Technical Appendix 12.1: Carbon Balance Assessment

12.1 Carbon Balance Assessment

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12 Carbon Balance Assessment

12.1 Executive Summary

12.1.1 This assessment uses the Scottish Government's Carbon Calculator for wind farms on peat to assess the benefit of displacing electricity from fossil fuels with renewable generated electricity, compared to the emissions of carbon required for the construction and operation of the revised Larbrax Wind Farm (the Proposed Development) over its 35-year lifetime, including embodied emissions from the infrastructure and reduction of stored carbon in peat and vegetation on site. It should be noted that at the current time (as of 01/10/24), the online Carbon Calculator is not available on the SEPA website and therefore the excel version of the tool has been used to produce these results. This is comparable to the online version that is currently available.

12.1.2 The results of the Carbon Calculator show that the Proposed Development is estimated to produce annual carbon savings of around 16,000 tonnes of CO_2e per year, through the displacement of grid electricity, based on the current average grid mix. Displacement of existing sources of generating capacity depends on the time of day and how the grid needs to be balanced.

12.1.3 The assessment of the Proposed Development estimates losses of around 14,000 tonnes of CO_2e, mainly due to off-site activities such as the manufacture of the turbines and battery storage. Overall ecological carbon losses are negative (the Carbon Calculator estimates that construction of the Proposed Development will result in fewer emissions than leaving shallow peat in situ). Restoration of degraded peatland is estimated to provide stored carbon gains of around 2,000 tonnes of CO_2e.

12.1.4 The estimated payback time of the Proposed Development, using the Scottish Government Carbon Calculator, is 0.7 years (approximately 8.5 months), with a minimum/maximum range of 0.5 to 1.0 years. There are no current guidelines about what payback time constitutes a significant impact, but 0.7 years is around 2% of the anticipated lifespan of the Proposed Development. Compared to fossil fuel electricity generation projects, which also produce embodied emissions during the construction phase and then significant emissions during operation due to combustion of fossil fuels, the Proposed Development has a low carbon footprint, and after less than a year the electricity generated is estimated to be carbon neutral and should displace grid electricity generated from fossil fuel sources. The carbon intensity of the electricity produced by the Proposed Development is estimated at 0.004 $kgCO_2e/kWh$. This is well below the outcome indicator for maintaining the electricity grid carbon intensity below 0.05 $kgCO_2e/kWh$ required by the Scottish Government in the Climate Change Plan update (Scottish Government, 2020) and therefore the Proposed Development is evaluated to have an overall beneficial effect on the carbon emissions associated with energy production.

12.2 Introduction

12.2.1 This Carbon Balance Assessment has been undertaken by Clare Wharmby on behalf of East Point Geo. Clare is a Full member of IEMA and a Chartered Environmentalist with over 15 years of experience undertaking carbon balance assessments for wind farms on peat across the UK.

12.2.2 Increasing atmospheric concentrations of greenhouse gases (GHGs), also called carbon emissions, are resulting in global heating which will cause catastrophic changes to our climate. A major contributor to this increase in GHG emissions is the burning of fossil fuels for primary energy or electricity generation; in the UK, 36.3% of electricity was generated from fossil fuels in 2023 (Department for Energy Security and Net Zero, 2024). With concern growing over climate change, reducing its cause is of utmost importance. The replacement of traditional fossil fuel power generation with renewable energy sources provides high potential for the reduction of GHG emissions. This is reflected in UK and Scottish Governments' delivery plans for climate targets (Carbon Budget Delivery Plan (Department for Energy Security and Net Zero, March 2023) and the update to the Climate Change Plan (Scottish Government, 2020)).

12.2.3 However, no form of electricity generation is completely carbon free; for onshore wind farms there will be emissions resulting from the manufacture of turbines, as well as emissions from both construction and decommissioning activities and transport.

12.2.4 In addition to the lifecycle emissions from the turbines and associated wind farm infrastructure, where a wind farm displaces other carbon storing or sequestering activity such as woodland, or there are other carbon stores that are disturbed such as peat bogs, there are potential emissions resulting from this displacement. Carbon losses and gains during the construction and lifetime of a wind farm, and the long-term impacts on the locations on which they are sited, need to be evaluated to understand the consequences of permitting such developments.

12.2.5 The aim of this Appendix Report is to provide clear information about the whole life carbon balance of the Proposed Development. This Appendix Report explains the policy basis for assessing carbon balance, explains the Scottish Government Carbon Calculator methodology used, details all the inputs into the model and provides an estimate of the expected net carbon savings over the lifetime of the Proposed Development, once carbon losses from materials and ecological disturbance have been considered, and includes a sensitivity analysis for key parameters.

12.3 Legislation, Policy and Guidelines

This assessment has been carried out in accordance with the principles contained within the following legislation and policy.

Legislation

12.3.1 One of the key drivers for the development of renewable energy is the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019, which sets a net-zero target for the Scottish emissions account by 2045 compared to the 1990 baseline.

Policy

12.3.2 The update to the Climate Change Plan (Scottish Government, 2020) recognises the need to continue the process of decarbonising the electricity grid and increasing generation capacity to support the delivery of electric heating and transport. However, the Climate Change Plan Update also recognises the importance of maintaining and restoring carbon storage in peat.

12.3.3 The Scottish Energy Strategy (Scottish Government, 2017) set a whole-system target to supply the equivalent of 50% by 2030 of all the energy for Scotland's heat, transport, and electricity consumption from renewable sources. The new Draft Energy Strategy and Just Transition Plan was published 10 January 2023 and is currently under consultation. The draft strategy recognises that the peatland impacts of onshore wind farms can be significant, and Scotland needs to balance the benefits from onshore wind deployment and the impact on carbon rich habitats. The draft strategy commits to convening an expert group, including representatives from industry, agencies, and academia to provide advice to the Scottish Government on how guidance could be developed to support both peatland and onshore wind aims. Furthermore, the strategy states that the Scottish Government will ensure that adequate tools and guidance are available to inform the assessment of net carbon impacts of development proposals on peatlands and other carbon-rich soils.

