UK in 2019 was 14,125MW, and installed offshore wind capacity 9,971MW, giving a total of 24,096MW. The RenewableUK website (RenewableUK, 2020), accessed on 16th October 2020, identifies installed operational UK wind capacity as 24,065MW, amounting to approximately 31% of total generation capacity (77,920 MW in 2017 (DBEIS, 2020c)). 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).

17. Comparing the electricity generated in the UK during 2019 of 323,005 gigawatt hours (GWh) (DBEIS, 2020d) with that generated from wind of 64,335 GWh (DBEIS, 2020b), wind energy accounted for approximately 20% of total generation. Therefore, a balancing capacity of 5% has been entered as the expected value required for the operational lifetime of the windfarm, with 10% additional emissions due to thermal inefficiency (Scottish Government, 2016)).

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

4.1.4 Carbon Dioxide Emissions from Turbine Life

19. 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. 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

20. The Site is typically plantation forestry, with blanket peat and other peaty soils present throughout the Site. Peat is notable in open areas, such as forestry rides, clearings and in the vicinity of surface water bodies.

4.1.6 Type of Peatland

21. The calculator offers two options for this item: Fen or Acid Bog. Peatland present on this site is consistent with the Acid Bog option.

4.1.7 Average Air Temperature at the Development

22. The closest Met Office climate station at a similar altitude to the Site is Eskdalemuir, at approximately 242m AOD and located approximately 22km north east of the Site, with an annual average maximum and minimum temperature of 10.9ºC and 3.4ºC, respectively (Met Office, 2020), giving a mean temperature of 7.2ºC. Based on this information a mean annual temperature of 7.2ºC is proposed for the expected value in the calculator, with minimum and maximum values of 3.4ºC and 10.9ºC, respectively, reflecting the extremes of the stated mean Met Office temperature ranges.

4.1.8 Average Depth of Peat at the Development

23. Extensive peat probing has been carried out, initially at representative locations across the Site and latterly in the vicinity of proposed infrastructure. In total, across the site 1,207 peat probes were recorded. Results of peat depth probing are summarised in Table 6.7 of **Chapter 6: Hydrology, Hydrogeology, Geology and Soils of the EIA Report**, where an average peat depth was 0.48m. The Scottish Executive guidance document on peat landslide hazard and risk assessments (Scottish Executive, 2006) defines peat as a soil having a depth greater than 50cm, with an organic matter content of more than 60%; thus indicating that 72% of probes across the site represent areas that are not classed as peat, by this definition. 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.

24. The large number of probing points provides a robust base for the average figure of 0.48m; however, for the purposes of the calculator, minimum and maximum average peat depths varying by ± 10% from the average have been applied, resulting in 0.43m and 0.53m, respectively, reflecting the variability of peat across the site.

4.1.9 Carbon Content of Dry Peat

25. As part of the ground investigation, four soil/peat core samples were taken using a Russian corer from widely distributed locations within the site where depths >1.0 m were found, during a site visit in September 2020. The sample locations were chosen using professional judgement of the local conditions that suggested the most likely locations for peat formation within the site. The intention was to obtain samples representing the upper limit of carbon content within the site. The samples were analysed for total organic carbon (TOC) at an MCERTS accredited laboratory.

26. With reference to the 60% organic content discussed in Section 4.1.8, the Site soil/peat TOC values suggest non-peat material. Visual evidence also suggested peaty layers were generally shallow across the Site, underlain by glacial till.

27. TOC results range between 16 – 19% and provide an average value of 17%. This value has been adopted as the expected value for the calculator with minimum and maximum values of 16% and 19%, respectively.

4.1.10 Average Extent of Drainage around Development Features at Development

28. The extent of drainage around construction strongly influences the total volume of peat impacted by the construction of the Proposed Development, which could influence the calculated carbon payback time considerably.

29. A review of the available literature (Nayak et al., 2008) found that the extent of drainage effects is 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.

30. Smith et al. (2011), identified the average extent of drainage impact at three sites (Cross Lochs, Farr Wind Farm 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.

31. As noted in Section 2, the site contains numerous drainage channels throughout the Site. Therefore, 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 evidence observed onsite, local conditions are variable. To account for this variability, minimum and maximum values of 5m and 15m have been used in the calculator, respectively.

32. 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

33. Drainage channels and peat gullies vary considerably with regards to their degree of revegetation and water levels. 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 Site is not considered to be intact peatland and a conservative value has been adopted for the expected depth to water table of 0.3m, with minimum and maximum values of 0.1m and 0.5m, respectively, included in the carbon calculator.

4.1.12 Dry Soil Bulk Density

34. Four peat core samples were analysed by laboratory for bulk density, in addition to carbon (as outlined above). Dry bulk density was analysed as ranging from 0.11 - 0.15gcm^{-3} (grams per cubic centimetre). Due to laboratory error, the bulk density laboratory outcomes are based on remoulded samples of peat, with this technique likely to lead to misrepresentation of peat in-situ. Given this situation, the calculator default expected, minimum and maximum values of 0.132gcm^{-3}, 0.072gcm^{-3} and 0.293gcm^{-3}, respectively, have been adopted. The laboratory results do, however, support the expected value.

4.2 Characteristics of Bog Plants

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

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

36. 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

37. 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 0.12tCha^{-1}yr^{-1} (tonnes carbon per hectare per year) to 0.31tCha^{-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.

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

4.2.3 Forestry Plantation Characteristics

39. It is proposed that there will be felling of areas equating to 82.23ha of forestry to facilitate construction of the Proposed Development, with 61.23ha being permanently lost, and the remainder planned to be replanted. Therefore 61.23ha has been applied in the calculator as the expected value.

40. For the purposes of the calculator, minimum and maximum areas of felling, varying by ±5% from the expected have been used, these values being 58.17ha and 64.29ha, respectively.

41. 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}). With regard to baseline forestry composition at the Site, **EIA Report Appendix 13.1 Forestry**, indicates that the main species are commercial conifers, with Sitka Spruce accounting for approximately 76 – 79% of the overall species composition.

42. 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 2.4tCha^{-1}yr^{-1} to 4.4tCha^{-1}yr^{-1}, respectively.

43. SNH (NatureScot) technical guidance suggests a YC value of 16m^{3}ha^{-1}yr^{-1} for Sitka which equates to 3.6tCha^{-1}yr^{-1} (Cannell, 1999). This value has therefore been applied as the expected value, with values 2.4tCha^{-1}yr^{-1} and 4.4tCha^{-1}yr^{-1} used as minimum and maximum values, respectively.

4.2.4 Counterfactual Emission Factors

44. These figures represent the estimated average emission of CO_2 resulting from generation of energy from different sources. **Table 2** presents the most current data available, which is fixed within the carbon calculator. These values are compiled from the 2019 Government GHG Conversion Factors for Company Reporting, for grid mix (DBEIS, 2020e) and DUKES 2019 (DBEIS, 2020f), for both coal-fired and fossil fuel-mix fuel sources.

Fuel Source	Data Year	Emission Factor
Coal Fired	2019	0.92
Grid Mix	2019	0.25
Fossil Fuel Mix	2019	0.45

Table 2: Carbon Dioxide emissions from electricity generation (tCO2MWh-1)

4.3 Development Infrastructure

4.3.1 Borrow Pits

45. Three potential borrow pit search area locations have been identified for the Proposed Development and the locations of these, and estimated extraction volumes are provided in **Appendix 6.5 Borrow Pit Assessment of the EIA Report**.