12.3.4 National Planning Framework 4 (NPF4) (Scottish Government, 2023) sets the national spatial strategy for Scotland, including spatial principles, regional priorities, national developments, and national planning policy. Policy 5 states that:

"c) Development proposals on peatland, carbon rich soils and priority peatland habitat will only be supported for:

ii. The generation of energy from renewable sources that optimises the contribution of the area to greenhouse gas emissions reductions targets;

d) Where development on peatland, carbon-rich soils or priority peatland habitat is proposed, a detailed site specific assessment will be required to identify:

iii. the likely net effects of the development on climate emissions and loss of carbon."

12.3.5 Onshore wind turbines: Planning Advice (Scottish Government, updated 2014) which under the heading of Securing Sufficient Information to Determine Planning Applications, for wind turbines proposed on peatland, refers to guidance on carbon calculations.

12.3.6 At a local level, the Supplementary Guidance to the Local Development Plan 2 for Dumfries and Galloway on wind farm development: Development Management Considerations (Dumfries and Galloway Council, 2020) states that *'the generation of heat and electricity from renewable energy sources are vital to reducing greenhouse gas emissions. SPP requires that the planning system facilitates the transition to a low carbon economy and supports the Scottish Government targets for meeting electricity and heat demand from renewable sources. The extent to which development proposals help to achieve these targets is a material consideration in the determination of applications.'*

12.3.7 However other impacts and considerations include carbon rich soils. The Guidance states that *'Wind farms may be successfully accommodated in areas of peatland where environmental constraints can be addressed, where disturbance to deep peat can be minimised and restoration opportunities maximised. However, siting wind farms on deep peat, even where peat vegetation is not currently dominant, can significantly undermine carbon benefits of renewable energy and prevent the full restoration of important tracts of peatland habitat through drainage impacts of turbine foundations and tracks, causing long- term disruption to hydrology. It is appropriate that constraints are considered at an early stage of development i.e. at site selection, to ensure wind farms are steered towards areas where constraints are likely to be lowest.'*

Guidance

12.3.8 The Environmental Impact Assessment Guide to Assessing Greenhouse Gas Emissions and Evaluating their Significance (IEMA, 2022) provides guidance for assessing the baseline against which the impact of a new project can be compared against, how to set an appropriate study boundary and how to communicate the impacts. This guidance has been considered in the content of this Appendix Report.

12.4 Assessment Methodology

12.4.1 GHG emissions are measured in tonnes of carbon dioxide equivalents (tCO_2e) which is a quantity that describes, for a given mixture and amount of GHG, the amount of carbon dioxide (CO_2) that would have the same global warming potential (GWP), when measured over a 100-year timescale. These units therefore enable comparison of different GHGs emitted, or saved, at different project stages.

Baseline Assessment Methodology

12.4.2 The stored carbon within the Site was estimated from the average peat depth, estimated from the Peat Management Plan using the average of the Phase 1 (100-meter grid) peat probes to estimate average depth. It should be noted that this recommended methodology for estimating average peat depth is likely to overestimate the quantity of peat at this site as the peat was unevenly distributed and concentrated in three main areas as noted in Technical Appendix 9.2: Peat Survey Report. The estimated peat volume was multiplied by the estimated percentage of carbon content and dry soil bulk density to get an estimate of stored carbon. Tonnes of carbon were converted to carbon dioxide

(tCO_2) by multiplying with the factor of 3.67, which converts from the atomic weight of carbon ('C') to the molecular weight of CO_2. Table 12.1 shows the parameters used to estimate the baseline of stored carbon.

Table 12.1 Parameters used to estimate baseline stored carbon within the Site

Parameter	Expected	Minimum	Maximum
Size of site based on red line boundary (ha)	345	328	362
Average peat depth across site (m)	0.57	0.51	0.63
Carbon content of dry peat (% by weight)	56 %	49 %	62 %
Dry soil bulk density (g/cm^3)	0.13	0.07	0.29

The Scottish Government's Carbon Calculator for Wind Farms on Peat Lands

12.4.3 The Scottish Government methodology, titled 'Calculating potential carbon losses and savings from wind farms on Scottish Peat lands: a new approach' (Nayak, et al, 2008), was designed in response to concerns on the reliability of methods used to calculate reductions in GHG emissions arising from large scale wind farm developments on peat land or forestry. Accompanying this methodology was an excel spreadsheet tool called the 'Carbon Calculator for wind farms on peat' which estimates the benefit of displacing conventionally generated electricity in the grid compared to the predicted direct and indirect emissions of carbon from construction, operation and decommissioning of a wind farm. It provides an estimate of the carbon payback time for the Proposed Development based on predicted emissions from construction materials and grid backup and losses and gains of stored carbon, including within forestry, but does exclude minor sources such as result of traffic generated during construction or operation.

12.4.4 The most recent version of the Carbon Calculator (v1.8.1) is a web-based application and central database, where all the data entered is stored in a structured manner. This web-based tool replaces all earlier versions of the Excel-based calculator and incorporates high-level automated checking, detailed user guidance and cells for identification of data sources and relevant data calculations. However, as of 01/10/24, the online version is not accessible and there is no published timeframe for when the online version will be available again. Therefore, this Appendix Report has used the Excel version of the tool (v2.14.1) which produces the same results as the online tool.

12.4.5 Table 12.3 at the end of this section outlines the input parameters used in the Carbon Calculator. Individual aspects of the methodology will be discussed further within this Appendix Report, in the context of actual inputs and outputs of the model.

12.5 Scope of Carbon Calculator

12.5.1 Table 12.2 shows the following potential emission sources, and savings, of carbon emissions from the three key project stages that are covered by the Carbon Balance Assessment.

Table 12.2 Carbon emissions and savings included in the assessment

Project phase	Included in assessment	Excluded from assessment
Construction	Carbon emissions resulting from the extraction, production and manufacture of turbine components, batteries and concrete required for foundations. The turbine and battery Lifecycle	Carbon emissions resulting from manufacture and transport of other materials required for foundations and tracks e.g., steel, sand, rock and geotextile. These materials are not explicitly included

Project phase	Included in assessment	Excluded from assessment
	Carbon Assessment (LCA) values are taken from the literature and put into the carbon calculator as direct input of values.	in the Scottish Government Carbon Calculator for wind farms on peat.
		Carbon emissions resulting from the transport of labour to the construction-site. This element is not included in the Scottish Government Carbon Calculator for wind farms on peat.
Operation	Carbon savings resulting from the generation of electricity by wind turbines and displacement of grid electricity generated by fossil fuels.	Carbon emissions resulting from transport of labour required throughout the lifetime of the Proposed Development. These elements are not explicitly included in the Scottish Government Carbon Calculator for wind farms on peat and are also not included within the boundary of the LCA.
	Carbon emissions resulting from the provision of back up generation within the UK electricity grid for intermittent renewable sources.	
	Carbon emissions from the manufacture and supply of materials for maintenance and repair are included within the boundary of the LCA.	Emissions from use of diesel in generators used to restart turbines following shutdown. This is likely to be a very small emission source.
	Carbon emissions during the lifetime of the Proposed Development resulting from the loss of active carbon-absorbing bog and forestry habitat.	Carbon emissions from the use of plant, equipment and materials from the site restoration – these are not included in the boundary of the LCA or explicitly within the carbon calculator.
	Carbon gains from the restoration of peat bog on site.	Carbon gains from any compensatory planting of forestry and additional planting to achieve biodiversity enhancement.
Decommissioning	Carbon emissions from the dismantling and disposal of turbines and associated infrastructure, including transport, are included within the boundary of the LCA but these are not separated from the overall embodied emissions of the turbines in the Carbon Calculator.	-

Temporal Scope

12.5.2 The temporal scope for savings is set as the same period as the anticipated lifespan of the Proposed Development, i.e., 35 years.

Study Area

12.5.3 For the carbon payback assessment, since GHG emissions and savings are both ultimately a global 'pool', this assessment is not restricted solely to those emissions or savings that occur within the Site. Land-based emissions from forestry are based on the Proposed Development footprint, but other activities, for example, emissions resulting from the extraction and production of steel for turbines, are still attributable to the Proposed Development even though they are likely to occur in other parts of the world.

12.6 Significance Criteria

12.6.1 In determining whether an application to build and operate a wind farm should be granted planning permission; the assessment of potential carbon losses and savings is a material consideration for the determining authority. It is one important consideration among many, and currently there are no official guidelines about what constitutes an acceptable or unacceptable payback time, therefore this assessment looks at a range of metrics, including the payback, the carbon intensity of electricity produced and the ratio of soil carbon losses to gain, to evaluate the impact of the Proposed Development on carbon emissions. Where appropriate, worst-case parameters have been utilised for this assessment, for both the infrastructure dimensions and the restoration areas, to ensure the impacts are accounted for.

Table 12.3 Input parameters used in the Carbon Calculator

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Wind Farm Characteristics					
Dimensions					
No. of turbines	4	4	4	Chapter 4: Development Description of the EIA Report states that the main components of the Proposed Development will comprise of up to four wind turbines each with a maximum tip height of up to 149.9 m.	None
Lifetime of wind farm (years)	35	35	35	Chapter 4 of the EIA Report states that the Proposed Development has been designed to have an operational life of up to 35 years.	None
Performance					
Turbine capacity (MW)	4.8	4.8	4.8	Chapter 4 of the EIA Report states that for assessment purposes, and unless otherwise stated, the Nordex N133 (4.8 Megawatt) (MW) turbine has been chosen as a representative candidate turbine based on specifications available in the marketplace with maximum blade tip height of up to 149.9 m.	None
Capacity factor – using direct input of capacity factor (percentage efficiency)	46.6	44.3	48.9	Chapter 4 of the EIA Report states that site specific wind data and modelling found that the Site has a capacity factor of 46.6%.	A range of +/- 5% has been used to calculate the likely minimum and maximum.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Backup					
Extra capacity required for backup (%)	0	0	0	The Carbon Calculator indicates that if over 20% of national electricity is generated by wind energy, the extra capacity required for backup is 5% of the rated capacity of the wind plant. SEPA has indicated that, for this parameter, the electricity generation capacity of Scotland, rather than the UK, should be considered. However, Chapter 4 states battery energy storage facility with a capacity of approximately up to 10 MW in total will be constructed to enable co-location of battery storage with the proposed wind turbines. This represents 50% of the rated capacity of the wind plant and therefore, this parameter has been set at zero. It should be noted that the carbon calculator does not have the functionality to include embodied carbon from manufacture of batteries, so this has been included in the lifecycle emissions of the turbine below.	This input parameter assumes that the BESS will provide sufficient storage to avoid the requirement of grid backup for the intermittent renewable generation.
Additional emissions due to reduced thermal efficiency of the reserve generation (%)	10	10	10	Fixed value within the Carbon Calculator for scenario where extra capacity for backup is required. This parameter is not used as the % of back up required is set to zero.	Extra emissions due to reduced thermal efficiency of the reserve power generation ≈ 10% (Dale et al 2004 referenced by the Carbon Calculator).
Carbon dioxide emissions from turbine	Direct input of total emissions			Chapter 4 of the EIA Report states that the candidate turbine is the Nordex N133 (4.8 Megawatt). There is a	

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
life - (e.g. manufacture, construction, decommissioning)				Lifecycle Assessment available for a Nordex Windfarm with Delta 4000 Turbines (Sphera Solutions, 2020). The product system assessed in this study is the N149/4.0-4.5 for a 25 year lifespan which is considered to be a reasonable model for the candidate turbine.	
Total CO_2 emission from turbine life ($tCO_2\ MW^{-1}$)	766	690	843	Units of gCO_2e/kWh of electricity over a 25 lifespan have been converted to tCO_2e per MWh and scaled to electricity generation over 35 years in order to avoid overestimating the emissions for the longer lifetime of the Proposed Development. The embodied carbon of the BESS has been estimated using data from a published LCA of a Lithium-ion BESS (Parlikar, et al. 2021). The value for the net emissions from production and end of life phase per MW have been calculated for the whole site and then added to the embodied turbine emissions. The whole life emissions for turbines and BESS have been divided by the installed capacity to get an estimate of tCO_2e per MW installed.	A range of +/- 10% has been used to calculate the likely minimum and maximum.
Characteristics of peat land before wind farm development					
Type of peat land	Acid Bog	Acid Bog	Acid Bog	There are only two options, of which one has to be selected within the Carbon Calculator: acid bog and fen. Based on Chapter 7: Ecology of the EIA Report, the Site is improved grassland, semi-improved acid grassland, and	None