46. The calculator requires entry of an average length and width for the borrow pits. The borrow pit search areas' total surface area, including earthworks, is 79,537m^2. It is proposed that the actual borrow pit(s) would be located within these search areas; however, it has been assumed the actual area utilised will be approximately one third of the search areas. In result, the total utilised surface area is 26,512m^2, equating to 8,837m^2 for each of the three locations, and a square of side of 94.0m. 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 ± 5% in surface area is proposed to reflect the minimum and maximum values. This equates to a square of side of 89.3m and 98.7m, respectively.

47. Based upon peat probing in the vicinity of the borrow pits, an expected average value for peat depth at the borrow pits of 0.30m is proposed. An error of ± 10% in peat depth is proposed to reflect the maximum and minimum values, resulting in a minimum of 0.27m and maximum of 0.33m.

4.3.2 Wind Turbine Foundations

48. The turbine foundations at the Proposed Development are expected to be rectangular with vertical walls. The dimensions of the wind turbine foundations are estimated to be up to 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 actual dimensions may vary by up to +5%, the maximum dimensions are 28.5m x 31.5m.

49. Based on the peat probing undertaken, the average peat depth at the turbine locations is estimated to be 0.46m. For the purposes of the calculator, a minimum and maximum depth of ± 10% is assumed, giving peat depths of 0.41m and 0.51m, respectively.

4.3.3 Hardstanding Area Associated with each Turbine

50. The eight crane hardstandings associated with the turbine bases are required for supporting lifting equipment.

51. The proposed dimensions for crane hardstandings associated with each turbine are approximately 34m x 94m (3,196m^2), as per **Chapter 4: Development Description** and **Figure 4.4 Typical Crane Hardstanding**. Assuming that actual dimensions may vary by up to + 5%, the maximum dimensions are 35.7m x 98.7m.

52. It is noted that the area of each hardstanding also sites each turbine location and therefore there is an element of double counting. However, this overestimation also allows for two crane boom assembly locations associated with each hardstanding; each has a proposed hardstanding area of 174m^2, within an overall surface excavation area of 238m^2.

53. Based on the peat probing undertaken, the average peat depth at the hardstanding area associated with each turbine is 0.49m. For the purposes of the calculator, a minimum and maximum depth of ± 10% is assumed, giving peat depths of 0.44m and 0.54m, respectively.

4.3.4 Access Tracks

54. The total length of access track to be constructed, including widening of existing tracks, is estimated to be approximately 14.64km. This includes the main Site access track and onsite access tracks, including all spurs to turbines and borrow pits. As the design and construction process progresses, there may be small changes in track length, as a result of micrositing etc. Minimum and maximum track lengths have been calculated based on the variation in lengths assumed for the constituent track types, below. This results in lengths of 13.98km and 16.30km, respectively.

55. Existing tracks onsite total 12km in length. This includes 8.6km of existing track, with up to approximately 1km estimated to require upgrade, and 3.4km of forestry road assumed to require upgrade. This results in a minimum length of 7.6km of existing track that can be used by the windfarm and this value has therefore been entered in the calculator as existing track length and minimum value. For the maximum value, 8.6km has been applied, assuming no upgrades are necessary.

4.3.5 Length of Access Track - Floating Track

56. Floating track is not planned as part of the windfarm track design. The value used in the calculator is therefore zero.

4.3.6 Length of Access Track - Excavated Track

57. Cut and fill construction will be used along the route of the proposed new access tracks. The estimated length of access track using cut and fill construction is 3.14km. This will have a minimum running width of 5.0m, with an estimated additional 1m shoulder on either side. WSP engineers have indicated the likely nominal running width will be 5.5m. This has been applied as the expected and maximum value, and has therefore been entered as 7.5m, including shoulders. The minimum excavated track width has been entered as 6m.

58. It is considered unlikely that the total length of cut and fill track will vary by more than ± 5%, giving minimum and maximum lengths of 2.99km and 3.30km, respectively.

59. The average excavated peat depth is 0.48m, based on measured peat depths within 25m of the proposed cut access track routes.