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				marshy grassland make up most of the Site, with blanket bog as the next most common habitat type. Therefore, acid bog has been selected as the most appropriate option.	
Average air temperature at site (°C)	8.5	8.3	8.7	Based on average annual temperature data for West Scotland for the time period 2004 – 2023. The data is sourced from the Meteorological Office (2024). Mean: 8.5 Count: 20 Standard Error: 0.10	A 95% confidence level has been calculated as the mean +/- 2 SE to estimate the likely minimum and maximum values of the range. Although, it is probable that average site temperatures are rising due to impacts of global climate change, the overall payback is not sensitive to temperature and therefore this parameter is not included in the sensitivity analysis.
Average depth of peat at the site (m)	0.57	0.51	0.63	Peat probing was carried out across the Site in accordance with the Scottish Government's Guidance on Developments on Peatland. Phase 1 probing was undertaken on a 100 m grid and comprised in total of 197 probes, with an average peat depth of 0.57m. This is likely to overestimate the average peat across the whole site as there are only three main peatland units within the site boundary but this parameter does not have a significant impact on the results.	A range of +/- 10 % has been used to calculate the likely minimum and maximum.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Carbon (C) Content of dry peat (% by weight)	56	49	62	The default values for carbon content of peat 49% and 62% is provided in the Carbon Calculator.	Upper and lower range provided as default. Midpoint used as expected value.
Average extent of drainage around drainage features at site (m)	10	7.5	12.5	Chapter 7 of the EIA Report explores the impact of indirect drainage on blanket bog and wet modified bog area and used 10 m as an estimated precautionary value of the extent of drainage around infrastructure.	A range of +/- 25 % has been used to calculate the likely minimum and maximum.
Average water table depth at site (m)	0.15	0.14	0.17	Technical Appendix 9.5: Outline Peat Management Plan (OPMP) of the EIA Report states that an assumption has been made that the upper 0.3 m of the peat profile is assumed to be acrotelm and any remaining depth is assumed to be catotelm. It is assumed that the water table would sit on average around the middle of the acrotelm and therefore an estimated water table depth of 0.15 m has been assumed for the site.	A range of +/- 10 % has been used to calculate the likely minimum and maximum.
Dry soil bulk density (g/cm^3)	0.132	0.072	0.293	The default values for dry soil bulk density of peat provided in the Carbon Calculator have been used. Expected = 0.132 g/cm^3 Minimum = 0.072 g/cm^3 Maximum = 0.293 g/cm^3	The range suggested in the Carbon Calculator has been used.
Characteristics of bog plants					

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Time required for regeneration of bog plants after restoration (years)	22.5	15	30	This parameter needs to be estimated and there are relatively few studies available on the average time taken for bog plant communities to regeneration following restoration. Rochefort et al (2003) estimate that a significant number of characteristic bog species can be established in 3–5 years, a stable high water-table in about a decade, and a functional ecosystem that accumulates peat in perhaps 30 years.	The overall Proposed Development site payback is not particularly sensitive to this parameter due to the slow rate of carbon fixation by bogs. The maximum value has been set at the limit of 30 years. The estimated value has been estimated at -25% of the maximum and the minimum at -50%.
Carbon accumulation due to C fixation by bog plants in un-drained peats (t C ha-1 yr-1)	0.215	0.12	0.31	Suggested acceptable literature values from Carbon Calculator. The overall result is not very sensitive to this input, so the default value can be used if measurements are not available.	The range suggested in the methodology from the literature for apparent C accumulation rate in peatland is 0.12 to 0.31 t C ha-1 yr-1 (Turunen et al., 2001, Global Biogeochemical Cycles, 15, 285-296; Botch et al., 1995, Global Biogeochemical Cycles, 9, 37-46, referenced by the Carbon Calculator). The SNH guidance uses a value of 0.25 t C ha-1 yr-1. Range of 0.12 to 0.31 t C ha-1 yr-1.
Forestry Plantation Characteristics					

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Area of forestry plantation to be felled (ha)	0.28	0.25	0.31	Chapter 4 and Technical Appendix 4.1: Larbrax Access Forestry Report of the EIA Report state that none of the coniferous woodland within the Site will be affected by the Proposed Development, however, to facilitate access into the site, there will be a need to remove approximately 0.28 ha of broadleaf trees and vegetation, the majority of which comprises dense and often impenetrable rhododendron which lines the edge of the B738.	A range of +/- 10 % has been used to calculate the likely minimum and maximum.
Average rate of carbon sequestration in timber (tC ha^{-1} yr^{-1})	2.03	1.82	2.23	Technical Appendix 4.1 of the EIA Report states that the area proposed to be felled for the access junction was found to be dominated by a dense understorey of rhododendron (*Rhododendron ponticum*) with individual broadleaves trees protruding through the dense thicket structure. For the purposes of this assessment, it has been assumed that this area consists of low yield mixed broadleaves that are on average 30 years old (Yield class 6, 3 m spacing). The Woodland Carbon Calculation Spreadsheet (April 2024) provides an estimate of total annual carbon sequestered (in tCO2e/ha/year) for each 5-year age period. The average annual sequestration rate has been looked up for the next 35 years. The CO_2e is converted to C by dividing by 3.67.	A range of +/- 10 % has been used to calculate the likely minimum and maximum.
Counterfactual emission factors					

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Coal-fired plant emission factor (tCO_2 MWh^{-1})	0.945	0.945	0.945	Fixed counterfactual emission factors are provided in the Carbon Calculator and cannot be altered. Values for both coal-fired and fossil fuel-mix emission factors are updated from DUKES data for the UK which is published annually. The source for the grid-mix emission factor is the list of emission factors used to report on greenhouse gas emissions by UK organisations published by BEIS.	
Grid-mix emission factor (tCO_2 MWh^{-1})	0.207	0.207	0.207		
Fossil fuel- mix emission factor (tCO_2 MWh^{-1})	0.424	0.424	0.424		
Borrow Pits					
Number of borrow pits	1	1	1	Chapter 4 of the EIA Report states that to minimise the volume of stone brought onto the Site for construction of the Proposed Development, and any associated environmental effects, it is proposed that stone will be sourced from an onsite borrow pit located east of Turbine 2 for new or upgraded tracks and hardstanding construction.	None
Average length of pits (m)	80	76	84	Chapter 4 of the EIA Report states that the borrow pit search area will measure approximately 6,400 m^2. The	

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average width of pits (m)	80	76	84	dimensions have been estimated as the square root of this area.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Average depth of peat removed from pit (m)	0.022	0.020	0.024	The OPMP (Technical Appendix 9.5 of the EIA Report) states that there is very minor pocket of peat under the proposed borrow pit. The average peat depth has been estimated from the total excavated peat volume at the borrow pit divided by the total area.	No variance required.
Foundations and hard-standing area associated with each turbine					
Method used to calculate CO_2 loss from foundations and hard-standing	Rectangular, with vertical sides			The simple method of calculation for turbine foundations was used for this application.	None
Average length of turbine foundations (m)	22.2	21.0	23.3	Chapter 4 of the EIA Report states that the turbines will be installed on foundations comprising both stone and steel-reinforced concrete. These typically measure up to approximately 25 m diameter which equates to a length and width of 22.2m of the same-sized rectangle.	A range of + 5% has been used to calculate the likely expected and maximum values of both length and width.
Average width of turbine foundations (m)	22.2	21.0	23.3		
Average depth of peat removed from turbine foundations (m)	0	0	0	Table 4.1 of the OPMP (Technical Appendix 9.5 of the EIA Report) shows that there is no peat required to be extracted for turbine foundations.	No variance required.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Average length of hard-standing (m)	50	48	53	Chapter 4 of the EIA Report states that adjacent to each turbine, an area of permanent hardstanding measuring approximately 2,819 m2 will be constructed for use as a crane pad. The exact geometry and position of the crane pads will depend on the turbine supplier's specifications, the crane selected for erection and the findings of detailed ground investigations prior to construction. Additional temporary hardstanding areas will be constructed for the secondary crane, boom erection and storage of turbine components, and these will measure approximately 1,117 m². The average length and width are calculated as the sqrt of the area of temporary and permanent land take for crane pads, clearance and laydown areas that is provided in Table 4.2 of Chapter 4 of the EIA Report.	A range of +/- 5 % has been used to calculate the likely minimum and maximum.
Average width of hard-standing (m)	50	48	53		
Average depth of peat removed from hard-standing (m)	0	0	0	Table 4.1 of the OPMP (Technical Appendix 9.5 of the EIA Report) shows that there is no peat required to be extracted for construction of the main hardstandings or blade laydowns and 2nd crane hardstandings.	No variance required.
Volume of concrete used in entire area (m3)	5,966	5,369	6,563	Chapter 4 of the EIA Report states that it is estimated that approximately 5,966 m³ of concrete will be required for the substation, control building and BESS compound and turbine foundations	A range of +/- 10% has been used to calculate the minimum and maximum.
Access tracks					

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Total length of access track (m)	3,000	2,850	3,150	Chapter 4 of the EIA Report states that approximately 1 km of existing track will be upgraded, and 2 km of new track will be built as part of the Proposed Development.	A range of +/- 5% has been used to calculate the minimum and maximum.
Existing track length (m)	0	0	0	Since the existing track will require some upgrading and has been included in the calculation of permanent land take, it has been included in the excavated road calculations rather than in the existing track length	A range of +/- 5% has been used to calculate the minimum and maximum.
Length of access track that is floating road (m)	0	0	0	All new and existing track is designed on the basis of cut rather than floating.	None.
Length of access track that is excavated road (m)	3,000	2,850	3,150	See above.	A range of +/- 5% has been used to calculate the likely minimum and maximum.
Excavated road width (m)	7.3	6.9	7.7	Table 4.2 of Chapter 4 of the EIA Report provides an area of permanent land take for new and existing access tracks. The average width has been calculated as the area divided by the length. This is wider than the stated 6m of running surface in Chapter 4 because it takes account of the excavation for verges and drains.	A range of +/- 5% has been used to calculate the likely minimum and maximum
Average depth of peat excavated for road (m)	0.05	0.04	0.06	The volume of peat excavated from access tracks has been taken from the OPMP (Technical Appendix 9.5 of the EIA Report) excavation calculations. The volume of peat was divided by the infrastructure area to get an average peat depth removed. It should be noted in reality that this is not	A range of +/- 20% has been used to calculate the likely minimum and maximum