60. The average peat depth for cut and fill sections of track, based on peat probing results, is considered robust, being based on 183 measured peat depths. 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 routeing will result in a change in the average depth of peat excavated. Given that micrositing will aim to minimise peat depth, a minimum peat depth of 0.43m and maximum of 0.53m (± 10%) is proposed for the calculator, based on an expected depth of 0.48m.

4.3.7 Length of Access Track – Rock Filled Road

61. It is assumed that where existing track is in place, minimal excavation would be required and therefore rock filled road will be used to widen the sections to be upgraded. The length of access track to be upgraded is estimated to be up to 4.40km, taking account of the 3.4km forest road, plus up to 1km of existing track requiring upgrade. Therefore, 4.40k has been applied as the maximum value in the calculator and 3.40km has been applied for the minimum, assuming the additional 1km of existing track will not require to be upgraded. For the purpose of this assessment, it is assumed that the length of track to be upgraded falls midway between the estimated minimum and maximum and has therefore been entered as 3.90km.

62. This will have a minimum running width of 5.0m, with an estimated additional 1m shoulder on either side. WSP engineers have indicated the likely nominal running width will be 5.5m. This has been applied as the expected and maximum value, and has therefore been entered as 7.5m, including shoulders. The minimum excavated track width has been entered as 6m.

63. It is considered unlikely that the total length of rock filled road will vary by more than ± 5%, giving minimum and maximum lengths of 3.23km and 3.56km, respectively.

64. The average peat depth within 25m of existing track is 0.55m. This has been entered as the expected value for rock filled road sections of track, with a minimum peat depth of 0.50m and maximum of 0.61m (± 10%) applied.

65. The depth of rock filled is assumed to be as per proposed upgrades to existing track construction diagram shown on **Figure 4.5 Typical Access Track, of the EIA Report**. This indicates tracks to be 0.3m depth, which has been entered into the calculator for the expected value, with ± 10% applied for minimum and maximum values, giving depths of 0.27m and 0.33m, respectively.

66. This approach is considered to be conservative given that it is expected that for the majority of existing tracks, these would remain undisturbed, with track widening only required in certain areas.

67. WSP engineers indicated that rock filled roads are designed to be impermeable and therefore are not drained. A value of zero has therefore been interred into the calculator for this.

4.3.8 Cable Trenches

68. It is intended that all cable trenches will follow the route of both existing and proposed new tracks and that there will be negligible impact for the purpose of the calculator. The value used is therefore zero.

4.3.9 Additional Peat Excavated

69. The proposed control building compound measures 25m x 25m, with a footprint of 625m^2. This has been applied in the calculator for both expected and minimum values. To account for further peat disturbance around the perimeter of the building and hardstanding, a value of 687.5m (+ 10%) has been applied for the maximum value.

70. Measured peat depths in this area indicate the depth to be 0.4m. This results in a volume of 250m^3, associated with the expected and minimum scenario and 275m^3 for the maximum.

4.3.10 Volume of concrete used in construction of the entire windfarm

71. WSP engineers have provided the following estimations for concrete volumes required by design infrastructure:

- A volume of 860m^3 is required for each of the eight turbine foundations, equating to 6,880m^3.
- A volume of up to approximately 100m^3 is required for the control building, based on the assumption that concrete would only be required for a ground slab, the rest of the structure would be block work or other 'typical' building construction, comprising rendered walls, slate roof, for example.
- A volume of 25m^3 is required for the met mast foundation.

72. This results in an overall total volume of 7,005m^3 of concrete. This value has been applied in the calculator as the expected value. For minimum and maximum values, ± 10% has been applied, resulting in 6,304.5m^3 and 7,705.5m^3, respectively.

4.4 Peat Landslide Hazard

73. A peat landslide ("peatslide") risk assessment has been carried out and this is detailed **in Appendix 6.1: Peat Stability Assessment of the EIA Report**. There was one medium risk and one high risk location identified initially; however, following a detailed assessment process, taking account of local ground conditions, appropriate micrositing, slope monitoring, slope support and drainage controls as specific mitigation, all areas of the Site are considered to be of 'Low' risk (or 'Negligible' or non-peat) in terms of peat stability.