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				a thin layer across the infrastructure but a small pocket of peat located on a corridor of thin peat / organic soil between Larbrax Moor and an adjacent valley floor mire to the north, one turning head on the approach to Turbine 1 and the junction access to the public road. However, the Carbon Calculator only allows an average peat depth across the infrastructure to be entered.	
Cable Trenches					
Length of any cable trench on peat that does not follow access tracks and is lined with a permeable membrane (e.g. sand) (m)	0	0	0	Chapter 4 of the EIA Report states that typically, cables will be laid in a trench 1.5 m deep and 1.5 m wide. To minimise ground disturbance cables will be routed along the side of the access tracks.	Assume all cable trenches follow access track routes.
Additional peat excavated (not accounted for above)					
Volume of additional peat excavated (m^3)	250	238	263	Table 4.1 in the OPMP (Technical Appendix 9.5 of the EIA Report) shows that no peat will be required to be excavated from the construction compound or the substation. However, 250m^3 are required to be permanently excavated for earthworks and this has been included here.	A range of +/- 5% has been used to calculate the likely minimum and maximum.
Area of additional peat excavated (m2)	0	0	0	See above	No variance required.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
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)	13.01	11.7	14.3	The Outline Biodiversity Enhancement Management Plan (OBEMP) (Technical Appendix 7.5 of the EIA Report) states that bog/peatland restoration and enhancement measures below that will be applied to priority peatland habitats covering up to approximately 13.01 ha, comprising 9.68 ha in Area A, 2.14 ha in Area B, and 1.19 ha in Area C. Although there is the potential to also reclaim up to approximately a further 2.31 ha of peatland habitats, these have not been included in this calculation.	A range of +/- 10% has been used to calculate the likely minimum and maximum.
Water table depth in degraded bog before improvement (m)	0.35	0.26	0.44	This parameter has not been directly measured but from experience in other similar environments, in peat that is degraded, the water table to be down between 30-40 cm.	A range of +/- 25% has been used to calculate the likely minimum and maximum.
Water table depth in degraded bog after improvement (m)	0.10	0.09	0.11	Target optimum water table depth for restoring peat is around 0.1m.	A range of +/- 10% has been used to calculate the likely minimum and maximum
Time required for hydrology and habitat of bog to return to its previous state on improvement (years)	17.5	15	20	The OBEMP (Technical Appendix 7.5 of the EIA Report) states that restoration is coming from a combination of livestock management, reduction of invasive species, surface reprofiling and damming of active drains; the	The minimum/maximum range has been set at 15 – 20 years and the midpoint has been used to calculate the expected value.

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
				objective is to achieve 'Good' condition blanket bog within 15 -20 years.	
Period of time when effectiveness of the improvement in degraded bog can be guaranteed (years)	35	35	35	The Carbon Calculator states that if the 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 the Proposed Development (35 years), the period of time when the improvement can be guaranteed should be entered as 35 years.	None
Improvement of felled plantation land					
Area of felled plantation to be improved (ha)	0	0	0	There are no areas of felled plantation to be restored to bog vegetation.	No variance required.
Restoration of peat removed from borrow pits					
Area of borrow pits to be restored (ha)	0	0	0	The OPMP (Technical Appendix 9.5 of the EIA Report) states that excavated peat will be re-used to reinstate what appears to be a cutover area adjacent to the temporary construction compound and on the north side of Larbrax Moor. This reinstatement will use the whole volume of extracted peat from the site and therefore the borrow pits are not required for restoration.	No variance required.
Early removal of drainage from foundations and hardstanding					

Online calculator reference:					
Parameter	**Expected**	**Minimum**	**Maximum**	**Data Source**	**Key Assumptions**
Removal of drainage from foundations and hardstanding	0	0	0	Since there is no peat around the foundations and hardstanding, there is no benefit to early removal of drainage.	No variance required.
Restoration of Application Site after decommissioning					
Will hydrology of the Proposed Development site be restored on decommissioning?	No	No	No	Chapter 4 of the EIA Report states that the operational life of the Proposed Development and associated infrastructure will be 35 years. Following this, an application could be submitted to retain or replace the turbines, or they could be decommissioned. The CEMP will be updated as required to ensure best practice is adopted during decommissioning of the Proposed Development and that activities are carried out in line with the legislation and guidance that is current at time of decommissioning. Therefore, the response to this question has been marked as 'no' as a worst case scenario. However, it should be noted, changing this response has no impact on the overall carbon payback at this site.	None
Will habitat of the Proposed Development site be restored on decommissioning?	No	No	No		
Choice of methodology for calculating emission factors	Site specific			As required for planning applications.	

12.7 Results of Carbon Balance Assessment

Baseline Conditions

12.7.1 It is not easy to set a simple baseline for climate change impacts because the impact is due to a global atmospheric pool of GHG emissions – each individual project has a very small overall impact on this pool, but there are many small projects and therefore effective climate change mitigation relies on reducing the impacts of all of these.

12.7.2 However, the key carbon balance impact of constructing a wind farm on peat land is the potential release of stored carbon and therefore the baseline looks at the estimated stored soil carbon onsite under existing conditions, as this will enable the percentage loss of this carbon through the Proposed Development to be estimated.

12.7.3 Table 12.4 shows the estimate of stored carbon in peat within the Site. Estimated volume and emissions have been rounded up to the nearest thousand cubic metres/tonnes.

Table 12.4 Estimated Stored Carbon in Peat at the Site

Parameter	Expected	Minimum	Maximum
Estimated volume of peat (m^3)	1,967,000	1,681,000	2,271,000
Estimated amount of carbon in soils (tC)	144,000	59,000	413,000
Estimated equivalent emissions of CO_2 (tCO_2)	529,000	218,000	1,514,000

12.7.4 Table 12.4 shows that there are approximately 2 million tonnes of peat onsite and if this were fully oxidised, this would equate to approximately 530,000 tonnes of CO_2 emissions. It is difficult to assess the future of this stored carbon in the absence of the Proposed Development, but it is probable that future climate change impacts will negatively affect this store of carbon, even in the absence of development.

Carbon Balance Assessment - Emissions

12.7.5 The results from the Carbon Balance Assessment have been divided into losses from activities resulting in the emission of carbon and savings from the avoidance of carbon emissions by displacing grid electricity from other fuel sources.

12.7.6 This section looks at the two key project stages of construction and operation (specific decommissioning activities are not included in the Carbon Calculator) and allocates emissions to those two stages. However, it should be noted that for some sources of emissions such as loss of future forest sequestration, it is difficult to be precise about when they will occur in the Proposed Development life cycle.

Table 12.5 Estimated Carbon Emissions during the Construction Phase

Emission source	Estimated emissions (tCO_2e)			% of overall emissions (expected scenario)
	Expected	Minimum	Maximum	
Losses due to turbine and battery storage lifecycle and construction materials	14,707	13,248	16,186	103.1%

Emission source	Estimated emissions (tCO_2e)			% of overall emissions (expected scenario)
	Expected	Minimum	Maximum	
CO_2 loss from excavated peat	-1,054	-1,019	-547	-7.4%
Subtotal of emissions during construction	**13,653**	**12,229**	**15,639**	**95.7%**

12.7.7 Table 12.5 shows that in total approximately 96% of the total losses occur during the Proposed Development construction phase. The majority of these are from the turbine and battery lifecycle, with a small proportion due to other materials used in construction (for example concrete for foundations). The excavation of peat from the borrow pit and for the track construction is predicted as a negative number. The reason that this negative result occurs is that the Carbon Calculator recognises that the infrastructure is planned on areas with minimal peat deposits and therefore excavation of this peat (estimated at approximately 1,577 m^3) produces fewer GHG emissions than leaving it *in situ* (as indicated by the negative emissions). This is because peat bogs release both methane and carbon dioxide, as well as sequestering carbon, while excavated peat is assumed to decompose to just carbon dioxide. Since methane is a much more potent GHG, the emissions of a shallow peat deposit in situ are estimated to be higher.