74. Entries in the calculator for this section are fixed as Negligible.

4.5 Improvement of Carbon Sequestration at the Development

75. 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 Proposed Development.

4.5.1 Improvement of Degraded Bog

76. At this stage, approximate areas for peat restoration have not been outlined. Therefore, for the purpose of this assessment, it has been assumed that there will be no improvement of degraded bog, representing a worst-case scenario in this respect. This section has therefore been entered as zero.

4.5.2 Improvement of Felled Plantation Land

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

4.5.3 Restoration of Peat Removed from Borrow Pits

78. Peat coverage at the proposed borrow pit search areas has an average recorded depth of 0.30m. 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.

79. The surface area of the utilised borrow pit design locations is estimated to be 26,512m^2 (2.65ha) in total.

80. Restoration is planned to be undertaken for all of the borrow pit design locations (±10%), giving a minimum of 2.39ha and maximum of 2.92ha.

81. 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 Site.

In Section 4.1.11, this was estimated to be 0.3m, with maximum and minimum values of 0.5m and 0.1m respectively.

82. 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 minimum time to recovery of 5 years and maximum of 20 years.

83. The calculator requires an entry for the period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years). The guidance states that this guarantee should be absolute and entry of a value beyond the lifetime of the windfarm should be accompanied by supporting evidence that this improvement can be guaranteed for the full period given. This includes the time requirement for the improvement to become effective. For example, if time required for hydrology and habitat to return to its previous state is 10 years and the restoration can be guaranteed over the lifetime of a windfarm (e.g. 25 years), the period of time when the improvement can be guaranteed should be entered as 25 years, and the improvement will be effective for (25 – 10) = 15 years. In the absence of such supporting information, 40 years has been entered for this section, reflecting the lifetime assumption applied for this assessment. On this basis the improvement will be effective for (40 – 10) = 30 years.

4.5.4 Removal of Drainage from Foundations and Hardstandings

84. 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.

4.6 Restoration of Development after Decommissioning

85. Consent is being sought 'in perpetuity', i.e. with no time limit. However, should decommissioning of any of the Proposed Development be required, or part thereof, it is considered that the environmental effects of decommissioning would be similar to, or less than, those during construction.

86. 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 Proposed 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.

4.6.1 Blocking of Gullies

87. If required, specific design plans for gully blocking will be determined post consent and assumed will be carried out using good practice techniques such as plastic piling to promote restoration of the local hydrology. In this case, it has been assumed that the Site will be restored on decommissioning. This is a precautionary approach in the absence of specific detail at this stage.

4.6.2 Blocking of Artificial Drainage Ditches

88. Given that there is no proposal to limit the lifetime of the Proposed Development it is assumed for the purpose of this assessment that artificial drainage ditches will not be blocked. This is a precautionary approach in the absence of specific detail at this stage.

4.6.3 Restoration of Habitat

89. Much of the Site is currently used for forestry operations. It has been assumed that during the operational phase and post decommissioning of the windfarm, such activities will continue.

4.6.4 Management to Favour Species Reintroduction

90. Given that there is no proposal to limit the lifetime of the Proposed Development it is assumed for the purpose of this assessment that habitats will not be restored on decommissioning. This is a precautionary approach in the absence of specific detail at this stage.

4.7 Choice of Methodology for Calculating Emission Factors

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

4.7.1 Summary of Input Data

92. The values entered into the carbon calculator are summarised in **Annex 1 of this report** (Project Online Calculator Reference: 84MD-S80H-KGJK).

5 Output from Carbon Calculator

93. Based on the figures input to the carbon calculator (Reference: 84MD-S80H-KGJK), as described in Section 4 and provided in **Annex 1**, the total carbon losses associated with the Proposed Development are summarised in **Table 3** and fully detailed in **Annex 2**.

Source of Losses	Carbon Losses (tCO_2)		
	Expected Value*	Minimum Value	Maximum Value
Turbine life cycle	40,332	40,111	40,553
Balancing capacity	35,320	0	35,320
Reduction in carbon fixing potential	918	259	1,704
Soil organic matter	6,235	-2,295	34,738
DOC & POC leaching	0	0	29
Felling of forestry	32,330	20,476	41,489
Total	115,135	58,550	153,834

Table 3: Total Carbon Losses Due to Windfarm

94. With the exception of the balancing capacity (assumed to be predominantly from conventional fossil fuel sources), the carbon losses are independent of the generation mix used to calculate the overall carbon balance. The calculator model indicates that, based on expected values, approximately 35% of the carbon losses are from turbine life cycle, 28% of the carbon losses are from the felling of forestry, 31% of the carbon losses are due to the requirement for balancing capacity and 5% due to losses of soil organic matter, as demonstrated in **Table 3**.

95. 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 4** and fully detailed in **Annex 2**. The counterfactual emission factor values for each generation source shown in **Table 4** were provided in **Table 2**.

Generation Source	Counterfactual Emission Factors (t CO2 MWh-1)	Expected Payback Time (Years)
Coal Fired	0.92	1.0
Grid Mix	0.25	3.7
Fossil Fuel Mix	0.45	2.1

Table 4: Carbon Payback Period

96. Based on the figures discussed in Section 4 and with reference to **Table 4**, if replacing the 'Grid Mix' source, the expected payback time is calculated to be approximately 3.7 years; however, it is considered more likely that energy generated by this development would replace the fossil fuel portion of the overall 'Grid Mix' scenario and based on 'Fossil Fuel Mix' replacement, the estimated payback time is 2.1 years.

6 Conclusions

97. Use of the carbon calculator with best estimate values, based on available information and applying the conservative 'Grid Mix' replacement scenario, indicates the Proposed Development will pay back the carbon emissions associated with its construction, operation and decommissioning in 3.7 years. Assuming a 40-year windfarm life, this equates to an overall carbon saving of 11 times the carbon emitted. Applying the more realistic 'Fossil Fuel Mix' scenario, equates to an overall carbon saving of 19 times the carbon emitted. It should also be noted that the windfarm lifespan is likely to be considerably longer.

98. In compiling carbon data, a conservative approach has been taken. Therefore, little allowance has been made for CO_2 gains due to onsite 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 Proposed Development will still be significantly greater than the attributable carbon emissions.

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Annex 1: Inputs to Online Calculator (Reference: 84MD-S80H-KGJK)

Carbon Calculator v1.6.1
Harestanes South Extension Location: 55.221874 -3.545992
SPR