Table 12.6 Estimated Carbon Emissions during the Operational Phase

Emission source	Estimated emissions (tCO_2e)			% of overall emissions (expected scenario)
	Expected	Minimum	Maximum	
Losses due to backup	-	-	-	0.0%
Losses due to carbon fixing potential	522	196	1,060	3.7%
Losses due to Dissolved Organic Carbon (DOC) & Particulate Organic Carbon (POC) leaching	14	3	30	0.1%
CO2 loss from drained peat	-	-	-	0.0%
Losses due to felling forestry	73	59	88	0.5%
Subtotal of emissions during operation	**609**	**258**	**1,179**	**4.3%**

12.7.8 Table 12.6 shows that only 4% of the emissions occur during the operational phase of the Proposed Development. The requirement for back-up power in the grid, which is assumed to come from a fossil fuel source, has been removed because of the planned BESS. Lost future carbon fixing potential both from bog and woodland contribute to the 4% of estimated losses during this project phase.

12.7.9 Emissions produced during the decommissioning phase are not included separately in the Carbon Calculator assessment, although an estimate of these are included within the lifecycle assessment of the turbines. Calculating emissions from this phase is difficult because the exact activities are not known but they are unlikely to be significant compared to the emission sources during construction and operation.

Carbon Balance Assessment – Gains

12.7.10 Table 12.7 shows the estimated carbon gains over the lifetime of the Proposed Development from restoration of degraded bog. The gains are negative because they are atmospheric removals or avoided emissions. It should be noted that the Carbon Calculator is conservative about estimating the gains from restoration and other biodiversity enhancement measures such as native woodland planting and any compensatory planting required, and therefore only accounts for changes in the balance of methane to carbon dioxide emissions from the restoration of degraded bogs. The gains from restoration are not apportioned between construction and operational phases of the development because of the uncertainty about when they will occur.

Table 12.7 – Estimated Carbon Gains

Source of gains	Estimated gains (tCO_2e)			% of overall gains (expected scenario)
	Expected	Minimum	Maximum	
Change in emissions due to improvement of degraded bogs	-2,266	-1,084	-3,727	100.0%

Comparison with the Baseline

12.7.11 The soil carbon losses from the Proposed Development are estimated at around -518 tCO_2e. This represents -0.1 % of the estimated total stored carbon onsite (as set out in Table 12.4). Therefore, the Carbon Calculator does not assess the Proposed Development to have a noticeable impact on soil carbon at the site.

Comparison of Soil Carbon Losses with Carbon Gains from Restoration

12.7.12 Table 12.8 shows a comparison of soil carbon losses with the estimated carbon gains from restoration. The estimated carbon is shown for the expected value within the carbon calculator. Table 12.8 shows that overall there are no soil carbon losses estimated; the small amount of reduced carbon fixing potential are more than compensated for by the restoration gains and the expected reduction in emissions from excavation of shallow peat. Overall, the net result of soil carbon losses against restoration gains is a gain of (-)2,784 tCO_2e.

Table 12.8 – Comparison of soil carbon losses with restoration gains

Soil carbon loss category	Expected tCO_2e	Restoration gain category	Expected tCO_2e
CO_2 loss from removed peat	-1,054	Change in emissions due to improvement of degraded bogs	-2,266
Losses due to reduced carbon fixing potential	522	-	-
Losses due to Dissolved Organic Carbon (DOC) & Particulate Organic Carbon (POC) leaching	14	-	-

Total soil carbon losses	**-518**	**Total restoration gains**	**-2,266**

Carbon Balance Assessment – Savings

12.7.13 Table 12.9 shows the estimated annual and lifetime CO_2 savings, based on the three different counterfactual emission factors. The highest estimated savings are for replacement of coal-fired electricity generation but there is minimal coal-fired generation remaining in the UK to be displaced. The average grid-mix of electricity generation represents the overall carbon emissions from the grid per unit of electricity and includes nuclear and renewables as well as fossil fuels. The average fossil fuel-mix represents the average carbon intensity of units generated from all fossil fuels within the grid. The average grid-mix tends to be used for estimating the savings from development of renewables, and the sensitivity analysis below considers both the impact of grid decarbonisation and the electrification of heat and transport on the payback period of the Proposed Development.

Table 12.9 Estimated Annual and Lifetime Carbon Savings from the Operation of the Proposed Development from the Displacement of Grid Electricity

Counterfactual emission factor – annual savings	Estimated savings (tCO_2e per year)		
	Expected	Minimum	Maximum
Coal-fired electricity generation	74,067	70,363	77,770
Grid-mix of electricity generation	**16,224**	**15,413**	**17,035**
Fossil fuel - mix of electricity generation	33,232	31,570	34,894
Counterfactual emission factor – lifetime savings (35 years)	**Estimated savings (tCO_2e over lifetime)**		
Coal-fired electricity generation	2,592,345	2,462,705	2,721,950
Grid-mix of electricity generation	**567,840**	**539,455**	**596,225**
Fossil fuel - mix of electricity generation	1,163,120	1,104,950	1,221,290

Payback Time and Carbon Intensity

12.7.14 There are two useful metrics for comparing different projects and different technologies. The Carbon Calculator tool calculates an estimated payback time, which is the net emissions of carbon (total of carbon losses and gains) divided by the annual estimated carbon savings. However, an alternative metric is the carbon intensity of the generated units of electricity. This calculation divides the net emissions by the total units of electricity expected to be produced over the lifetime of the Proposed Development. This calculation is useful as it is independent of the grid emission factor of displaced electricity.