Core input data

Input data	Expected value	Minimum value	Maximum value	Source of data
Windfarm characteristics				
Dimensions				
No. of turbines	8	8	8	WSP Design Team
Duration of consent (years)	40	40	40	WSP Design Team
Performance				
Power rating of 1 turbine (MW)	5.6	5.6	5.6	WSP Design Team
Capacity factor	30.9	27	34	WSP Design Team
Backup				
Fraction of output to backup (%)	5	0	5	Nayak et al. (2008)
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	WSP
Average annual air temperature at site (°C)	7.18	5.84	8.42	Met Office
Average depth of peat at site (m)	0.49	0.441	0.539	WSP surveys
C Content of dry peat (% by weight)	55	49	62	WSP surveys / lab analysis
Average extent of drainage around drainage features at site (m)	10	5	15	23. Smith et al. (2011)
Average water table depth at site (m)	0.3	0.1	0.5	WSP surveys
Dry soil bulk density (g cm^{-3})	0.132	0.072	0.293	Default values
Characteristics of bog plants				
Time required for regeneration of bog plants after restoration (years)	5	3	10	WSP prof judgement
Carbon accumulation due to C fixation by bog plants in undrained peats (tC ha^{-1} yr^{-1})	0.25	0.12	0.31	SNH, 2003
Forestry Plantation Characteristics				
Area of forestry plantation to be felled (ha)	61.23	58.17	64.29	Harestanes South EIA-R Appendix 14.1 Forestry
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	3.6	2.4	4.4	Cannel (1999) / SNH technical guidance
Counterfactual emission factors				
Coal-fired plant emission factor (t CO2 MWh^{-1})	0.92	0.92	0.92	
Grid-mix emission factor (t CO2 MWh^{-1})	0.25358	0.25358	0.25358	
Fossil fuel-mix emission factor (t CO2 MWh^{-1})	0.45	0.45	0.45	
Borrow pits				
Number of borrow pits	3	2	3	EIA-R Appendix 6.7
Average length of pits (m)	94	89.3	98.7	EIA-R Appendix 6.7
Average width of pits (m)	94	89.3	98.7	EIA-R Appendix 6.7
Average depth of peat removed from pit (m)	0.3	0.27	0.33	EIA-R Appendix 6.7
Foundations and hard-standing area associated with each turbine				
Average length of turbine foundations (m)	30	28.5	31.5	WSP Design Team
Average width of turbine foundations (m)	30	28.5	31.5	WSP Design Team
Average depth of peat removed from turbine foundations(m)	0.46	0.41	0.51	WSP Survey data
Average length of hard-standing (m)	94	94	98.7	WSP Design Team
Average width of hard-standing (m)	34	34	35.7	WSP Design Team
Average depth of peat removed from hard-standing (m)	0.49	0.44	0.54	WSP Survey data
Volume of concrete used in construction of the ENTIRE windfarm				
Volume of concrete (m^3)	7005	6304.5	7705.5	WSP Design Team

Access tracks				
Total length of access track (m)	14638	13980.85	16295.15	WSP Design Team
Existing track length (m)	7600	7600	8600	WSP Design Team
Length of access track that is floating road (m)	0	0	0	WSP Design Team
Floating road width (m)	5	5	5	WSP Design Team
Floating road depth (m)	0	0	0	WSP Design Team
Length of floating road that is drained (m)	0	0	0	WSP Design Team
Average depth of drains associated with floating roads (m)	0	0	0	WSP Design Team
Length of access track that is excavated road (m)	3143	2985.85	3300.15	WSP Design Team
Excavated road width (m)	7.5	6	7.5	WSP Design Team
Average depth of peat excavated for road (m)	0.48	0.43	0.53	WSP surveys
Length of access track that is rock filled road (m)	3895	3395	4395	WSP Design Team
Rock filled road width (m)	7.5	6	7.5	WSP Design Team
Rock filled road depth (m)	0.3	0.27	0.33	WSP Design Team
Length of rock filled road that is drained (m)	0	0	0	WSP Design Team
Average depth of drains associated with rock filled roads (m)	0	0	0	WSP Design Team
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	WSP Design Team
Average depth of peat cut for cable trenches (m)	0	0	0	WSP Design Team
Additional peat excavated (not already accounted for above)				
Volume of additional peat excavated (m^3)	250	250	275	WSP Design Team
Area of additional peat excavated (m^2)	625	625	687.5	WSP surveys
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)	0	0	0	WSP
Water table depth in degraded bog before improvement (m)	0.3	0.1	0.5	Scottish Government, 2016
Water table depth in degraded bog after improvement (m)	0.29	0.099	0.49	WSP
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	10	5	20	WSP
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	10	5	20	WSP
Improvement of felled plantation land				
Area of felled plantation to be improved (ha)	0	0	0	WSP
Water table depth in felled area before improvement (m)	0.3	0.1	0.5	Scottish Government, 2016
Water table depth in felled area after improvement (m)	0.29	0.099	0.49	WSP
Time required for hydrology and habitat of felled plantation to return to its previous state on improvement (years)	10	5	20	WSP
Period of time when effectiveness of the improvement in felled plantation can be guaranteed (years)	10	5	20	WSP
Restoration of peat removed from borrow pits				
Area of borrow pits to be restored (ha)	2.65	2.39	2.92	WSP Soil and Peat Management Plan
Depth of water table in borrow pit before restoration with respect to the restored surface (m)	0.3	0.1	0.5	Scottish Government, 2016
Depth of water table in borrow pit after restoration with respect to the restored surface (m)	0.29	0.099	0.49	WSP
Time required for hydrology and habitat of borrow pit to return to its previous state on restoration (years)	10	5	20	WSP
Period of time when effectiveness of the restoration of peat removed from borrow pits can be guaranteed (years)	40	40	40	WSP
Early removal of drainage from foundations and hardstanding				
Water table depth around foundations and hardstanding before restoration (m)	0.3	0.1	0.5	WSP
Water table depth around foundations and hardstanding after restoration (m)	0.29	0.099	0.49	WSP
Time to completion of backfilling, removal of any surface drains, and full restoration of the hydrology (years)	5	2	5	Isselin Nondedeu et al. (2007)
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	WSP
Will you attempt to block all artificial ditches and facilitate rewetting?	No	No	No	WSP
Will the habitat of the site be restored on decommissioning?	No	No	No	
Will you control grazing on degraded areas?	No	No	No	WSP
Will you manage areas to favour reintroduction of species	No	No	No	WSP
Methodology				
Choice of methodology for calculating emission factors	Site specific (required for planning applications)			