12.7.15 Table 12.10 shows the estimated payback time, if the electricity generated by the Proposed Development is assumed to displace electricity generated by the grid for a range of different displaced fuels, and the carbon intensity of the units produced.

Table 12.10 Estimated Payback Time in Years and Carbon Intensity of the Units of Electricity Produced

Counterfactual emission factor	Estimated time to payback (years)		
	Expected	Minimum	Maximum
Coal-fired electricity generation	0.2	0.1	0.2
Grid-mix of electricity generation	**0.7**	**0.5**	**1.0**
Fossil fuel - mix of electricity generation	0.4	0.3	0.5
Carbon intensity of electricity generated	**Carbon intensity (kgCO_2e/kWh)**		
Carbon intensity based on grid-mix	0.004	0.003	0.006

12.7.16 Table 12.10 shows that the Proposed Development is estimated to have a payback of 0.7 years based on the current grid mix and the carbon intensity of units produced would be significantly lower than the current grid mix (the value of 0.207 kgCO_2e/kWh is currently used in the Carbon Calculator). It should also be noted that the assessment boundary of the carbon intensity of electricity generated by the Proposed Development is far wider than the direct operational emissions included in the measurement of carbon intensity of the grid mix; if these were included, the impact of the Proposed Development would be shown to be even more beneficial.

Sensitivity analysis

12.7.17 The assessment of the payback of the Proposed Development is limited by both the Carbon Calculator and the parameters used to estimate the Site characteristics. Within the Carbon Calculator there are several parameters known to have a potentially significant impact on overall estimated payback time; for some of these parameters there is also a degree of uncertainty over the inputs due to data collection restraints. To demonstrate the robustness of the estimated payback, the sensitivity analysis below shows the impact of varying two of the key parameters on the payback time under a grid mix counterfactual emission factor, whilst holding all other parameters constant, as shown in Table 12.11.

Table 12.11 Impact of changing individual parameters on expected payback in years

Sensitivity analysis	Estimated time to payback (years) (based on expected scenario, grid mix electricity factor)		
	As assessed: Expected	50% increase	100% increase
Extra capacity required for backup (%)- impact of increasing from 0% to 2.5% and 5%	0.7	1.1	1.5
Average extent of drainage around drainage features at site (m) – impact of increasing from 10m by 50% and 100%	0.7	0.7	0.8

12.7.18 Table 12.11 shows that increasing the average extent of drainage by 50% and 100% has very little impact on the overall payback of the site. This is mainly due to the avoidance of peat by the infrastructure layout. Changing the grid backup percentage has a noticeable impact on payback but the suggested range is between 0 and 5% and therefore it unlikely that this would be any higher than 5%, providing an upper limit to this parameter.

Impact of Electricity Grid Decarbonisation

12.7.19 The most significant cumulative effect of the Proposed Development is on the long-term grid electricity carbon factor. As the supply of renewable electricity increases, the overall average national grid carbon factor is predicted to decrease. The cumulative effect of these projects would be to reduce the projected emissions savings of an individual project as each unit of grid electricity would be worth less carbon. This effect will be higher as renewable energy develops further into the future; however, at the same time the requirements and composition of the electricity grid, and therefore the carbon emissions per unit of electricity, is less predictable.

12.7.20 For long-term renewable electricity generation developments, initial carbon emissions invested in the construction of the project are balanced against the savings from displacing energy use with higher operational emissions. In the initial stages of large-scale wind deployment, increased renewable generation displaced coal-fired generation in the grid and the overall grid factor decreased from 2005 to the current day. The current grid mix carbon intensity is largely driven by the proportion of natural gas-generated electricity, but this fuel source is much harder to displace as it provides important balancing power and functionality to the national grid, in the absence of significant energy storage options. Therefore, for assessing the current situation, it is arguable that while some of the electricity generated by onshore wind are likely to displace fossil fuel generated units, there will be times when renewable generation will be displacing other low carbon generation sources.

12.7.21 However, looking forward over the time frame of the Proposed Development, there are other trends in electrification that are likely to become increasingly important, in particular the electrification of domestic and commercial heating and passenger and freight transport. The current system of mainly fossil fuel-based heating and transport systems should be replaced over time by electrification of these systems. If this system change continues at pace, future renewable projects are likely to be at least partially displacing this relatively carbon-intensive energy use with renewable electricity.

12.8 Summary

12.8.1 The results of the Carbon Calculator show that the Proposed Development is estimated to produce annual carbon savings of around 16,000 tonnes of CO_2e per year, through the displacement of grid electricity, based on the current average grid mix. Displacement of existing sources of generating capacity depends on the time of day and how the grid needs to be balanced.

12.8.2 The assessment of the Proposed Development estimates losses of around 14,000 tonnes of CO_2e, mainly due to off-site activities such as the manufacture of the turbines and battery storage. Overall ecological carbon losses are negative (the Carbon Calculator estimates that construction of the Proposed Development will result in fewer emissions than leaving shallow peat in situ). Restoration of degraded peatland is estimated to provide gains of around (-)2,000 tonnes of CO_2e.

12.8.3 The estimated payback time of the Proposed Development, using the Scottish Government Carbon Calculator, is 0.7 years, with a minimum/maximum range of 0.5 to 1.0 years. There are no current guidelines about what payback time constitutes a significant impact, but 0.7 years is around 2% of the anticipated lifespan of the Proposed Development. Compared to fossil fuel electricity generation projects, which also produce embodied emissions during the construction phase and then significant emissions during operation due to combustion of fossil fuels, the Proposed Development has a low carbon footprint, and after less than a year the electricity generated is estimated to be carbon neutral and should displace grid electricity generated from fossil fuel sources. The carbon intensity of the electricity produced by the Proposed Development is estimated at 0.004 kgCO_2e/kWh. This is well below the outcome indicator for maintaining the electricity grid carbon intensity below 0.05 kgCO_2e/kWh required by the Scottish Government in the Climate

Change Plan update (Scottish Government, 2020) and therefore the Proposed Development is evaluated to have an overall beneficial effect on the carbon emissions associated with energy production.

12.9 References

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