Annex 2: Payback Time and CO_2 Emissions from Online Calculator (Reference: 84MD-S80H-KGJK)

1. Windfarm CO2 emission saving over...	Exp.	Min.	Max.
...coal-fired electricity generation (t CO2 / yr)	111,565	97,484	122,758
...grid-mix of electricity generation (t CO2 / yr)	30,751	26,870	33,836
...fossil fuel-mix of electricity generation (t CO2 / yr)	54,570	47,682	60,045
Energy output from windfarm over lifetime (MWh)	4,850,657	4,238,438	5,337,293

Total CO2 losses due to wind farm (tCO2 eq.)	Exp.	Min.	Max.
2. Losses due to turbine life (eg. manufacture, construction, decomissioning)	40,332	40,111	40,553
3. Losses due to backup	35,320	0	35,320
4. Lossess due to reduced carbon fixing potential	918	259	1,704
5. Losses from soil organic matter	6,235	-2,295	34,738
6. Losses due to DOC & POC leaching	0	0	29
7. Losses due to felling forestry	32,330	20,476	41,489
Total losses of carbon dioxide	115,135	58,550	153,834

8. Total CO2 gains due to improvement of site (t CO2 eq.)	Exp.	Min.	Max.
8a. Change in emissions due to improvement of degraded bogs	0	0	0
8b. Change in emissions due to improvement of felled forestry	0	0	0
8c. Change in emissions due to restoration of peat from borrow pits	-435	0	-931
8d. Change in emissions due to removal of drainage from foundations & hardstanding	-638	0	-3,087
Total change in emissions due to improvements	-1,073	0	-4,017

RESULTS	Exp.	Min.	Max.
Net emissions of carbon dioxide (t CO2 eq.)	114,062	54,533	153,834
Carbon Payback Time			
...coal-fired electricity generation (years)	1.0	0.4	1.6
...grid-mix of electricity generation (years)	3.7	1.6	5.7
...fossil fuel-mix of electricity generation (years)	2.1	0.9	3.2
Ratio of soil carbon loss to gain by restoration (not used in Scottish applications)	5.81	-0.57	No gains!
Ratio of CO2 eq. emissions to power generation (g/kWh) (for info. only)	23.51	10.22	36.29

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